

Pennsylvania Climate Action Plan

November 20, 2018 (DRAFT)

Prepared for:



Prepared by:



Acknowledgements and Disclaimer

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This report was prepared in response to the Pennsylvania Climate Change Act (Act 70 of 2008), which requires the DEP to develop an inventory of greenhouse gases (GHG) and administer a Climate Change Advisory Committee (CCAC), a voluntary registry of GHG emissions, and a Climate Change Action Plan. Revisions to the Action Plan are required every three years. The Pennsylvania CCAC provided input and feedback to the DEP and ICF for the preparation of this Plan. The CCAC is composed of 18 members plus 3 “ex Officio members.”

This 2018 Climate Action Plan Update is the fourth iteration of the Pennsylvania Climate Action Plan and builds on the work the commonwealth has already done. Different than years past, this 2018 Update offers a plan that more comprehensively addresses the changing climate in Pennsylvania by focusing on both the impacts of climate change (adapting to the impacts of climate change) and the prevention or slowing of human-caused climate change (reducing greenhouse gas emissions that cause climate change).

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Acronyms, Abbreviations and Plan Terms

ACEEE	American Council for an Energy-Efficient Economy
AECs	Alternative Energy Credits
AEO	Annual Energy Outlook
AEPS	Alternative Portfolios Energy Standard
AFIG	Alternative Fuels Incentive Grant
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAQ	Bureau of Air Quality
BAU	Business as Usual
BBtu	Billion British Thermal Units
BOC	Building Operator Certification
BRT	Building Retuning Training
CAP	Climate Action Plan
CCAC	Climate Change Advisory Committee
CDC	Center for Disease Control
CGE	Computable General Equilibrium
CHP	Combined Heat and Power
CO₂e	Carbon Dioxide Equivalent
C-PACE	Commercial Property Assessed Clean Energy
CSA	Community Supported Agriculture
CSE	Cost of Saved Energy
CTE	Career and Technical Education
DCED	Department of Community and Economic Development
DCNR	Department of Conservation and Natural Resources
DEP	Pennsylvania Department of Environmental Protection
DEPA	Drive Electric PA Coalition
DG	Distributed Generation
DLI	Department of Labor and Industry
DOE	U.S. Department of Energy
DPI	Disposable Personal Income
DVRPC	Delaware Valley Regional Planning Commission

EDF	Environmental Defense Fund
EE	Energy Efficiency
EERE	Department of Energy, Office of Energy Efficiency and Renewable Energy
EERS	Energy Efficiency Resource Standard
EIA	Energy Information Administration
EPA	U.S. Environmental Protection Agency's
EPO	DEP Energy Programs Office
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
FEMA	Federal Emergency Management Agency
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
GP	General Permit
GPS	Global Positioning System
GSP	Gross State Product
GWh	Gigawatt Hours
HVAC	Heating, Ventilation, and Air-Conditioning
ICC	International Code Council
IECC	International Energy Conservation Code
IGCC	Integrated Gasification Combined Cycle
IRC	International Residential Code (IRC)
LCOE	Levelized Cost of Electricity
LED	Light-Emitting Diode
LEED	Leadership in Energy and Environmental Design
LFG	Landfill Gas
LPG	Liquefied Petroleum Gas
MMT	Million Metric Ton
MOVES	EPA's MOtor Vehicle Emission Simulator
MT	Metric Ton
NGOs	Non-Governmental Organizations
NPV	Net Present Value
NREL	National Renewable Energy Laboratory

O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
P3	Public-Private Partnerships
PA	Pennsylvania
PAGHSP	PA Green & Healthy Schools Partnership
PEDA	Pennsylvania Energy Development Authority
PEMA	Pennsylvania Emergency Management Agency
PennDOT	Pennsylvania Department of Transportation
PennTAP	The Pennsylvania Technical Assistance Program
PUC	Pennsylvania Public Utility Commission
RAC	DLI Review and Advisory Council
RGGI	Regional Greenhouse Gas Initiative
SCC	Social Cost of Carbon
SEM	Strategic Energy Management
SEPTA	Southeastern Pennsylvania Transportation Authority
SIT	State Inventory Tool
SRF	State Revolving Fund
SWE	Pennsylvania Statewide Evaluator
UCC	Uniform Construction Code
USDA	U.S. Department of Agriculture
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound
WWTP	Wastewater Treatment Plant
ZEC	Zero Emissions Credit

Plan Terms

Adaptation	The process of adjusting to new or changing climate conditions to reduce or avoid negative impacts to valued assets and take advantage of emerging opportunities (U.S. Climate Resilience Toolkit 2018).
Capital Expenditure	Represents the money spent by the private sector in 2015 dollars.
Cost per Ton of CO₂ Reduced	Represents the net present value of the action used to reduce CO ₂ divided by the total cumulative CO ₂ reduced over the study period. This metric represents the per-unit cost of reducing CO ₂ . Negative cost-per-ton represents net cost savings.
Disposable Personal Income	Represents the total after-tax income, of individuals, available for spending or saving in 2015 dollars.
Disposable Personal Income Per Household	Represents the total after-tax income, of individuals, available for spending or saving in 2015 dollars, normalized by the number of households in PA (obtained from the U.S. Census).
Energy Consumed	End-use consumption of energy fuels and electricity in Pennsylvania's residential, commercial, industrial, and transport sectors.
Energy Generated	Grid-connected electricity generating units located within Pennsylvania or other energy generation sources located in Pennsylvania facilities.
Energy Expenditure Savings	Reductions in end-use energy costs (fuels and/or electricity) in 2015 dollars realized in Pennsylvania's residential, commercial, industrial, and transport sectors.
Gross State Product	Measure of a state's output in 2015 dollars. This metric represents the sum of value added for all industries in the state and is the counterpart of the Nation's gross domestic product (GDP).
Maintenance and Repair Costs	Costs associated with upkeep in 2015 dollars. These costs encompass fixed operation and maintenance (costs independent of volume such as taxes, insurance, personnel and administration) and variable operation and maintenance (costs dependent on volume such as consumables, waste disposal and unscheduled repairs).
Mitigation	Reducing and stabilizing the levels of heat-trapping greenhouse gases in the atmosphere (NASA 2018).
Net Present Value	The difference between expenditures (cash outflows or costs) and savings (cash inflows or benefits). These expenditures and savings are discounted to present values to represent the time value of money (the precept that money available now is worth more than an identical sum in the future).

	Note: NPV is only one metric used to assess the economic effects of an action. It does not include externality costs, such as those of GHGs or other emissions. A positive NPV indicates that cash inflows are greater than costs, whereas a negative NPV indicates the opposite. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action (e.g., cost per ton of CO ₂ reduced, or macroeconomic benefits). A discount rate of 1.75% was used in this analysis, as representative of a societal policy perspective.
Public Expenditures	The money spent by the public sector as investments, subsidies, or rebates in 2015 dollars.
Program Costs	Incentives and administrative expenses in 2015 dollars.
Resilience	The capacity of a community, business or natural environment to prevent, withstand, respond to, and recover from disturbances, while retaining the basic functions of the system (U.S. Climate Resilience Toolkit 2018).

Executive Summary

The Pennsylvania Climate Change Act (Act 70 of 2008, or Act) provides for a periodic report on potential climate change impacts and economic opportunities for the commonwealth. The Act requires the Department of Environmental Protection (DEP) to:

- Develop an inventory of greenhouse gases (GHG);
- Administer a Climate Change Advisory Committee (CCAC);
- Set up a voluntary registry of GHG emissions; and
- Prepare and update a Climate Change Action Plan. Revisions to the Action Plan are required every three years. This document is the third update to the original Climate Change Action Plan, which was issued by DEP in December 2009.

Why Do We Need a Climate Action Plan?

In recent years, extreme weather and catastrophic natural disasters have become more frequent and more intense. Like many parts of the United States, Pennsylvania is expected to experience higher temperatures, changes in precipitation, sea level rise, and more frequent extreme events and flooding because of climate change in the coming decades. Climate impacts in Pennsylvania are real and continue to put Pennsylvanians at risk. Key impacts include:

- More frequent extreme weather events, including large storms, periods of drought, heat waves, heavier snowfalls, and an increase in overall precipitation variability, with increased infrastructure disruption and need for emergency management.
- Increased risks of injury and death from extreme weather events.
- Increased human health risks from air pollution, diminished water quality, and heat stress such as exacerbated asthma or increased water-borne illnesses.
- Changing pest, weed, and disease management challenges for farmers and livestock producers.
- Increased demand for energy, particularly during warmer summer months, meaning higher energy costs for consumers and increased strain on the grid to provide reliable power.
- More frequent flooding and associated disruptions due to sea level rise in communities and cities in the Delaware River Basin, including the city of Philadelphia.
- Potential for wetland drying in the Ridge and Valley ecoregion, resulting in ecosystem changes.
- Potential for degraded water quality in the tidal freshwater portion of the Delaware estuary.

These impacts could alter the many fundamental—but often not explicit—assumptions about climate that are intrinsic to the commonwealth’s infrastructure, governments, and businesses. Estimates indicate that recent extreme events alone have cost governments (leaders), citizens, and businesses in the United States more than \$1.1 trillion since 1980. Climate change can also affect vital determinants of health such as clean air, safe drinking water, sufficient food, and secure shelter. Health impacts from climate change are expected to cause around 250,000 additional deaths globally per year between 2030

and 2050, as well as additional direct damage costs estimated to be around \$2-4 billion per year by 2030.

Based on decades of research and evidence, it is widely accepted that these events are highly likely a result of climate change caused by human activities. Therefore, it is critical that leaders, citizens, and businesses in the Commonwealth of Pennsylvania:

- ▶ Consider how the commonwealth's climate may change in the future,
- ▶ Understand what (if any) impacts would occur if those changes are not addressed, and
- ▶ Take action to adapt to the changes and reduce the GHG emissions that are causing them, while making the economy stronger and meeting the needs of all Pennsylvanians.

Plan Goals and Targets

The Commonwealth of Pennsylvania's government has already been leading on climate action through a series of activities, including: legislative action; planning, research, and information gathering; and program implementation. This Plan builds on past and ongoing activities to inform future action. More specifically, this 2018 Climate Action Plan Update comprehensively considers the changing climate in Pennsylvania by addressing both the impacts of climate change ("adaptation" to climate impacts) and the causes of climate change (reducing and stabilizing greenhouse gas emissions, or "mitigation").

Goals: To ensure the effectiveness of this Plan, overarching adaptation goals and emissions reduction targets are used to frame the strategies. This Plan identifies two adaptation-focused goals, which can be achieved by actions from citizen, businesses, and leaders in the commonwealth:

- ▶ Minimize disruptions to Pennsylvania's citizens, economy, and environment from climate-related hazards.
- ▶ Increase Pennsylvania's ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from climate-related disruptions.

Targets: Meanwhile, the mitigation targets used in this Plan for gauging the results of a set of potential GHG reduction strategies are:

- ▶ 26 percent reduction of net GHG emissions by 2025, from 2005 levels
- ▶ 80 percent reduction of net GHG emissions by 2050, from 2005 levels

If all states achieved similar GHG reduction targets, and other nations met comparable goals, climate science analysis suggests that global temperature rise could be kept below the 2-degree Celsius threshold cited by experts as the level beyond which dire consequences would occur, including sea level rise, superstorms, and crippling heat waves.

In addition to the above goals and targets, and per Act 70 of 2008, cost-effectiveness is also a key factor in strategy selection.

How this Plan was Developed

The strategies in this report reflect an iterative process between the DEP Energy Programs Office, Bureau of Air Quality, and Policy Office; their sister agencies (DCNR, the Pennsylvania Departments of Agriculture, Community and Economic Development, Health, Transportation, General Services, the Pennsylvania Fish and Boat Commission, and Pennsylvania Public Utility Commission); the Climate Change Advisory Committee; and other stakeholders. More specifically, DEP's process included the following steps:

1. DEP, with the support of the analysis team (ICF), separately identified strategies with adaptation benefits and strategies with emissions reduction benefits. DEP and the analysis team iteratively prioritized and integrated the strategies, prioritizing those with both adaptation and emissions reductions benefits.
2. DEP and the team refined the list of strategies based on sister agency and CCAC feedback, and selected strategies and actions to quantitatively model to estimate GHG reductions, cost-effectiveness, and other effects. Strategies were selected for modeling based on an initial screen of potential contributions to GHG reductions—strategies that were expected to result in larger GHG reductions were quantitatively assessed. Most of the quantified strategies focus on clean energy, in line with the fact that the vast majority of emissions (88 percent in 2015) in Pennsylvania come from energy production and consumption.
3. DEP and the analysis team then conducted modeling for selected strategies for GHG, energy, and micro-economic effects.
4. Macro-economic modeling (e.g., changes in jobs) for each strategy was conducted using the REMI PI+ model.
5. Lastly, DEP and the analysis team outlined additional specific actions within each strategy for leaders, citizens, and businesses, and specified implementation steps for modeled actions.

Plan Sectors, Strategies, and Actions

Sectors: The Plan is organized by and addresses eight sectors:

- | | |
|-------------------------|----------------------------------|
| ▶ Energy Consumption | ▶ Outdoor Recreation and Tourism |
| ▶ Energy Production | ▶ Waste |
| ▶ Agriculture | ▶ Water |
| ▶ Ecosystems & Forestry | ▶ Human Health |

Strategies: Within each sector, the Plan identifies sector-specific climate change impacts, as well as one or more strategies to adapt to climate change impacts and reduce emissions within that sector.

Altogether, the Plan identifies 19 strategies, as follows:

- ▶ Increase end use energy conservation and efficiency
- ▶ Implement sustainable transportation planning and practices
- ▶ Develop, promote, and use financing options to encourage energy efficiency
- ▶ Increase use of clean, distributed electricity generation resources
- ▶ Create a diverse portfolio of clean, utility-scale electricity generation
- ▶ Reduce upstream impacts of fossil fuel energy production
- ▶ Increase production and use of alternative fuels

- ▶ Use agricultural best practices
- ▶ Provide resources and technical assistance to farmers to adapt
- ▶ Improve protection of and optimize ecosystems
- ▶ Monitor, identify, and remove ecosystem vulnerabilities
- ▶ Help the outdoor tourism industry manage shifting climate patterns
- ▶ Reduce and use waste sent to landfills
- ▶ Use stormwater best management practices
- ▶ Promote integrated water resources management and water conservation
- ▶ Improve reliability and accessibility of public information about climate-related health risks
- ▶ Bolster emergency preparedness and response
- ▶ Lead by example in commonwealth and local government practices and assets
- ▶ Incorporate historical and projected climate conditions into siting and design decisions for long-term infrastructure

Actions: Each strategy encompasses multiple actions—specific policies, programs, or activities for state and local leaders (i.e., government), citizens, and businesses. The strategy descriptions include lists of these specific leadership, citizen, and business actions, as well as information on strategy benefits and costs, including climate resilience, environmental, and economic benefits and costs.

The Plan explicitly models the benefits and costs for 15 leadership actions within seven of the strategies, ones deemed the most practical and impactful in reducing GHG emissions, as listed below.

- ▶ Increase end use energy conservation and efficiency
 - Update building codes
 - Increase adoption of energy efficiency, and expand Act 129
 - Create an Act 129-like conservation and efficiency program for natural gas
 - Expand energy assessments and provide more trainings on energy efficiency for industry
- ▶ Implement sustainable transportation planning and practices
 - Reduce vehicle miles traveled for single-occupancy vehicles
 - Implement a strategic plan and incentives for increasing electric vehicle use
 - Increase the use of clean public transportation through electric municipal bus fleets
- ▶ Increase use of clean, distributed electricity generation resources
 - Invest in and promote building-scale solar
 - Incentivize and increase use of combined heat and power
- ▶ Create a diverse portfolio of clean, utility-scale electricity generation
 - Increase Alternative Energy Portfolio Standard(AEPS) Tier 1 targets, and further increase in-state generation and use of renewables
 - Implement policy to maintain nuclear generation at current levels
 - Limit carbon emissions through an electricity sector cap and trade program
- ▶ Reduce upstream impacts of fossil fuel energy production
 - Implement policies and practices to reduce methane emissions across oil and natural gas systems
- ▶ Increase production and use of alternative fuels

- Increase recovery and use of gas from coal mines, agriculture, wastewater, and landfills for energy
- ▶ Use agricultural best practices
 - Implement and provide training for no-till farming practices

In addition, the Plan includes nearly 100 additional leadership actions that were not quantitatively modeled, but that can help the commonwealth to reduce GHG emissions, adapt to the changing climate, and reduce the risks of climate impacts. Examples of these types of actions include:

- ▶ Expand home weatherization programs
- ▶ Support community solar legislation and develop model local ordinances
- ▶ Expand integrated farm management and conservation planning
- ▶ Promote forest conservation, growth, and adaptation, as well as urban trees
- ▶ Implement programs to encourage citizens and business to reduce waste (including food waste) and use recycling and composting programs through reduce, reuse, and recycle actions
- ▶ Review existing emergency response, preparedness, evacuation, and management plans
- ▶ Incorporate climate change considerations into decision making processes and criteria
- ▶ Develop or update floodplain mapping using the best available science and accounting for the impacts of climate change

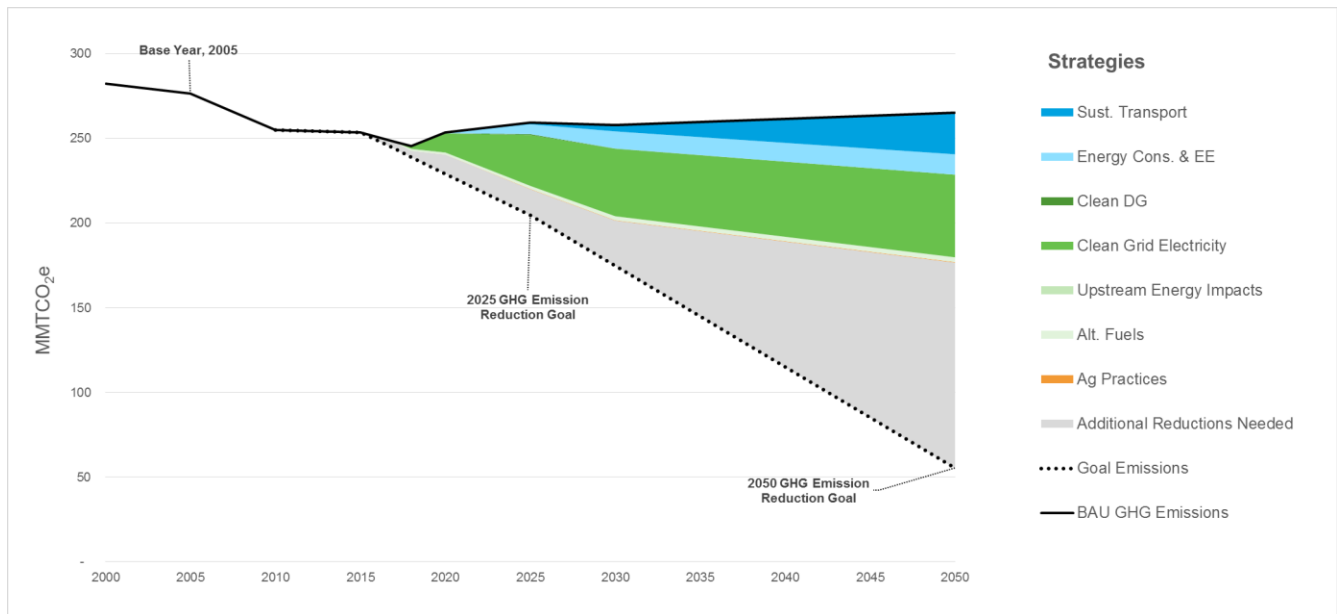
Because climate change is a universal issue that effects everyone, leadership, citizens, and businesses must all play a role in reducing GHG emissions and adapting to climate change impacts. Therefore, in addition to the leadership actions, this Plan separately identifies dozens of actions that citizens and businesses could take to advance climate action.

Benefits and Costs for Modeled Strategies and Actions

The Plan summarizes the benefits and costs of the 15 quantitatively analyzed actions. Notably, the modeled actions in this Plan represent only a subset of the potential actions under a subset of the identified strategies. In other words, the benefits and costs of the quantified actions do not comprehensively account for all the strategies and actions identified in the Plan. If Pennsylvania pursues actions and strategies beyond those that were quantitatively assessed, there would be additional benefits and costs from both reducing GHG emissions and adapting to climate change. In addition, if the commonwealth pursues the quantified strategies and actions in a different way than the team assumed, the benefits and costs will differ from this analysis.

The benefits and costs of the 15 quantified emissions reduction actions are compared to 2005 GHG emission levels and further compared to a business as usual (BAU) scenario in which emissions are projected through 2050 to show the GHG benefits over time. In the BAU scenario, annual GHG emissions in 2050 are expected to be about 5 percent higher than annual GHG emissions in 2015, but about 4 percent lower than emissions in 2005. As shown in Figure 1, the 15 quantified actions significantly reduce GHG emissions compared to the BAU scenario and are expected to result in:

- A 21 percent decrease in annual GHG emissions in 2025 as compared to 2005 levels, and
- A 36 percent decrease in annual GHG emissions in 2050 as compared to 2005 levels.

Figure 1. GHG Reductions Through 2050 for All Strategies, Grouped by Sector


The results for 2025 and 2050 fall short of meeting the modeling targets of 26 percent (2025) and 80 percent (2050) relative to 2005 GHG emissions. However, these findings are consistent with what other jurisdictions are seeing—actions with large GHG reduction potential, such as those quantified for this Plan, are not quite enough to meet 2025 or 2050 targets, when taken alone.

For example, the America’s Pledge report, *Fulfilling America’s Pledge: How States, Cities, and Businesses are Leading in the United States to a Low Carbon Future*, shows that implementation of ten key climate actions—which are, for the most part, similar to what was modeled for this Plan—will likely result in a 21 percent reduction of annual GHG emissions in 2025 as compared to 2005 levels for America’s Pledge, U.S. Climate Alliance, and Climate Mayors participants.

This finding further emphasizes the need for more ambitious and quick climate action from all actors, including leadership, businesses and citizens. This is particularly relevant for 2025 when there is less uncertainty than 2050 and more visibility into potential implementable actions.

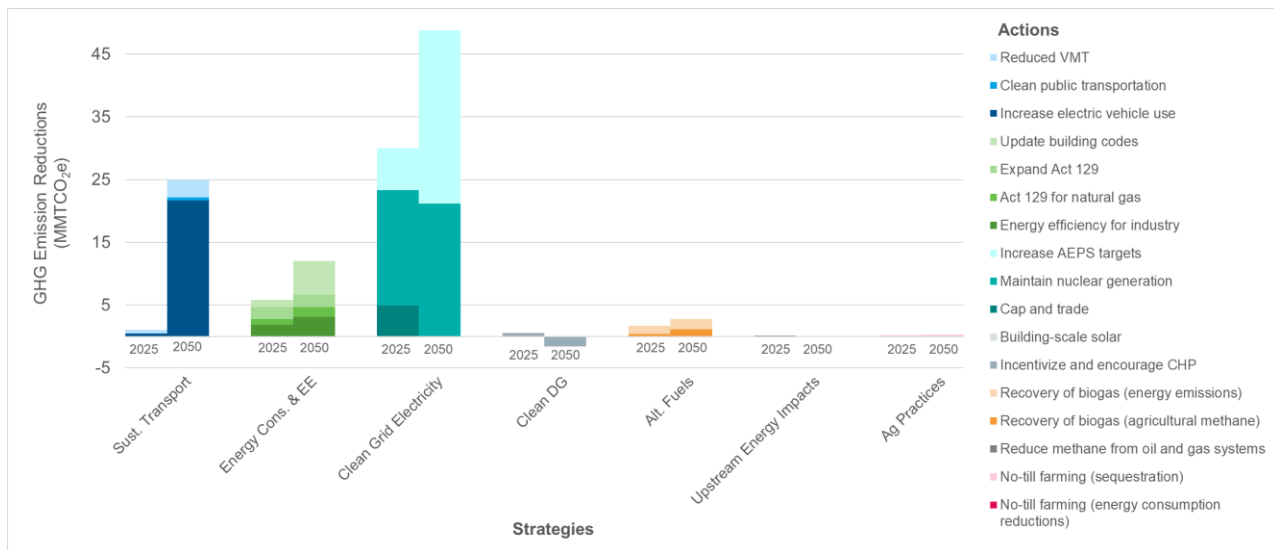
While considering results, it is worth noting:

- As highlighted above, due to resource and time constraints, the modeling conducted for this report only focuses on a subset of strategies and actions that could reduce GHG emissions in Pennsylvania. Additional strategies and actions qualitatively addressed in this report would likely result in additional GHG reductions. For example, sequestration of carbon through forests offers a lot of potential for GHG reductions in Pennsylvania. Effective conservation and management of forests through programs such as the Nature Conservancy’s Working Woodlands program can help accelerate and maintain forests as carbon sinks. This program has protected over 62,000 acres and accelerated restoration on 5,000 acres in Pennsylvania alone, with the result that almost 3.5 million tons of carbon will be sequestered over the life of the projects.

- The results do not consider new or updated federal policies that reduce GHG emissions.
- There are high levels of uncertainty associated with forecasting GHG emissions through 2050. Although this analysis provides single estimates of GHG emissions reductions from the quantified strategies, it would be useful to conduct sensitivity analyses that examine a range of aggressiveness for underlying modeling assumptions (e.g., market penetration rates or costs of certain technologies).

Figure 2 shows the GHG emissions reductions of each quantified action within the seven quantified strategies in both 2025 and 2050. As seen, the strategy to create a diverse portfolio of clean, utility-scale electricity generation has the most significant emission reduction impacts in both 2025 and 2050. Large GHG reductions are seen for energy conservation and efficiency measures in both 2025 and 2050, while the benefits of sustainable transportation measures do not really come into play until after 2025. While relative reductions from the other strategies are smaller, they still play a vital role in overall GHG reductions that could be achieved by implementing this Plan.

Figure 2. Annual GHG Reductions Compared to BAU for All Quantified Strategies and Actions in 2025 and 2050

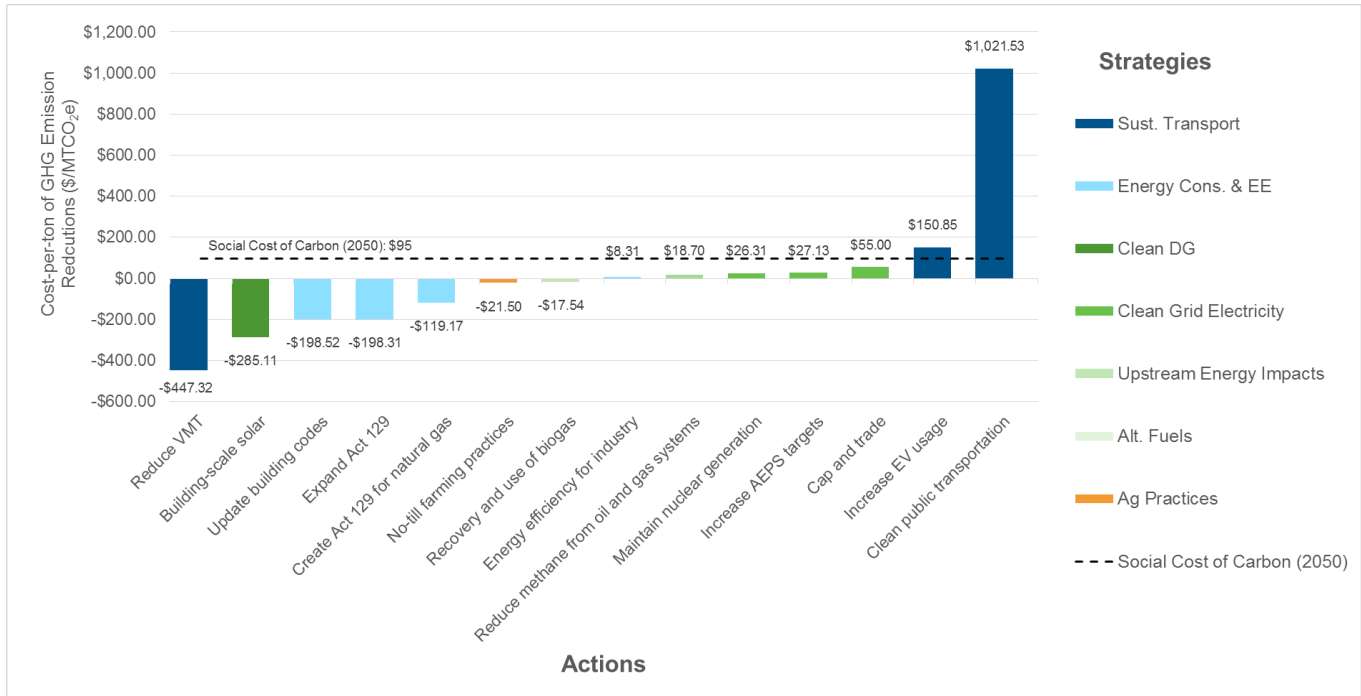


To assess cost-effectiveness, the team looked at multiple factors which, when considered together, can be used to understand the cost-effectiveness of a strategy. Cost-effectiveness measures assessed include:

1. **Net present value (NPV)**, provided for each strategy action, which is a narrow analysis of direct costs and benefits, and uses zero NPV as a benchmark. This is useful as a simple microeconomic perspective. NPV does not include externality costs, such as those of GHGs or other emissions. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action.
2. **Cost per ton of CO₂e**, provided for each strategy action, which uses the social cost of carbon as a benchmark. Anything that falls below the benchmark could be considered cost-effective based on one perspective. This is useful as a climate policy perspective (see Figure 3).

3. **Macroeconomic factors** (described below), which captures multiple benefit and cost effects, including employment, gross state product, and personal income. This is useful as a richer set of indicators.

Figure 3. Cost per Ton of CO₂ Reduced for All Actions, By Sector (\$/MTCO₂e)



Note: Blue shading indicates emission reductions from strategies within the Energy Consumption sector; green shading indicates emission reductions from strategies within the Energy Production sector; and orange shading indicates emission reductions from strategies within the Agriculture sector.

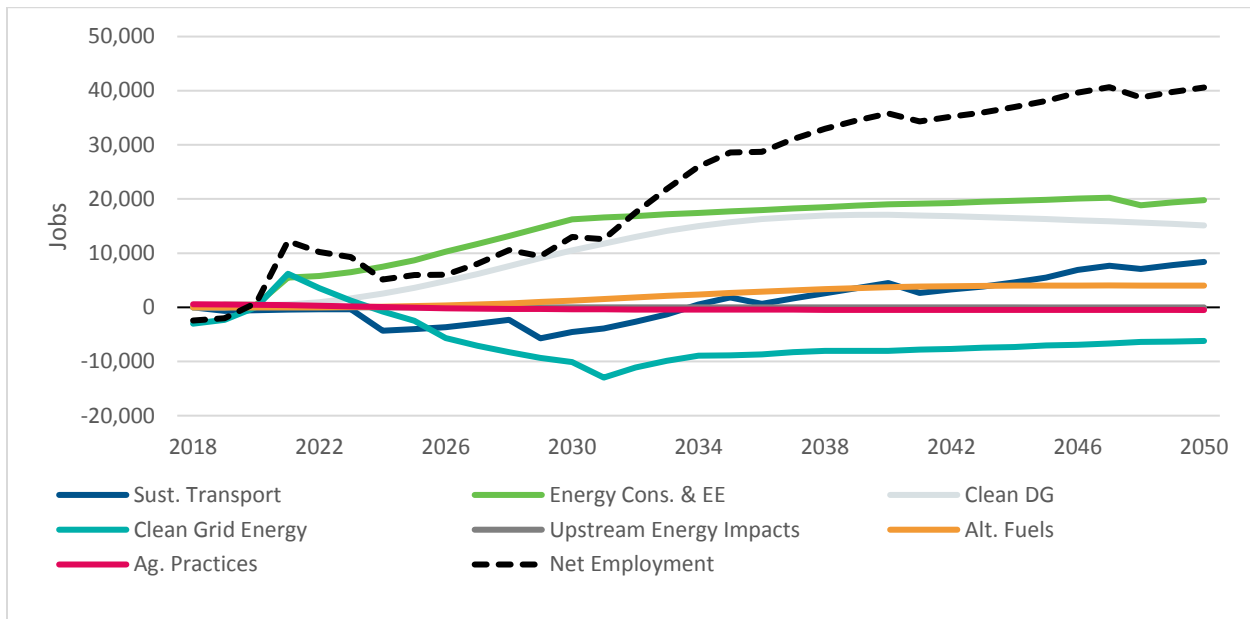
Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use. Note: the team looked primarily at the impacts from new natural gas combustion in new CHP systems and did not quantify the potential from using CHP to capture waste heat from existing combustion systems.

The Social Cost of Carbon (SCC) included in this chart is the 2050 SCC assuming a 2.5% discount rate (EPA 2016)

To achieve an understanding of the macroeconomic impacts of the Climate Action Plan (CAP), DEP and the analysis team examined the impacts on employment, gross state product (GSP), and personal disposable income for commonwealth residents. The overall net impacts of the CAP strategies on the Pennsylvania economy are positive. For example, if just the 15 quantified actions were implemented, approximately 40,000 jobs would be created in 2050.

Figure 4 shows the number of jobs supported through 2050 if all quantified actions are implemented for each of the seven quantified strategies. The trendlines by strategy are similar for GSP and personal disposable income, with the following net total results across strategies:

- ▶ **By 2050, Disposable Personal Income be increasing \$2.35 billion annually.**
- ▶ **By 2050, Gross State Product will be increasing \$3.76 billion annually.**

Figure 4. Number of Annual Jobs Supported Through 2050, by Strategy


In aggregate, the suite of strategies recommended in this Plan maximize GHG reductions and are cost-effective for Pennsylvania. However, DEP, other agencies, and the Pennsylvania state legislature will need to prioritize and phase strategy implementation for both the quantified and non-quantified strategies in this Plan. The year 2025 is rapidly approaching and actions with large GHG and economic benefits and relatively low cost and political barriers offer Pennsylvania the best short-term solutions. In parallel, initiating actions that may take more time and resources to implement and have more trade-offs to consider will help Pennsylvania maximize the potential impact of this Plan.

Energy conservation and efficiency actions appear to be likely candidates for immediate implementation when looking at Figure 2, Figure 3, and Figure 4. These actions offer relatively large GHG reductions over time, provide cost savings (negative cost-per-ton of GHG reduced), and support growth in jobs. Many of the energy conservation and efficiency actions outlined in this Plan build upon existing Pennsylvania policies and programs that have widespread support, so they also offer a low barrier for implementation. Furthermore, many of these actions have important resilience benefits.

The case for sustainable transportation practices gets more compelling as time goes on. Considering Figure 2, Figure 3, and Figure 4, most of the GHG benefits of this strategy come after 2025, positive job results are not seen until 2030, and the costs of reductions for actions under this strategy are relatively high compared to other actions. Nonetheless, state and local governments need to act now to realize the eventual benefits of this strategy and ensure infrastructure and policies are in place to drive and support market transformation. This will take time as the strategy will require public and private investment, scaling of infrastructure (e.g., bike shares and electric vehicle charging), and changes to consumer behavior to achieve the projected large climate and economic benefits through 2050.

Creating a diverse portfolio of clean, utility-scale electricity generation presents the most important trade-offs to consider. This strategy has a potentially large impact on almost every sector of the

Pennsylvania economy, as well as residents, businesses, and government. As shown in Figure 2, this strategy drives the largest reductions in GHG emissions of all the modeled strategies. It also appears to be cost-effective when considering the cost-per-ton of GHG reduced as compared to the social cost of carbon (see Figure 3). It also has positive resilience impacts. However, some actions under this strategy may take more effort to implement. Additionally, the creation of clean utility-scale generation results in some possible negative net macroeconomic impacts, due to the multiple effects on Pennsylvania's generation mix and related energy industries.

1 Why Do We Need a Climate Action Plan?

In recent years, extreme weather and catastrophic natural disasters have become more frequent and more intense. Like many parts of the United States, Pennsylvania is expected to experience higher temperatures, changes in precipitation, sea level rise, and more frequent extreme events and flooding over the next century (Shortle et al. 2015, Horton et al. 2014). Based on decades of research and evidence, it is commonly accepted that these events are highly likely a result of climate change caused by human activities and specifically emissions of greenhouse gases (GHGs) (IPCC 2014).

Since the early 20th century, temperatures have already increased by more than 1.8 °F (Shortle et al. 2015). If GHG emissions aren't curtailed significantly, the commonwealth is projected to be approximately 5.4 °F warmer by 2050 than it was at the end of the 20th century (Shortle et al. 2015). Similarly, average annual precipitation has increased by approximately 10 percent over the past 100 years and, by 2050, it is expected to increase by 8 percent, with a 14 percent increase during the winter season (Shortle et al. 2015). Global average sea level, which has risen by about 7–8 inches since 1900 (with about 3 inches of that increase occurring since 1993), is expected to rise at least several inches in the next 15 years and by 1–4 feet by 2100 (USGCRP 2017).

Climate impacts in Pennsylvania are real and continue to put Pennsylvanians at risk. Key impacts in Pennsylvania (Shortle et al. 2015) include:

- More frequent extreme weather events, including large storms, periods of drought, heat waves, heavier snowfalls, and an increase in overall precipitation variability, with increased infrastructure disruption and need for emergency management.
- Increased risks of injury and death from extreme weather events.
- Increased human health risks from air pollution, diminished water quality, and heat stress such as exacerbated asthma or increased water-borne illnesses.
- Changing pest, weed, and disease management challenges for farmers and livestock producers.

Climate Change Impacts Already Happening

Climate change has had and will continue to have significant impacts. For example:

In Pennsylvania

- Temperatures increased by more than 1.8 °F since the early 20th century and are expected to increase by an additional 5.4 °F by 2050.
- Annual precipitation has increased by approximately 10 percent since the early 20th century and is expected to increase by another 8 percent by 2050.

In the United States

- Extreme weather events have cost a total of \$1.1 trillion collectively since 1980.
- More extreme events such as Superstorm Sandy can have significant costs (e.g., \$65 billion) individually.

Globally

- Sea level has risen 7-8 inches since 1900 (with half of the increase since 1993), and is expected to rise 1-4 feet by 2100.

- Increased demand for energy, particularly during warmer summer months, meaning higher energy costs for consumers and increased strain on the grid to provide reliable power.
- More frequent flooding and associated disruptions due to sea level rise in communities and cities in the Delaware River Basin, including the city of Philadelphia.
- Potential for wetland drying in the Ridge and Valley ecoregion.
- Potential for degraded water quality in the tidal freshwater portion of the Delaware estuary.

The impacts included in this report draw from the *Pennsylvania Climate Impacts Assessment* (Shortle et al. 2015). The assessment is updated every three years and provides scientific projections of changes in temperature and precipitation in Pennsylvania and the potential impacts in the commonwealth. Additional details on expected climate change impacts can be found in the latest assessment update.

These impacts could alter the many fundamental—but often not explicit—assumptions about climate that are intrinsic to the commonwealth’s infrastructure, governments, and businesses. For example, bridges are designed for certain flooding return intervals, energy systems are designed for certain temperature ranges, farmers plant crops suited to historical climate conditions, ski mountain operators count on specific snow-making conditions, and communities are planned around historical floodplains. If not properly accounted for, changes in climate could result in more frequent road washouts, higher likelihood of power outages, shifts in economic activity, among other impacts. It is estimated that events such as these have cost governments (leaders), citizens, and businesses in the United States more than \$1.1 trillion since 1980 (USGCRP 2017).

Climate change can also affect vital determinants of health such as clean air, safe drinking water, sufficient food as well as secure shelter. This can include impacts from increased extreme weather events such as heat, droughts, and floods, wildfire, decreased air quality, and illnesses transmitted by food, water, and disease carriers such as mosquitoes (National Climate Assessment). Climate change is expected to cause around 250,000 additional deaths globally per year between 2030 and 2050 (WHO 2018). This includes deaths from malnutrition, malaria, diarrhea, and heat stress. There are additional direct damage costs to health from climate change, which is estimated to be around \$2-4 billion per year by 2030 (WHO 2018).

Therefore, it is critical that leaders, citizens, and businesses in the Commonwealth of Pennsylvania:

- ▶ Consider how the commonwealth’s climate may change in the future,
- ▶ Understand what (if any) impacts would occur if those changes are not addressed, and
- ▶ Take action to adapt to the changes and reduce the emissions that are causing them, while making the economy stronger.

The Commonwealth of Pennsylvania’s government has already been leading on climate action through a series of work and activities. **The Pennsylvania Climate Change Act (Act 70 of 2008)** requires the Department of Environmental Protection (DEP) to develop an inventory of greenhouse gases (GHG) and administer a Climate Change Advisory Committee (CCAC), a voluntary registry of GHG emissions, and a Climate Change Action Plan. Revisions to the Action Plan are required every three years. (PA General Assembly 2008). In addition to this Act, other actions the Commonwealth of Pennsylvania has or is taking include:

- **Legislative Action**

- **The Alternative Energy Portfolio Standard (AEPS) (Act 213 2004)** requires that 18 percent of electricity supplied by Pennsylvania electric distribution companies be generated by alternative energy sources by 2021. Alternative Energy Credits (AECs) can be used for compliance. Electricity generated in state or AECs can qualify as Tier 1 or Tier 2 sources: Tier 1 sources must comprise 8 percent of generation and may include solar, wind, low-impact hydro, geothermal, biomass, biologically derived methane gas, coal-mine methane and fuel cell resources; Tier 2 sources must comprise 10 percent of generation and may include waste coal, distributed generation (DG), demand-side management, large-scale hydro, municipal solid waste, wood pulping and manufacturing byproducts, and integrated gasification combined cycle (IGCC) coal (PA PUC 2018).
- **House Bill 118 (Act 40 of 2017)** prohibits in-state utility companies from using solar renewable energy credits from out-of-state projects to fulfill solar energy source requirements (PA General Assembly 2017).
- **Pennsylvania Commercial Property Assessed Clean Energy (C-PACE) (Act 30 of 2018)** approves a financing mechanism that enables low-cost, long-term funding for energy efficiency upgrades to commercial and industrial properties, including renewable energy projects and installation of high efficiency heating, ventilation, and air-conditioning (HVAC) systems. The C-PACE program is expected to support the creation of new clean energy projects, enhance property values, and lower business costs by reducing the up-front costs of installing energy-efficient projects (Governor Tom Wolf 2018).

- **Planning, Research, and Information Gathering**

- **The Pennsylvania Department of Environmental Protection**
 - Previous versions of the Pennsylvania Climate Action Plan provide analysis and recommendations with the goal of finding cost-effective measures to reduce GHG emissions to mitigate climate change impacts in line with Act 70 requirements (see above). Since 2009, the Climate Action Plan has been updated every three years.
 - The *Pennsylvania Climate Impacts Assessment Update* was also prepared in response to Act 70, and requires the DEP to conduct a study of the potential impacts of global climate change on Pennsylvania over the next century. Three versions of this report have been released to date (Shortle et al. 2015).
 - DEP is finalizing the *Electric Vehicle Roadmap*. The Roadmap has been developed and the Drive Electric PA Coalition (DEPA) is looking to take elements of the electric vehicle (EV) Roadmap and start working on ways to accelerate EV adoption in PA to state, municipal, private business fleets, as well as, individual purchasers of EVs (PA DEP 2018a).
 - The *Finding Pennsylvania's Solar Future Plan* brought together expert stakeholders from across sectors to explore whether Pennsylvania has sufficient photovoltaic potential to increase in-state solar generation to provide 10 percent of in-state

electricity consumption by 2030. Stakeholders explored likely pathways to achieving that target and used modeling to identify associated economic, environmental, and health impacts. (PA DEP 2018b).

- In Pennsylvania, multiple State Energy Planning/Marketing planning efforts are underway. For 2018-19, DEP will synthesize the work that has been done into one cohesive, strategic energy plan.
- **The Pennsylvania Department of Conservation and Natural Resources (DCNR)** has led multiple climate initiatives including developing a *Climate Change Adaptation and Mitigation Plan* in 2018, outlining 123 action steps to be undertaken to make the state more resilient to potential climate change impacts. The DCNR has also reported other climate change issues such as the 2015 report, *Planning for the Future*, in addition to conservation activities through the long-standing Wild Resource Conservation Program.
- **The Pennsylvania Department of Community and Economic Development (DCED)** manages financing programs for grants and loans for clean and alternative energy projects including buildings, equipment and land development activities; grants and loans to individuals and small businesses for high-performance, energy-efficient building projects; grants and loans for geothermal and wind energy projects; and grants and loans for alternative energy production projects involving solar technologies as enacted by the Alternate Energy Investment Act of July 2008.
- **Program Implementation**
 - **The Alternative Fuels Incentive Grant (AFIG) Program (Act 166 of 1992)** aims to create new markets for alternative fuels, fleets, and technologies to enhance the state's energy security with the objectives of improving the environment, supporting economic development, and enhancing quality of life (PA DEP 2018c).
 - **Pennsylvania's Energy Efficiency and Conservation Law (Act 129 of 2008)** requires the commonwealth's major electric distribution companies to develop energy efficiency and conservation plans and adopt other methods of reducing the amount of electricity consumed by customers over three phases by implementing programs such as incentives for high-efficiency appliances, efficient new buildings, and industrial process upgrades. Efficiency and conservation programs must be cost-effective over fifteen years and savings are verified by third parties (PA PUC and PA PUC 2017).
 - **The Natural Gas Energy Development Program (Act 13 of 2011)** aims to increase the use of domestically produced natural gas resources through impact fee provisions, upgraded environmental regulations, and local ordinance preemption and restrictions. Broadly, the program imposes new environmental obligations of natural gas producers, but also promotes natural gas production while raising revenue through the impact fees (PA General Assembly 2012).
 - **Other Programs, include:**

- **Regional Pooled Municipal Energy Implementation Program.** The Delaware Valley Regional Planning Commission (DVRPC) plans to build off of their existing successful Regional Streetlight Procurement Plan for the implementation of more rounds with interested municipalities as a model to develop a best practices step-by-step report for other regions interested in executing a regional pooled energy implementation program.
- **Wastewater Treatment Plant (WWTP) Operators Energy Outreach.** According to the United States Department of Energy's (DOE's) WWTP Energy Data Management Manual, electricity alone can constitute 25% to 40% of a wastewater treatment plant's annual operating budget. A series of training events will be provided for 50 – 80 operators of smaller to mid-sized municipally owned WWTP.
- **Energy Assurance Activities.** DEP has recently updated the Energy Assurance Plan which includes a Petroleum Shortage Response Plan. As a critical next step in ensuring resiliency efforts, DEP and the Pennsylvania Emergency Management Agency (PEMA) are educating local governments on planning and responding to energy emergencies from disasters.
- **Building Operator Certification (BOC).** The BOC program on average saves roughly 100,500 kWh of electricity per certified operator per year. This represents a savings of \$10,500 annually for a 5-year period. DEP is contracting with the Pennsylvania College of Technology's National Sustainable Structures Center to provide BOC Level 1 trainings to PA facility managers and HVAC mechanics/technicians from K-12 schools, higher education, and government agencies.
- **Building Retuning Training (BRT).** DEP is contracting with the Pennsylvania Technical Assistance Program (PennTAP) to provide BRT walkthroughs of facilities and workshops that include obstacles to implementation for local governments and schools in Southwestern PA.
- **Energy Codes Training.** DEP is contracting with the Pennsylvania Municipal League to offer 2015 International Energy Conservation Code (IECC) trainings by the sub-contractor Performance Systems Development to code officials, builders, design professionals and third-party inspectors.
- **Energy Efficiency (EE) Assessments for Small to Mid-Sized Manufacturers/Agricultural Sector.** PennTAP and Emerging Technology Applications Center are contracted to provide EE assessments and technical assistance for small to mid-sized manufacturers.
- **DEP Outreach to Schools.** Several DEP staff members have been participating in the PA Green & Healthy Schools Partnership (PAGHSP) for several years, a collaboration of government agencies, nonprofits, K-12 schools, higher education institutions, and individuals who are committed to promoting healthy schools within the commonwealth. The PAGHSP plans to organize and implement several workshops

over the course of the next year focusing on Eco-Schools USA, a framework for engaging students in school environmental initiatives, including energy.

- **Pennsylvania Energy Development Authority (PEDA) Grant Program.** PEDA's mission is to finance clean, advanced energy projects in Pennsylvania. No funding is proposed at this time. DEP staff continue to manage existing grants and provide administrative support to the program.
- **Green Energy Loan Fund.** DEP staff oversee the grant with Reinvestment Fund who administers the Pennsylvania Green Energy Loan Fund for large building energy efficiency retrofits.

Pennsylvania's Energy and GHG Emissions

The Importance of Energy in Pennsylvania

Since the start of the commercial petroleum industry in the 1850s, Pennsylvania has been a leader in energy markets. The commonwealth is rich in natural fossil resources, starting with coal in the 18th century, oil in the 19th century, and focusing on natural gas in the 21st century. In addition to its wealth of carbon-based fuels, Pennsylvania's energy landscape now features renewables and other alternative energy resources. Advances in renewable technologies and policy and program initiatives are allowing these low-carbon energy sources to play increasingly pivotal roles in Pennsylvania's energy story.

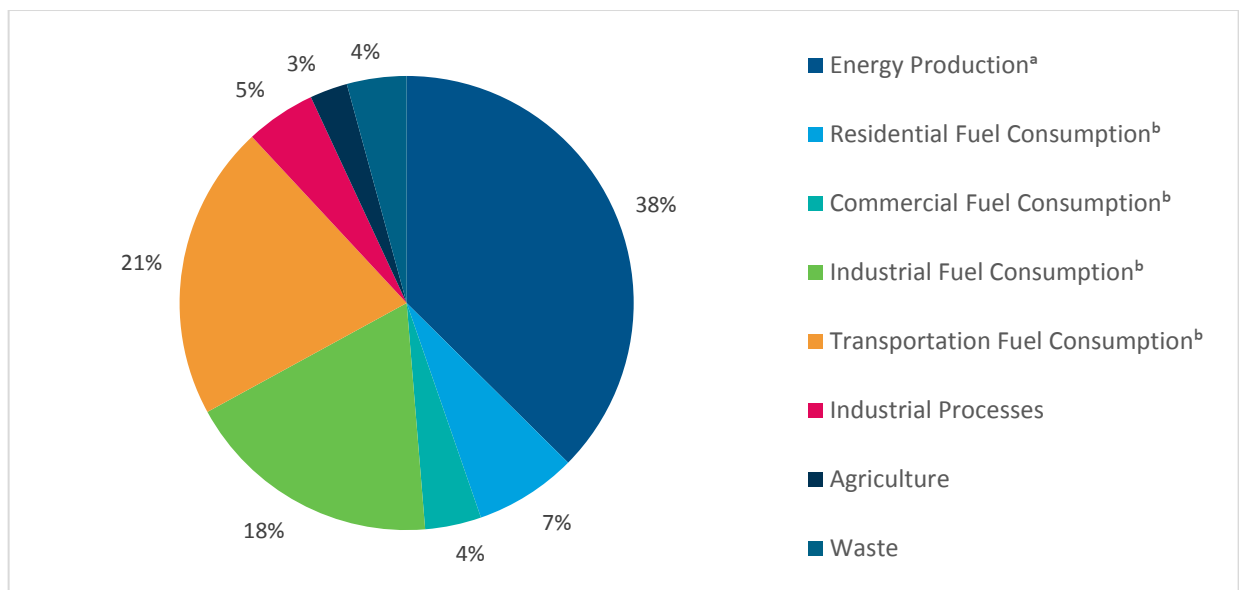
Because of its strong resource base, Pennsylvania is consistently one of the top energy-producing states in the United States and is one of the country's leading electricity exporters. This results in many economic benefits for the commonwealth (e.g., clean energy is a large economic driver for Pennsylvania – all 67 counties have residents working on clean energy and Pennsylvania ranks 11th among all 50 states and Washington D.C. in clean energy jobs (E2 2018)), but also comes with the serious responsibility of understanding and minimizing the associated risks and effects (e.g., 88 percent of 2015 GHG emissions, in Pennsylvania come from energy production and consumption). For more information on Pennsylvania's energy picture, refer to the DEP *Energy Assessment Report for the Commonwealth of Pennsylvania* once released. This report characterizes current, future, and potential energy trajectories in Pennsylvania, providing readers with an overview of the commonwealth's energy picture and the potential opportunities for future energy development. It includes both a business-as-usual energy assessment through 2050 and an assessment of energy resource potential opportunities through 2050. The analyses presented in this Plan are generally consistent with the information presented in the *Energy Assessment Report for the Commonwealth of Pennsylvania*.¹

¹ The "business as usual" (BAU) scenario in this analysis differs from the data presented in *Energy Assessment Report for the Commonwealth of Pennsylvania*. BAU electricity generation from traditional nuclear in the Energy Assessment report only accounted for the closure of Three Mile Island; the closure of Beaver Valley Nuclear Power Station was announced after the Energy Assessment was completed, but has been included in the BAU for the Climate Action Plan analysis.

Pennsylvania's Past GHG Emissions

Pennsylvania generates its statewide GHG inventory using the U.S. Environmental Protection Agency's (EPA) State Inventory Tool (SIT). The Inventory includes emissions from the residential, commercial, industrial, transportation, electricity production, agriculture, waste management, forestry, and land use sectors. In 2015, total statewide emissions in Pennsylvania were 288 MMTCO₂e while net emissions (accounting for emissions sinks from forestry and land use) were 257 MMTCO₂e. These emissions have been reduced since 2005, when total statewide emissions were 329 MMTCO₂e and net emissions were 294 MMTCO₂e. Emissions reductions have occurred primarily due to a shift in the proportion of high carbon-emitting electricity generation sources, such as coal, to lower and zero emissions generation, such as natural gas and renewables, as well as reductions in overall energy use in the residential, commercial, transportation, and electric power sectors across the commonwealth from 2005 to 2015. Figure 5 show contributions from each sector to overall GHG emissions in 2015 in Pennsylvania.

Figure 5. Proportion of 2015 GHG Emissions (Excluding Sinks) by Sector



^a Energy Production includes emissions from electricity generation, coal mining, and natural gas and oil production.

^b Fuel Consumption includes emissions from direct fuel consumption. It does not include emissions from electricity consumption.

Pennsylvania's GHG inventory accounts for emissions based on the amount of electricity generated by various fuels in the commonwealth, regardless of if that electricity is used in Pennsylvania or if it is exported to other states. An alternative way to inventory GHG emissions is to account for emissions associated with electricity used within the commonwealth. This alternative approach is applied in this Plan as it allows DEP to fully capture emissions within Pennsylvania's borders and effects of its policies and programs that address both electricity use (e.g., Act 129) and generation (e.g., the AEPS). It considers changes in GHG emissions a result of both:

- Changes in end use electricity consumption; and
- Changes in the mix of fuels used to generate electricity, which is accounted for by using an electricity grid emission factor that varies over time.

Pennsylvania's Future GHG Emissions without Additional Action

The benefits and costs of these 15 emissions reduction actions identified are measured relative to 2005 base year GHG emission levels to assess target achievement and further compared to a business as usual (BAU) scenario in which emissions are projected through 2050 to show the GHG benefits over time. 2015 is the most recent year for which a complete set of data is available for historical emissions. Therefore, GHG emissions are projected for 2016-2050 using a combination of the Energy Information Administration's (EIA) Annual Energy Outlook, SIT projections, and other supporting data sources.

In the BAU scenario, depicted in Figure 6, total and net emissions (including emissions sinks) are expected to increase by 4 percent and 5 percent, respectively, from 2015 to 2050. Net emissions (including sinks) are used for setting and tracking GHG reductions over time and assessing achievement of GHG targets.

Figure 6. BAU GHG Emissions (MMTCO₂e)

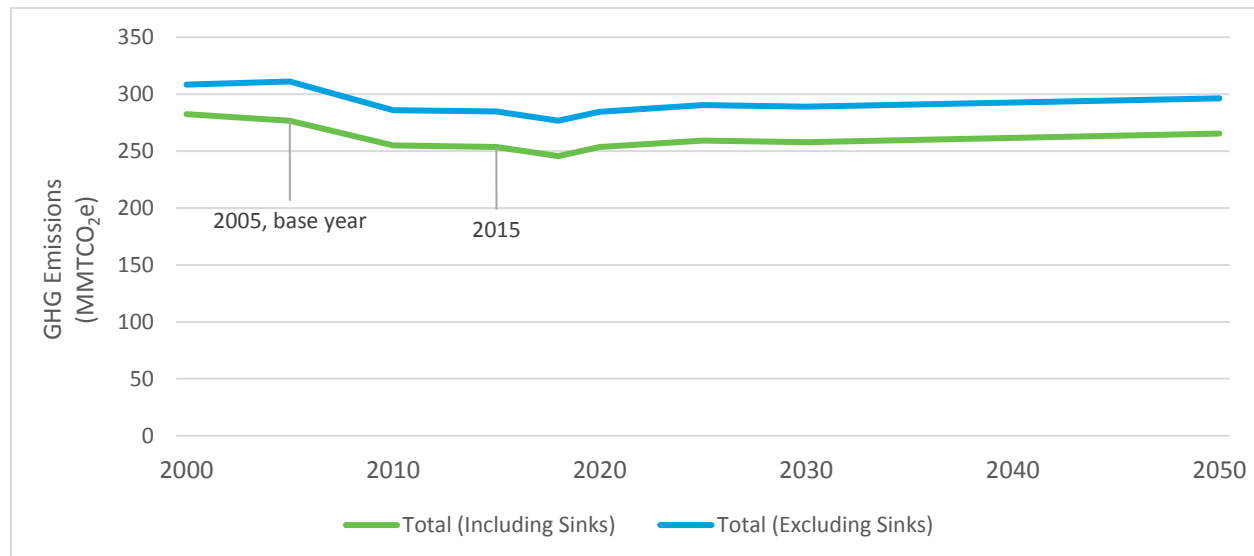
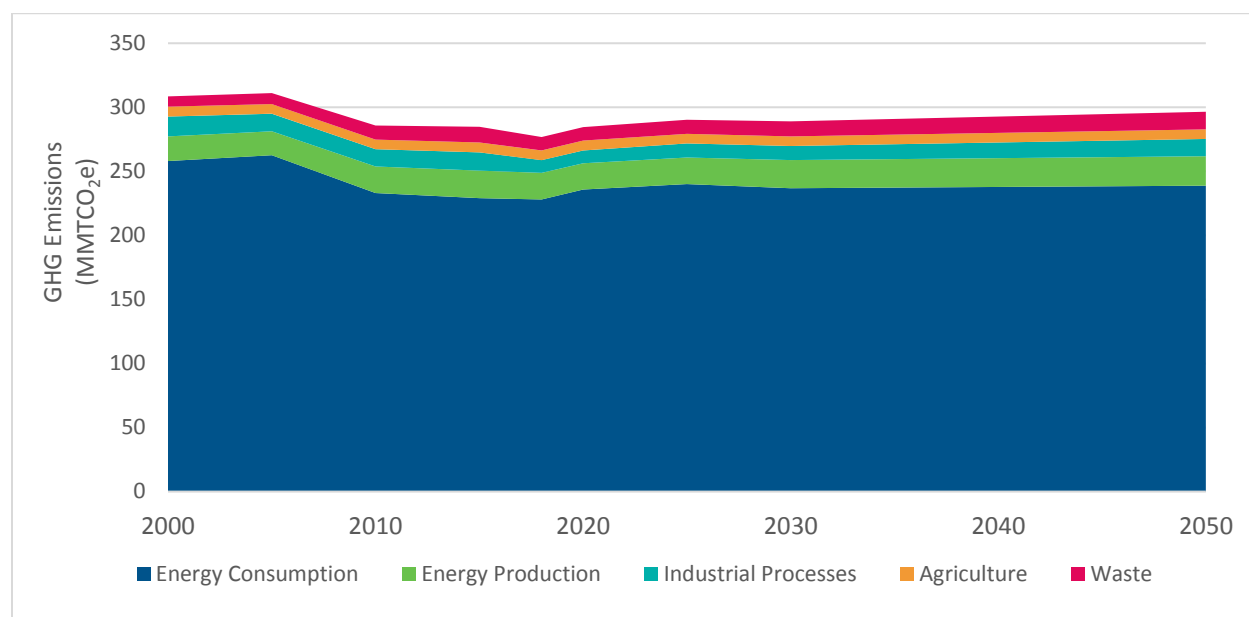


Figure 7 and Table 1 show the contribution of each sector to total GHG emissions in the BAU scenario through 2050 (leaving out emissions sinks). Overall energy sector emissions are expected to increase by about 5 percent from 2015 to 2050. Emissions from energy consumption are expected to increase by 4 percent from 2015 through 2050, with emissions from transportation sector electricity consumption expected to increase by four times as electric vehicle adoption grows across Pennsylvania. Emissions from energy production (e.g., fugitive emissions from coal mining and natural gas and oil production) are expected to grow 8 percent from 2015 to 2050.

Industrial sector electricity consumption emissions are also expected to increase significantly from 2015 to 2050, rising by 26 percent in the BAU scenario. Emissions from the agriculture sector are projected to decrease 5 percent while waste sector emissions increase by 12 percent. The amount of carbon sequestered by the land use and forestry sector are projected to remain relatively constant from 2015 to 2050.

Figure 7. BAU GHG Emissions (Excluding Sinks) by End-Use Sector (MMTCO₂e)

Table 1. BAU GHG Emissions by End-Use Sector (MMTCO₂e)

Sector	2000	2005	2015	2025	2030	2050
Energy Consumption	258	263	229	240	237	239
Energy Production	19	19	21	21	22	23
Industrial Processes	15	14	14	11	11	14
Agriculture	8	8	8	8	8	7
Waste	8	9	12	11	12	14
Total Emissions	308	313	284	291	290	297
Emissions Sinks	-26	-34	-31	-31	-31	-31
Net Emissions	282	277	255	253	259	258

Note: Totals may not sum due to independent rounding

Climate Action Plan Organization

The remainder of this Plan includes:

- Section 2: What's Included In this Plan**, describes overarching goals of the Plan, methods used to develop the Plan and its contents, and the sectors, strategies, and actions covered by the Plan.
- Section 3: Pennsylvania's Climate Impacts, Emission Reduction, and Adaptation Opportunities** presents a list of potential strategies and actions leaders, citizens, and business in Pennsylvania can take to address and adapt to climate change. Where feasible, modeled and qualitative impacts of each strategy are presented.

- **Section 4: Benefits and Costs for Modeled Strategies and Actions** provides a summary of quantitative impacts and GHG reductions and micro- and macro-economic modeling results by strategy and action.

2 What's Included in this Plan?

Adaptation Goals and Emission Reduction Targets

This 2018 Climate Action Plan Update comprehensively considers the changing climate in Pennsylvania by addressing both the impacts of climate change (“adaptation”) and the causes of climate change (reducing greenhouse gas emissions, or “mitigation”). To ensure the effectiveness of this Plan, overarching adaptation goals and GHG emissions reduction targets are used to frame the strategies. In addition to the goals and targets outlined below, and per Act 70 of 2008, cost-effectiveness is also a key factor for strategy selection.

Helping Pennsylvanians Adapt to the Impacts of Climate Change

This Plan identifies two adaptation-focused goals, which can be achieved by actions from leaders (government), citizens, and businesses in the commonwealth:

- ▶ Minimize disruptions to Pennsylvania’s citizens, economy, and environment from climate-related hazards.
- ▶ Increase Pennsylvania’s ability to anticipate, prepare for, and adapt to changing conditions and withstand, respond to, and recover rapidly from climate-related disruptions.

Driving Ambitious Action to Reduce Pennsylvania’s GHG Emissions

Pennsylvania currently does not have GHG reduction mandates or goals. Yet, to ensure its contributions to human-caused climate change are not irreversible, all Pennsylvanians (citizens, businesses, and leaders) must understand how they can help keep global temperature increases below 2 degrees Celsius. This threshold for global temperature rise is cited by experts as the level beyond which dire consequences would occur, including sea level rise, superstorms, and crippling heat waves (IPCC 2014). It’s been projected that United States GHG emissions would need to be reduced 26-28% by 2025 and 80% by 2050 to ensure global temperatures stay below that level (UNFCCC 2015). The targets are also in line with GHG reduction targets set by many other countries and states.²

For these reasons, this Plan uses similar targets as guides for modeling the effects of a series of GHG emission reduction strategies. If all states achieved such targets, and other nations met comparable goals, climate science analysis suggests that global temperature rise could be kept below the 2-degree Celsius threshold. Accordingly, the GHG reduction targets used for modeling purposes in this Plan are:

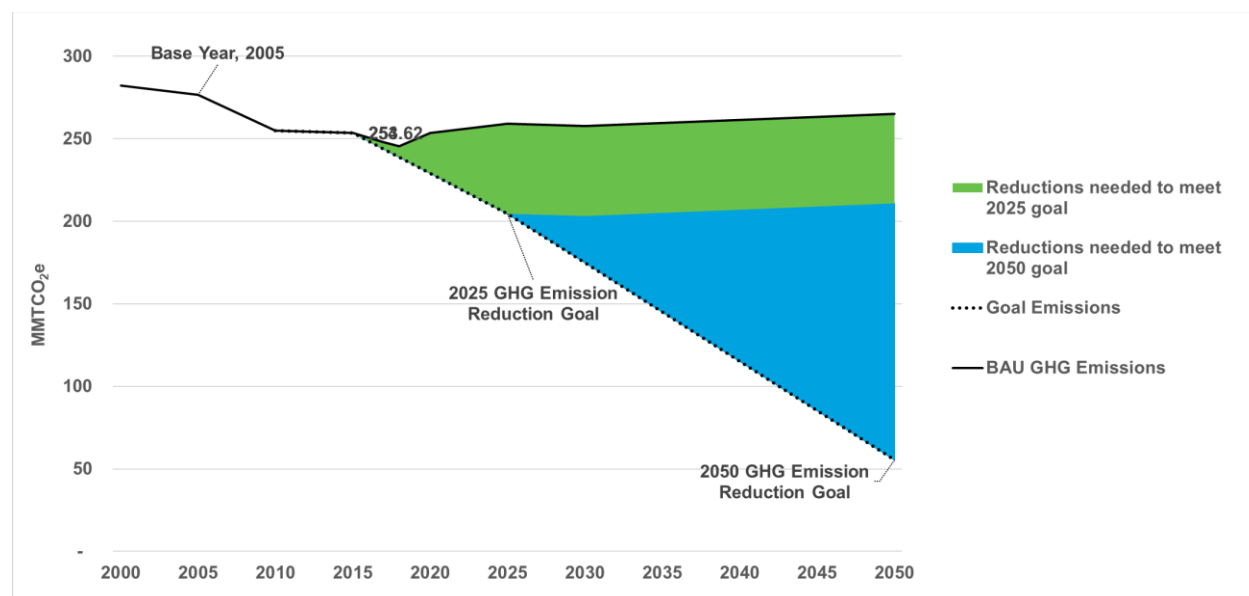
- ▶ 26 percent reduction of net GHG emissions by 2025, from 2005 levels.

² For example, the U.S. Climate Alliance, which includes 16 states, set the same GHG reduction target for 2025. Additionally, the Under2 Coalition promotes a guiding principle that their parties pursue emission reductions consistent with a trajectory of 80 to 95 percent below 1990 levels, which is line with 80 percent reduction of 2005 levels. By this standard, an 80 percent reduction by 2050 target that uses 1990 as a base year could be considered science-based. Aligning the targets within the 2018 CAP to targets set by other states helps to ensure that any target selected is achievable and that the corresponding GHG reduction strategies remain viable and cost effective.

- ▶ 80 percent reduction of net GHG emissions by 2050, from 2005 levels.

In the BAU scenario, net annual GHG emissions in Pennsylvania were 277 MMtCO₂e in 2005. Net annual GHG reductions of 26 percent in 2025 would result in 205 MMtCO₂e, and an 80 percent reduction would yield 55 MMtCO₂e. These targets are illustrated in Figure 8.

Figure 8. BAU Net GHG Emissions and GHG Reductions Required to Meet Modeling Targets (MMtCO₂e)



How this Plan was Developed

The strategies in this report reflect an iterative process between the DEP Energy Programs Office (EPO), Bureau of Air Quality (BAQ), and Policy Office and their sister agencies (DCNR, the Pennsylvania Departments of Agriculture, Community and Economic Development, Health, Transportation, General Services, the Pennsylvania Fish and Boat Commission, and Pennsylvania Public Utility Commission), the Climate Change Advisory Committee (CCAC) and other stakeholders.

1. DEP and the supporting analysis team (ICF) started by separately identifying strategies with adaptation benefits and strategies with emissions reduction benefits. The team then iteratively prioritized and integrated the strategies, prioritizing those with both adaptation and emissions reductions benefits.
 - To identify strategies with adaptation benefits, DEP and the analysis team developed an extensive list of adaptation-focused policies, programs, and actions based on a literature review of numerous sources. The team then consolidated the actions and refined strategies based on feedback from Pennsylvania agencies, evaluation against criteria (e.g., impacts addressed, emissions co-benefits, early-action characteristics), and opportunities to eliminate redundancies.
 - To identify strategies with emissions reduction benefits, the team compiled a list of strategies from previous Pennsylvania CAPs, DEP and CCAC suggestions, strategies

identified by other jurisdictions, and a comprehensive review of energy resource potential in Pennsylvania.

2. DEP and the team then refined the list based on internal DEP and CCAC feedback, and worked with them to select strategies to quantitatively model to estimate GHG reductions, cost-effectiveness, and other effects. Strategies were selected for modeling based on an initial screen of potential contributions to GHG reductions—strategies that were expected to result in larger GHG reductions were quantitatively assessed. Most of the strategies focused on clean energy, in line with the fact that the vast majority of emissions (88 percent in 2015) in Pennsylvania come from energy production and consumption.
3. DEP and the analysis team then conducted modeling for selected strategies for GHG, energy, and micro-economic effects. The modeling process was iterative, with the analysis team seeking feedback and input from DEP and the CCAC at certain points throughout the process to ensure their assumptions and inputs were captured. This Plan provides a high-level summary of the methods used for quantitative modeling in respective strategy sections. More detailed information on modeling assumptions, methods, data, and results for GHG emissions, energy, criteria air pollutant emissions, and micro-economic impacts can be found in Appendix A, and below in the description of benefits and costs for each strategy.
4. Macro-economic modeling (e.g., changes in jobs) was conducted using the REMI PI+ model. This is a structural economic forecasting and policy analysis model that integrates several analytic techniques including input-output, computable general equilibrium (CGE), econometric, and economic geography methodologies. REMI is a dynamic model, with forecasts and simulations to include behavioral responses to wage, price, and other economic factors. It can be used for estimating national, regional, and state-level impacts of any policy changes. The dynamic modeling framework supports the option to forecast how changes in the economy, and adjustments to those changes, will occur on an annual basis.
 - REMI functions by forecasting two states of the world. The first is the state of the regional economy under some standard assumptions of employment and population changes. This first forecast is referred to as the control forecast. The second forecast, in which the model user incorporates the desired policy changes, is referred to as the alternative forecast or the simulation. The difference between the two forecasts would be the estimated effect of the policy. Policy changes that were input into REMI were modeled by the analysis team as described above.
5. Lastly, DEP and the analysis team outlined additional specific actions within each strategy for leaders, citizens, and businesses and specified implementation steps for modeled actions.

Plan Sectors, Strategies, and Actions

This report is first organized by sector. Within each sector, multiple strategies are outlined. The term “strategy” encompasses multiple actions—specific policies, programs, or activities for state and local leaders, citizens, and businesses.

Sectors

This Plan is organized by sectors, including:

- ▶ Energy Consumption
- ▶ Energy Production
- ▶ Agriculture
- ▶ Ecosystems & Forestry
- ▶ Outdoor Recreation & Tourism
- ▶ Waste Management
- ▶ Water Resources
- ▶ Human Health

Strategies

The strategies presented in this Plan include actions that can reduce GHG emissions, increase energy efficiency and adoption of clean energy practices and technologies, address existing vulnerabilities, avoid creation of future vulnerabilities, and build Pennsylvania’s capacity to adapt to climate change over time. Many of these strategies may entail significant costs, but all are projected to provide sizeable benefits in the long run, as Pennsylvania’s governments, businesses, and citizens work to ensure that the commonwealth continues to thrive over the coming century. While some strategies focus narrowly on specific sectors, many have actions, benefits, costs, and climate impacts that cut across sectors Table 2 below summarizes where to find each strategy within the report, as well as other sectors related to the strategy. It also indicates which strategies include actions with quantified benefits and costs and if the strategy addresses climate mitigation, adaptation, or both

Table 2: Summary of Strategies

	Energy Consumption	Energy Production	Agriculture	Ecosystems & Forestry	Outdoor Rec & Tourism	Waste	Water	Human Health	Includes Modeled Actions	Reduces GHG Emissions	Increases Ability to Adapt
Increase end use energy conservation and efficiency	*		•			•	•	•	✓	✓	✓
Implement sustainable transportation planning and practices	*			•				•	✓	✓	✓
Develop, promote, and use financing options to encourage energy efficiency	*		•			•	•	•		✓	✓
Increase use of clean, distributed electricity generation resources		*	•			•	•	•	✓	✓	✓
Create a diverse portfolio of clean, utility-scale electricity generation		*	•			•	•	•	✓	✓	✓
Reduce upstream impacts of fossil fuel energy production		*		•		•	•	•	✓	✓	
Increase production and use of alternative fuels		*	•			•		•	✓	✓	✓
Use agricultural best practices	•		*	•		•	•	•	✓	✓	✓
Provide resources and technical assistance to farmers to adapt			*	•			•	•			✓
Improve protection of and optimize ecosystems				*	•		•	•		✓	✓
Monitor, identify, and remove ecosystem vulnerabilities				*	•			•			✓
Help the outdoor tourism industry manage shifting climate patterns				•	*		•	•			✓
Reduce waste sent to landfills, and expand beneficial use of waste		•	•			*		•		✓	✓
Use stormwater best management practices	•						*	•		✓	✓
Promote integrated water resources management and water conservation	•						*	•			✓
Improve reliability and accessibility of public information about climate-related health risks								*			✓
Bolster emergency preparedness and response								*			✓
Lead by example in commonwealth and local government practices and assets	•	•	•	•	•	•	•	•		✓	✓
Incorporate historical and projected climate conditions into siting and design decisions for long-term infrastructure	•	•	•	•	•	•	•	•			✓

* strategy presented in this sector

• strategy relates to this sector

Actions

Actions include various policies, programs, or activities that leaders (state and local government), citizens, and businesses can take to reduce GHG emissions and adapt to climate change impacts. Within each strategy, the Plan outlines a list of specific actions that each stakeholder group can take. Of the many actions listed, the analysis team quantitatively analyzed 15 of the actions that leaders could take, as shown in Table 3. Table 4 identifies additional actions the analysis team qualitatively analyzed, which would provide additional benefit to the commonwealth.

Table 3. Emissions Reduction Actions for Leaders Modeled for the 2018 PA Climate Action Plan (CAP) Update, Organized by Sector and Strategy

Sectors	Strategies	Actions Included in Quantitative Modeling	GHG Emission Reductions in 2025 (MtCO ₂ e)	GHG Emission Reductions in 2050 (MtCO ₂ e)
Energy Consumption	Increase end use energy conservation and efficiency	• Update building codes	1,164,587	5,374,682
		• Increase adoption of energy efficiency, and expand Act 129	1,916,947	1,984,261
		• Create an Act 129-like conservation and efficiency program for natural gas	845,010	1,567,198
		• Expand energy assessments and provide more trainings on energy efficiency for industry	1,901,335	3,110,031
	Implement sustainable transportation planning and practices	• Reduce vehicle miles traveled for single-occupancy vehicles	573,260	2,820,936
		• Implement a strategic plan and incentives for increasing electric vehicle use	474,100	21,689,937
		• Increase the use of clean public transportation through electric municipal bus fleets	13,948	458,048
Energy Production	Increase use of clean, distributed electricity generation resources	• Invest in and promote building-scale solar	NA ^a	48,210
		• Incentivize and increase use of combined heat and power (CHP)	544,502	-1,561,128 ^b
	Create a diverse portfolio of clean, utility-scale electricity generation	• Increase Alternative Energy Portfolio Standard(AEPS) Tier 1 targets, and further increase in-state generation and use of renewables	6,703,719	27,639,941
		• Implement policy to maintain nuclear generation at current levels	18,412,115	21,152,811

		<ul style="list-style-type: none"> Limit carbon emissions through an electricity sector cap and trade program 	4,899,227	NA ^c
	Reduce upstream impacts of fossil fuel energy production	<ul style="list-style-type: none"> Implement policies and practices to reduce methane emissions across oil and natural gas systems 	104,879	29,598
	Increase production and use of alternative fuels	<ul style="list-style-type: none"> Increase recovery and use of gas from coal mines, agriculture, wastewater, and landfills for energy 	1,673,531	2,796,683
Agriculture	Use agricultural best practices	<ul style="list-style-type: none"> Implement and provide training for no-till farming practices 	208,331	328,070

^a There is sufficient building scale solar in 2025 in the BAU to meet the 6% solar carve out assuming 90% is utility scale and 10% is building scale, so there are no GHG reductions from BAU in 2025. We see non-zero savings starting in 2026.

^b A negative value indicates an increase in GHG emissions.

^c The GHG emission reductions from expanding AEPS requirements and maintaining nuclear generation are projected in this modeling analysis to meet the cap in 2050 without a cap and trade program.

To the extent feasible, interactions between some actions and strategies are captured in the modeling effort. Specifically:

- Increase end use energy conservation and efficiency.** GHG emissions are reduced directly through changes in end use energy consumption from the energy efficiency actions identified in Table 3. The modeling for this strategy also factors in changes in electric generation carbon intensity from the strategy “create a diverse portfolio of clean, utility-scale electricity generation.” Accordingly, GHG emissions estimates are a joint function of electricity usage reductions and carbon intensity per unit of consumption. Reductions in energy consumption from efficiency actions are also factored into other actions’ impacts, both within the energy efficiency strategy and across strategies. For example, BAU electricity consumption used to estimate reductions from the “increase adoption of energy efficiency, and expand Act 129” action is adjusted based on impacts estimated from the “update building codes” action. And such BAU electricity consumption adjustments are also applied to other power sector strategies, such as “Create a diverse portfolio of clean, utility-scale electricity generation.”
- Implement sustainable transportation planning and practices.** GHG emissions are reduced directly through reductions in vehicle miles traveled (VMT), electrification of passenger vehicle fleets, and adoption of zero emissions transit buses from the actions identified in Table 2. The modeling also factors in the change in electricity-sector carbon intensity over time from the “create a diverse portfolio of clean, utility-scale electricity generation” strategy, such that the emissions impacts of increased electricity usage from electric vehicles as adjusted accordingly. Also, the “implement a strategic plan and incentives for increasing electric vehicle use” action

factors in the reduced average VMT per vehicle resulting from the “reduce vehicle miles traveled for single-occupancy vehicles” action.

- **Increase use of clean, distributed electricity generation resources.** GHG emissions are reduced through the installation of distributed renewable energy sources. As emissions reductions are estimated based on the reduction in grid electricity consumption, the modeling conducted by the analysis team for this strategy also factors in the change in electricity carbon intensity over time as driven by the “create a diverse portfolio of clean, utility-scale electricity generation.”
- **Create a diverse portfolio of clean, utility-scale electricity generation.** This Plan accounts for Scope 2 GHG emissions (or GHG emissions caused at the powerplant level by end-use electricity consumption), assuming all electricity consumption is sourced from generation in Pennsylvania. Therefore, a reduction in the carbon intensity of Pennsylvania’s generation will result in a lower emission factor being applied to Scope 2 emissions from electricity consumption – these impact emissions for most all other strategies. In particular, it allows reductions from both lower carbon intensity of utility-generated electricity and reductions in end-use electricity consumption to contribute toward meeting the targets outlined in this Plan. As part of this strategy, the analysis team assumes that both the AEPS expansion and maintaining current levels of nuclear generation contribute to meeting the emission reductions target set by the power sector carbon cap and trade action. Remaining reductions needed to meet the cap and trade emissions reduction target are obtained through shifting dispatch of coal-fired generation to natural gas-fired generation.
- **Increase production and use of alternative fuels.** GHG emissions are reduced through changes in end use energy consumption due to increased use of alternative fuels resulting from the actions identified in Table 3. The modeling conducted by the analysis team for this strategy also factors in the change in electricity carbon intensity over time as driven by the “Create a diverse portfolio of clean, utility-scale electricity generation.”

The actions in Table 3 represent only a subset of the potential actions, within a subset of the identified strategies. In other words, the benefits and costs quantified in this analysis do not comprehensively account for those that could accrue from the full set of strategies and actions identified in this Plan. If Pennsylvania leaders pursue actions and strategies beyond those that were quantitatively assessed (see Table 4), and if citizens and businesses committed to act accordingly, there would be additional benefits and costs from reducing GHG emissions and adapting to climate change.

Table 4. Emissions Reduction and Adaptation Actions for Leaders Qualitatively Assessed for the 2018 PA CAP Update, Organized by Sector and Strategy

Sectors	Strategies	Actions Qualitatively Assessed
Energy Consumption	Increase end use energy conservation and efficiency	<ul style="list-style-type: none"> • Expand home weatherization programs. • Increase support for market trends for energy efficient technologies. • Replace high carbon and GHG producing fuels or energy sources with less environmentally impactful options. • Educate consumers about the benefits of occupant performance and low energy usage improvements in building system technologies.
		<ul style="list-style-type: none"> • Develop people-mover systems, such as West Virginia University's Personal Rapid Transit system. • Continue and expand efforts to assess climate risks to transportation and land use planning, and incorporate expected future conditions into capital planning, project design, and routine operations, maintenance, and inspection practices.
		<ul style="list-style-type: none"> • Improve preparedness for increased frequency of extreme events by improving coordination between agencies and other stakeholders and by improving real-time monitoring of flooding, traffic, and other conditions. • Prioritize and provide guidance to local governments on transportation and land use planning that promotes efficient use of public resources, reduces congestion, and minimizes GHG emissions through multi-modal transportation networks and compact, transit-oriented development that uses smart growth practices and complete streets.
		<ul style="list-style-type: none"> • Educate citizens and business on the benefits of transportation demand-side management measures and clean and efficient transport options. • Increase adoption of people-powered transportation options such as walking school buses or commuter bicycle paths. • Reduce non-CO₂ emissions (hydrofluorocarbons) from truck and stationary refrigeration systems. • Participate in the Transportation Climate Initiative, and help develop and implement regional market-based policies that would both reduce carbon pollution from the transportation sector and fund clean transportation investments.
	Implement sustainable transportation planning and practices	<ul style="list-style-type: none"> • Expand use of performance contracting. • Create state and local clean energy tax incentives. • Establish/expand residential energy efficiency loan programs similar to Keystone HELP. • Evaluate options for and engage in public-private partnerships (P3), and capitalize on them. • Encourage utilities to provide on-bill financing or repayment. • Fund a green bank through new revenue streams (e.g., energy efficiency charges on utility bills in Vermont). • Encourage broad implementation of recent commercial PACE legislation. • Explore residential PACE once consumer protections are in place.
	Develop, promote, and use financing options to encourage energy efficiency	

Energy Production	Increase use of clean, distributed electricity generation resources	<ul style="list-style-type: none"> • Support community solar legislation and develop model local ordinances (e.g., to streamline community solar development).
	Create a diverse portfolio of clean, utility-scale electricity generation	<ul style="list-style-type: none"> • Establish a workgroup to help optimize siting of renewables, and to review and streamline permitting and regulations at the state and local levels. Focus on high value, implementable actions such as community choice aggregation and battery storage. • Establish a CO₂ emissions fee for power generators as part of a carbon tax or other GHG pricing policy action.
	Increase production and use of alternative fuels	<ul style="list-style-type: none"> • Increase biofuel production in Pennsylvania (e.g., expand on biodiesel requirements). • Finalize the draft air general permit which incentivizes increased beneficial use of landfill gas, and reduces downtime due to maintenance at existing projects.
Agriculture	Use agricultural best practices	<ul style="list-style-type: none"> • Expand integrated farm management and conservation planning • Expand regional planning initiatives, especially in agricultural areas, focusing on agricultural security zones and local food security • Revise / update existing conservation and agricultural measures to see how they could further support resilience to climate change, and modify where necessary • Provide financial incentives and support for agricultural best practices.
		<ul style="list-style-type: none"> • Establish a network of agro-meteorological stations statewide to collect climate observations, including estimates of evapotranspiration, to support research and development of agricultural practices. • Expand the collection and dissemination of local weather information for irrigation planning. • Improve the accuracy of existing real-time weather warning and forecasting systems for drought and extreme events. • Develop and disseminate seasonal climate forecasts. • Conduct or sponsor research to understand topics such as climate change effects on weeds, insects, and diseases; best practices for agricultural emergency response plans; conservation best practices; and methods for maintaining the genetic diversity of crops. • Facilitate information sharing networks for farmers and the agricultural research community to share experiences and best practices.
	Provide resources and technical assistance to farmers to adapt	
Ecosystems and Forestry	Improve protection of and optimize ecosystems	<ul style="list-style-type: none"> • Conserve and enhance areas representing the full range of wildlife and fish habitats and promote connectivity (e.g., using land exchanges, conservation easements, leases; by removing barriers) to allow species to migrate to suitable habitat.

		<ul style="list-style-type: none"> Promote forest conservation, growth, and adaptation, as well as urban trees (e.g., by establishing a carbon banking and trading system that pays landowners to plant and manage working forests on both private and public land).
		<ul style="list-style-type: none"> Restore wetlands and riparian areas, expand or revise current minimum riparian buffer zones, and implement living shoreline programs to provide natural flood abatement, breeding habitat, and improved stream conditions (including improved thermal conditions).
		<ul style="list-style-type: none"> Preserve and create open spaces, parks, and trails that allow people to continue to engage in outdoor activities and maintain connectivity to natural resources. Protect wildlife and fish habitat and species that support recreational opportunities like hunting, fishing, and wildlife viewing.
		<ul style="list-style-type: none"> Educate recreational land users about the importance of climate change impacts on ecosystems and the dangers of illegal hunting and fishing, pollution, and development.
		<ul style="list-style-type: none"> Retrofit existing parks and trails and create new parks and trails to strengthen the community, improve habitat connectivity, provide more water sources for human users recreating in higher temperatures, enhance natural stormwater and flood management, and connect paths to schools, workplaces, and retail centers to promote pedestrian use.
		<ul style="list-style-type: none"> Promote alternatives to mowing, including meadows, native plants, and trees
	Monitor, identify, and remove ecosystem vulnerabilities	<ul style="list-style-type: none"> Establish a statewide monitoring and research network of academics, civil society, and citizen scientists to establish baseline conditions and monitor ecosystem factors, such as physical changes, species distribution (including invasive species), weather conditions, disease outbreaks, and general ecological conditions.
		<ul style="list-style-type: none"> Identify and prioritize species, habitat, and ecosystems most vulnerable to climate change and other stressors to better target protection and management actions.
		<ul style="list-style-type: none"> Review existing legal, regulatory and policy frameworks that govern protection and restoration of wildlife and fisheries habitats, and identify opportunities to improve their ability to address climate change impacts.
		<ul style="list-style-type: none"> Develop a central database to store relevant ecosystem data.
Outdoor Recreation and Tourism	Help the outdoor tourism industry manage shifting climate patterns	<ul style="list-style-type: none"> Establish a formal climate change working group building on existing partnerships, comprised of commonwealth agencies, federal agencies, academic institutions, the business community, and environmental non-governmental organizations (NGOs).
		<ul style="list-style-type: none"> Explore developing new collaboratives with surrounding states.
		<ul style="list-style-type: none"> Create a business ombudsman or technical assistance center for affected recreational industries and establish a source of grant funding or tax incentives to help industry and municipalities transition from winter to summer activities.

		<ul style="list-style-type: none"> • Educate facilities about diversification opportunities for more warm-weather or cold-weather activities (e.g., ski slopes can maintain mountain bike trails for warm weather) with consideration of environmental impacts.
Waste	Reduce and use waste sent to landfills, and expand beneficial use of waste	<ul style="list-style-type: none"> • Implement programs to encourage citizens and business to reduce waste (including food waste) and use recycling and composting programs through reduce, reuse, and recycle actions. • Encourage the use of digesters for methane capture and recovery. • Support solar projects on landfill land.
Water	Use stormwater best management practices	<ul style="list-style-type: none"> • Require mandatory compliance with PA DEP's Stormwater Best Management Practices Manual. • Provide incentives for the installation and use of gray water and rainwater harvesting and consider existing international guidelines for increased reclaimed, recycled, and gray water use for non-potable applications (e.g., irrigation, toilet flushing). • Revise stormwater regulations to accommodate increases in precipitation and run-off • Promote green infrastructure by instituting laws, regulations, and local ordinances requiring implementation of green infrastructure with new development or substantial redevelopment and revising the State Revolving Fund (SRF) state ranking criteria to require a thorough analysis and maximization of the use of green infrastructure, where appropriate.
	Promote integrated water resources management and water conservation	<ul style="list-style-type: none"> • Reduce impervious surfaces by requiring installation of permeable surfaces, buffers, and vegetated filters for all transportation-related projects; developing and enforcing a stormwater retention standard for new development and redevelopment; and/or implementing a fee for impervious surfaces. • Support additional research on climate change impacts on water supply and basin hydrology, including with hydrologic models to project changes in surface runoff and groundwater. • Assess the impact of climate change on critical water supply and wastewater infrastructure, and encourage the development of facility-specific adaptation plans. • Include climate change projections and modeling results in water supply and water quality planning to enhance reliability, improve quality, and improve instream flows and fish passage.
Human Health	Improve reliability and accessibility of public information about climate-related health risks	<ul style="list-style-type: none"> • Support efforts to develop new surveillance databases and increase data quality and availability, especially for climate-sensitive morbidity. • Update Community Health Assessments to include climate change and health tracking metrics. • Increase interdisciplinary collaboration among medical and health professionals and other environmental and social scientists to better understand the linkage between climate change and disease. • Help local health departments assess their capacity to respond to health threats and to integrate climate preparedness into their hazard response plans and daily operations. • Enhance education of health-care professionals to understand the health risks of climate change, including diagnosis and treatment for health outcomes that may become more prevalent.

	Bolster emergency preparedness and response	<ul style="list-style-type: none"> • Work locally with vulnerable groups to assist at-risk communities with the development, adoption, practice, and evaluation of response, evacuation, and recovery plans.
		<ul style="list-style-type: none"> • Regularly map locations of vulnerable populations and use the information to focus interventions and outreach.
		<ul style="list-style-type: none"> • Review occupational health and safety standards to identify occupations at significant risk due to climate change, and revise as necessary.
		<ul style="list-style-type: none"> • Review existing emergency response, preparedness, evacuation, and management plans.
		<ul style="list-style-type: none"> • Expand the scope of the state hazard mitigation plan to factor in expected vulnerabilities from climate change impacts.
		<ul style="list-style-type: none"> • Evaluate and improve the adequacy, effectiveness, accuracy, and technological capabilities of forecasting, early-warning, and emergency-preparedness systems.
		<ul style="list-style-type: none"> • Foster collaboration between communication service providers and agencies to provide reliable communications in times of power outages and emergencies.
		<ul style="list-style-type: none"> • Establish heat advisories, increase availability of cooling stations, invest in efficient HVAC systems at targeted Recreation Centers which are provided with renewable energy backup systems, and implement other preventive measures to reduce the impact of extreme heat events.
		<ul style="list-style-type: none"> • Evaluate the capacity of existing disease prevention programs, enhance surveillance of disease and disease-causing agents, and enhance the capacity of public health programs that control disease-causing agents.
		<ul style="list-style-type: none"> • Restructure disaster-recovery policies to ensure that redevelopment efforts strive to reduce long-term risk.
Cross-Cutting	Lead by example in commonwealth and local government practices and assets	<ul style="list-style-type: none"> • Establish a strategic energy management plan for public facilities that includes benchmarking and specific energy, water, and transportation emissions reductions targets and goals.
		<ul style="list-style-type: none"> • Maximize onsite renewable energy generation and purchase additional renewable power through renewable energy certificates (RECs) direct purchasing.
		<ul style="list-style-type: none"> • Implement a state-wide benchmarking strategy and platform (such as EnergyStar's Portfolio Manager) for energy and water consumption. Engage the PUC and PA's gas, electric and water utilities to automate billing and utility data input into the selected benchmarking platform, and encourage others (businesses, industry, schools, and municipalities) to implement similar programs to establish their baseline consumption patterns.
		<ul style="list-style-type: none"> • Establish a state-wide Governor's Sustainability Council and/or interagency workgroup dedicated to the implementation of leadership actions listed in the CAP, as well as actions in department-level plans.
		<ul style="list-style-type: none"> • Incorporate climate change considerations into decision making processes and criteria. For example, add climate change resilience as a prioritization factor for new capital projects.
		<ul style="list-style-type: none"> • Consider ENERGYSTAR certification, Leadership in Energy and Environmental Design (LEED) Gold, Net Zero Buildings, Zero Energy Codes, Passive House standards, and climate resilience design guidelines as higher-performance basis of design for new construction and major renovation projects in public buildings.
		<ul style="list-style-type: none"> • Inventory state buildings and energy use patterns to identify savings opportunities.

	<ul style="list-style-type: none"> • Implement emissions reduction and climate resilience activities in public facilities, including distributed generation, least impact backup power generation, energy efficiency, water efficiency, climate resilient vegetation, and proper tree maintenance.
	<ul style="list-style-type: none"> • Require energy efficient and alternative fuels use in fleet vehicles and equipment.
	<ul style="list-style-type: none"> • Conduct more training, education, and outreach for facility managers and the workforce.
	<ul style="list-style-type: none"> • Ensure that key government operations have planned to provide least impact backup power supply on-site to protect important security features in the case of more frequent or prolonged blackouts.
	<ul style="list-style-type: none"> • Highlight climate action already occurring in Pennsylvania and learn from best practice examples within and outside the commonwealth.
Incorporate historical and projected climate conditions into siting and design decisions for long-term infrastructure	<ul style="list-style-type: none"> • Establish statewide design guidelines for incorporating climate change, similar to New York City's design guidelines (NYC Mayor's Office of Recovery and Resiliency 2018). • Integrate climate change considerations into agency-level capital planning processes and seek to ensure that state investments in infrastructure and development projects (direct or indirect) reflect potential climate change impacts, especially future risk projections. • Implement new or modified policies (e.g., zoning regulations, tax incentives, and rolling easements) that encourage appropriate land use and reduce repetitive losses. • Develop or update floodplain mapping using the best available science and accounting for the impacts of climate change. • Adopt insurance mechanisms and other financial instruments, such as catastrophe bonds, to protect against financial losses associated with infrastructure losses. • Encourage owners and operators of critical energy infrastructure to evaluate vulnerability to the impacts of climate change, including the risk of damage; the potential for disruptions and outages from flooding, sea level rise, extreme heat, drought, erosion and other extreme weather events; and the impacts of new climate change weather data on energy demand.

3 Emission Reduction and Adaptation Opportunities

This section of the report presents Pennsylvania’s expected climate change impacts, as well as opportunities to reduce emissions and adapt to these impacts in the following sectors:

- ▶ Energy Consumption
- ▶ Energy Production
- ▶ Agriculture
- ▶ Ecosystems and Forestry
- ▶ Outdoor Recreation and Tourism
- ▶ Waste Management
- ▶ Water Resources
- ▶ Human Health

Each sector section includes:

- Sector background and relevance in Pennsylvania
- Climate impacts for the sector
- Opportunities to adapt and reduce emissions, by strategy

Each strategy includes:

- A brief description of the strategy
- A list of actions that state and local leaders can take to support the strategy
- A summary of strategy benefits and costs including both quantitative and qualitative assessments of climate resilience, environmental, and economic benefits and costs
- Performance indicators and metrics that Pennsylvania could use to measure progress toward the strategy
- Color-coded text boxes outlining actions that citizens and businesses can take to support the strategy

Energy Consumption

End-use energy consumption is the largest source of GHG emissions in Pennsylvania. Energy is consumed in four principal sub-sectors:

Sector	Major End Uses
Transportation	Personal vehicle and fleet motor fuels and electricity use
Residential	Fuels and electricity for space conditioning, water heating, appliances, lighting, electronics
Commercial	Fuels and electricity for space conditioning, water heating, lighting, office equipment, IT systems
Industrial	Fuels and electricity for process technologies, motor systems, lighting

The transportation sector was the greatest consumer of energy in the commonwealth between 2000 and 2012, but as of 2013, the industrial sector became the largest consumer, followed by the transportation, residential, and commercial sectors.

Industrial facilities vary in their energy needs depending on processes and other end-uses occurring at a given facility. They tend to use some combination of electricity, natural gas, petroleum such as residual or distillate fuel oils, coal, and renewable sources. Most industrial facilities purchase electricity from utilities, but some generate their own electricity on site.

In residential buildings, the greatest energy end-use is for space conditioning while electronics, lighting, and other appliances account for a large portion of total electricity consumption. Water heating, air conditioning, and refrigeration make up the bulk of the remaining residential consumption. Natural gas and electricity are the most-consumed energy sources in residential buildings, but heating oil, coal, wood, and propane are also used in some areas (EIA 2013).

As is the case in residential buildings, space conditioning is largest consumer of energy in commercial buildings, however the energy use breakdowns for commercial sector vary considerably based on the type of building. Offices have different energy needs than schools, which have different needs than shopping malls and warehouses. Generally, electricity and natural gas are the primary energy sources in commercial buildings (EIA 2017c).

Transportation energy use includes the petroleum products, biofuels, natural gas, and electricity used to power various modes of transportation across Pennsylvania (EIA 2018). Motor gasoline, the most-consumed fuel in Pennsylvania, and diesel fuel power cars, motorcycles, trucks, buses, trains, and boats, while jet fuel is used to power commercial airplanes. Some vehicles utilize compressed or liquefied natural gas, and others run on alternative fuels like biodiesel or ethanol, and increasingly, electricity.

Climate Change Impacts

The expected impacts of climate change on energy consumption in Pennsylvania (Shortle et al. 2015) include:

- Increased demand for energy, particularly electric power, due to higher temperatures during summer months. This could result in higher energy costs for consumers.
- Decreased heating energy demand due to higher temperatures during winter months, though Shortle et al. show this decrease is not expected to offset the increase in cooling energy demand.
- Disruptions to energy supply chains due to extreme weather events such as floods, severe storms, or severe temperatures. This could result in decreased power grid reliability.
- Disruptions to the transportation network due to extreme weather events, which could affect transportation reliability overall and, in turn, could affect transportation system energy consumption.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Energy Consumption sector, the analysis team has identified three main strategies to reduce emissions and adapt to climate impacts:

- ▶ **Increase end use energy conservation and efficiency**
- ▶ **Implement sustainable transportation planning and practices**
- ▶ **Develop and implement financing options to encourage energy efficiency**

These Energy Consumption strategies include seven actions that were quantitatively analyzed (see Table 5 below). Together, these seven actions are expected to result in:

- ▶ Annual GHG reductions in 2025: **6,889,187 MTCO₂e** (3% reduction from 2005 levels of 262,602,782 MTCO₂e)
- ▶ Annual GHG reductions in 2050: **37,005,093 MTCO₂e** (14% reduction from 2005 levels of 262,602,782 MTCO₂e)

GHG reductions and cost per ton of GHG reduced (a measure of cost-effectiveness), by strategy and individual action, are presented in

Figure 9 and Table 5 below.

Figure 9. Annual GHG Reductions Compared to BAU Through 2050 for Energy Consumption Strategies and Actions (MMTCO₂e)

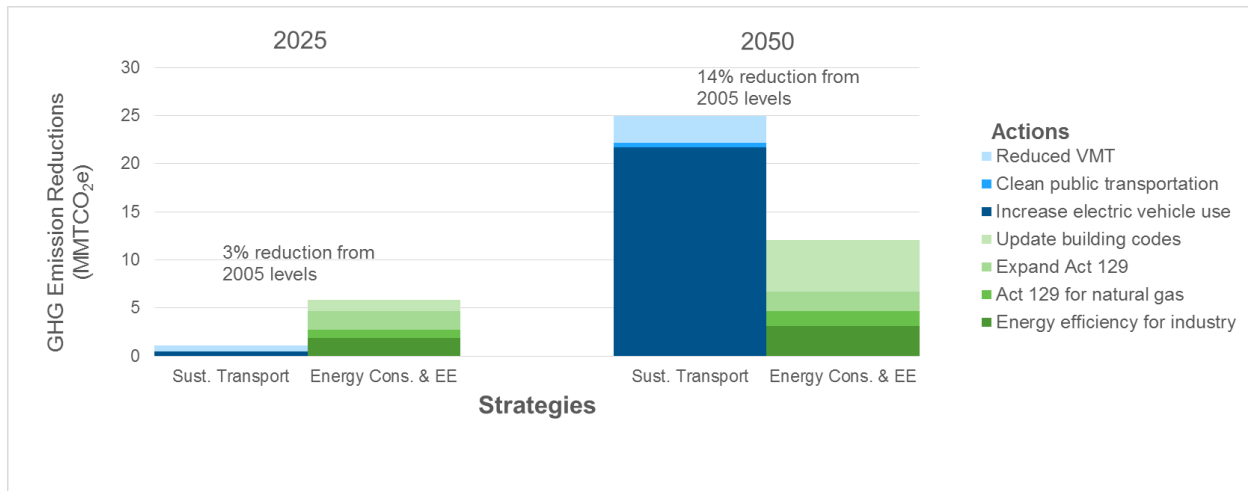


Table 5. Annual GHG Reductions in 2025 and 2050 and Cost per Ton of GHGs Reduced for Energy Consumption Strategies and Actions

Strategies and Actions Included in Higher-Level Strategy Quantitative Modeling	Annual GHG Reductions in 2025 (MTCO ₂ e)	Annual GHG Reductions in 2050 (MTCO ₂ e)	Cost per Ton of GHG Reduced (\$/ton of CO ₂ e)
Increase end use energy conservation and efficiency	5,827,879	12,036,172	-\$127
Update building codes	1,164,587	5,374,682	-\$199

Increase adoption of energy efficiency, including by expanding Act 129	1,916,947	1,984,261	-\$198
Create an Act 129-like conservation and efficiency program for natural gas	845,010	1,567,198	-\$119
Expand energy assessments and provide more trainings on energy efficiency for industry	1,901,335	3,110,031	\$8
Implement sustainable transportation planning and practices	1,061,309	24,968,921	\$71
Reduce vehicle miles traveled for single-occupancy vehicles	573,260	2,820,936	-\$447
Implement a strategic plan and incentives for increasing electric vehicle use	474,100	21,689,937	\$151 ^a
Increase the use of clean public transportation through electric municipal bus fleets	13,948	458,048	\$1,022

^a No state or federal incentives were included in the cost-per-ton estimate for vehicle electrification due to the uncertainty of their availability. However, if available, incentives could substantially reduce the cost-per-ton of implementing these actions.

Notes: Negative cost-per-ton represents net cost savings.

Increase End Use Energy Conservation and Efficiency

End-use energy is the energy consumed by the user, including electricity, gasoline, and natural gas. Energy usage may be reduced through conservation and efficiency measures that result in environmental and economic benefits. Energy conservation, which includes behavioral and operational measures and programs, such as changing temperature settings, turning off unused lights and energy consuming devices, reducing the operation hours for space conditioning and energy systems, and changing industrial process operations, is less costly to implement, easiest to accomplish, and has instant – though often smaller - economic benefits compared to energy efficiency measures. Energy efficiency, which this strategy mainly focuses on, includes improving the overall and operating performance of building envelopes (e.g., better windows, insulation, and air sealing), kitchen and laundry appliances, lighting (e.g., LED and other advanced technologies), heating and cooling systems (e.g., ground-source heat pumps, variable refrigerant flow, and ductless systems), as well as influencing the behavior of consumers to reduce their energy use. Reducing energy demand through energy efficiency or conservation can help offset some of the expected increases in energy demand due to higher temperatures, helping individual consumers and the grid overall.

Leadership Actions

State and local leaders can increase energy efficiency by requiring and/or incentivizing more energy efficient design standards and technologies, as well as by improving efficiency of government-owned facilities and equipment (see Lead by Example strategy). For example, leaders can:

- **Update building codes** and allow or incentivize local “stretch” code adoption and high performance/net zero buildings. The commonwealth’s legally defined process for energy codes

adoption is summarized below. In the future the Pennsylvania legislature could enact measures similar to its 2017 law enabling the City of Philadelphia an exception to adopt and more stringent commercial energy codes. States like New York and Massachusetts allow local jurisdictions to adopt “stretch” codes that exceed state legal minimum stringency. In addition, local governments can use their other development policy powers, such as density bonus incentives, to encourage higher-efficiency new construction.

- **Residential.** The Department of Labor and Industry (DLI) would use its authority to promulgate and upgrade the Pennsylvania Uniform Construction Code (UCC), through modifications subject to public hearings and approval by the DLI Review and Advisory Council (RAC). Residential energy code provisions are based the International Code Council (ICC)’s triennial International Energy Conservation Code (IECC) and International Residential Code (IRC) triennial code updates.
 - **Commercial.** DLI would update the commercial energy code provisions through the same overall process, but would draw on the IECC’s commercial provisions, as well as those of ASHRAE Standard 90.1. In addition, 2017 state legislation enabled the City of Philadelphia to adopt a more stringent code for commercial buildings.
- ▶ **Increase adoption of energy efficiency, and expand Act 129** to increase targets, increase or eliminate cost caps,³ and create beneficial programmatic changes.⁴ The legislature would need to act to increase the annual savings targets set in the original Act 129 legislation. Increasing the impact of Act 129 programs would also need complementary state legislative or regulatory action to reform ratemaking and resource acquisition policies, such that utilities would have better financial results by investing in energy efficiency.
 - ▶ **Create an Act 129-like conservation and efficiency program for natural gas.** To implement this action, the Pennsylvania legislature needs to pass legislation that creates an Energy Efficiency Resource Standard (EERS) for natural gas. In creating a natural gas EERS, lawmakers could look to other states that have created similar programs, such as the 2011 EERS enabled by the Green Communities Act in Massachusetts (<https://malegislature.gov/Laws/SessionLaws/Acts/2008/Chapter169>), or the recently enacted EERS in New Jersey through Bill A3723 (<https://legiscan.com/NJ/bill/A3723/2018>) (ACEEE 2018).

Using a format similar to the Act 129 requirements, natural gas EERS legislation would set annual incremental natural gas savings targets for regulated natural gas distribution companies, and establish a set planning cycle and implementation periods.
 - ▶ **Expand energy assessments and provide more trainings on energy efficiency for industry.** This action is somewhat tied to the future of Act 129-type EERS policies for electricity and gas. To the extent that savings targets increase, and complementary policies are instituted, Pennsylvania

³ Lifting cost caps would increase short term rate impacts, but if the measures are cost-effective, total customer costs would still be lower over the lifetime of the measures.

⁴ While Act 129 historically and in modeling done for this analysis does not result in the largest GHG reductions, it is extremely cost-effective and generally reduces the costs of other policies; e.g., reducing electricity usage below BAU levels reduces the cost of serving that load with renewable energy.

utilities will be both better enabled and more motivated to seek energy efficiency solutions in the industrial sector. To drive energy performance in such large organizations, however, developing a comprehensive approach to energy management is important. One of the most promising frameworks for this kind of effort is Strategic Energy Management (SEM), which states like New York support through its NYSEDA (New York State Energy Research and Development) Strategic Energy Management Program (<https://www.nyserda.ny.gov/All-Programs/Programs/Strategic-Energy-Management>). A statewide SEM program would help companies set up comprehensive programs with goals, metrics, and analytics tools to drive operational improvements as well as efficiency investments. It would help large customers take advantage of utility programs while also driving savings across the entire organization.

The above actions in **bold** are reflected in the quantified key metrics below. Other actions leaders can take include:

- ▶ Expand home weatherization programs beyond those currently identified as low-income households and provide greater penetration of these programs for those currently eligible.
- ▶ Increase financial and technical support for market trends for energy efficient technologies such as LED indoor and street lighting and automated control systems.
- ▶ Replace high carbon and GHG producing fuels or energy sources with less environmentally impactful options.⁵
- ▶ Educate consumers about the benefits of occupant performance and low energy usage improvements in building system technologies.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Increased energy efficiency can offset some of the increases in energy demand due to higher cooling needs. This, in turn, can:

- Reduce the strain on the overall energy system, particularly during peak loads—enhancing electricity grid reliability, reducing the risk of power outages, and reducing operating costs for utilities.
- Reduce energy costs for Pennsylvania citizens and businesses—particularly important if electric bills would otherwise increase due to higher temperatures.
- Reduce criteria air pollutant emissions, the health impacts of which could be exacerbated by higher temperatures (Shortle et al. 2015).

Several building design elements can also make buildings more resilient to energy supply disruptions and droughts. For example, passive design features can reduce the need for mechanical heating or

⁵ In some instances, for example electrification of heating systems (replacing heating oil), actions may counteract each other; in this example switching to electric heating increases electricity use, which is counter to the intention of Act 129.

cooling during outages, and water efficiency and recycling can reduce water demand during times of drought.

Environmental Benefits & Costs

In addition to the effects quantified in this report, energy efficiency in buildings can provide environmental benefits in the form of improved indoor air quality. Some building upgrade methods are designed to address issues related to moisture and mold, and these can improve indoor air quality and occupant health.











Economic Benefits & Costs

In addition to quantified effects such as increases in income and employment, efficiency is known for creating local economic benefits in the form of investment and jobs within a community. A recent analysis showed that Pennsylvania employs more than 65,000 people in the energy efficiency industry (E2 2018). Some energy investments generate most of their effects in selected, sometimes distant locations; efficiency, however, can be implemented in almost any jurisdiction, thus providing additional social equity in the distribution of economic benefits.

Key Metrics

Net Present Value: \$37,486 Million^a

Cost-per-ton of GHG Reduced: - \$127/ MTCO₂e

	2025	2050		2025	2050
	GWh Electricity Consumption Reduced			BBtu Nat. Gas Consumption Reduced	
	10,638	31,160		38,255	109,927
	MTCO₂e GHG Emissions Reduced			MT Air Pollutant Emissions Reduced	
	5,827,879	12,036,172		NO _x	4,774
				SO ₂	7,612
				Hg	0.14
	Capital Expenditures (\$ Million)			Program Costs (\$ Million)^c	
	\$1,059	\$1,143		\$463	\$488
	Number of Jobs Supported			Impact on GSP (\$ Million)	
	8,691	19,793		\$695	\$1,561
	Increase in Disposable Personal Income Per Household (\$/Household)			Energy Expenditure Savings (\$Million)^d	
	\$105	\$267		\$1,6389	\$5,309

^a Net Present Value for this strategy includes capital expenditures, energy savings, and program costs.

^b A negative "cost-per-ton" indicates cost savings.

^c Program Costs include incentives and administrative expenses

^d Energy Expenditure Savings in this strategy represent energy bill savings on fuels and electricity.

Key Analysis Assumptions:

- Quantified metrics reflect the policies, programs, and actions in **bold** above.
- Future versions of building codes for residential (base code IECC 2009) and commercial (base code ASHRAE 2007) new construction are implemented every six years through 2050 with a 90 percent compliance rate.
- Energy efficiency improvements, including by expanding Act 129, are estimated by relying on maximum achievable potentials presented in the Pennsylvania Statewide Evaluator's (SWE) Energy Efficiency Potential Study for Pennsylvania (PA PUC 2015). For residential the maximum achievable potential is 1.5 percent from 2021-2050; for commercial the maximum achievable potential is 0.8 percent from 2021-2025, followed by 1.0 percent annual incremental savings for years 2026-2050.
- Efficiency and conservation programs for natural gas, similar to Act 129, are modeled based on a national review of state energy savings targets for natural gas efficiency policies and the Massachusetts EERS target of 1.1 percent annual incremental natural gas savings from 2020-2025 followed by 1.0 percent from 2026-2050 (ACEEE 2017).
- Efficiency and conservation improvements for industry are aligned with the maximum achievable potentials presented in the Pennsylvania Statewide Evaluator's (SWE) Energy Efficiency Potential Study for Pennsylvania (PA PUC 2015) for electricity (annual 1.2 percent through 2050) and in a Georgia Institute of Technology study (GIT 2009) for natural gas (annual 0.6 percent through 2050).

Other Key Performance Indicators

In addition to the metrics listed above, example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Monthly and annual purchased energy
- Final energy or electricity consumption per person served/floor area served for a particular sector
- Energy productivity – nationally, this is GDP per unit of total primary energy consumed
- Energy intensity – energy consumed per unit of work done or square footage
- Electricity or natural gas total energy unit savings from efficiency
- Investment in energy efficiency
- Absolute amount of energy consumed
- Costs of residential, commercial, and industrial energy bills

What You Can Do to Increase End Use Energy Conservation and Efficiency

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Install energy efficient lighting and appliances.
- ▶ Conduct a home energy audit to identify other efficiency opportunities.
- ▶ Install smart thermostats, home energy management systems, and other smart controls.
- ▶ Avoid energy intensive activities during peak times (especially late afternoon and evening). For example, run appliances (e.g., dishwashers, dryers) during utility off-peak hours.
- ▶ Practice energy conservation by moderating temperature settings, turning off unused devices and lights, unplugging devices when not in use or charging, and using natural light when available.

- ▶ Conduct regular maintenance on HVAC systems to ensure optimal operation and energy use.

What Businesses Can Do to Increase End Use Energy Conservation and Efficiency

Pennsylvania businesses can support this strategy by increasing the energy efficiency of business operations. See examples of actions in the “What You Can Do” box above.

In addition, businesses in the following industries can play a role in supporting this strategy by taking the following actions:

Construction Professionals and Designers

- ▶ Construct buildings to protect against projected changes in climate through measures such as efficient orientation, insulation, windows, and other features that reduce energy demand and provide resiliency benefits.

Utilities

- ▶ Deploy energy efficiency programs to reduce emissions overall and counteract the increase in peak demand due to increased use of air conditioning.
- ▶ Invest in smart grid technology, including energy storage to increase renewable power generation, and demand response programs to help customers cut their peak power usage.

Commercial Office Buildings

- ▶ Enable power management functions on IT systems and utilize sleep settings on electronic office equipment.
- ▶ Consolidate stand-alone office equipment and use smart power strips.
- ▶ Commission and periodically re-tune buildings.

Implement Sustainable Transportation Planning and Practices

Considering climate changes in long-range transportation planning and transportation infrastructure design improves the chances that infrastructure will be planned and designed for the conditions it will experience over its lifetime. This is particularly important for long-lived or capital-intensive infrastructure.

Leadership Actions

The Commonwealth of Pennsylvania plans to advance this strategy by pursuing a selection of the following policies, programs, and actions. Actions in bold are reflected in the quantified key metrics below:

- ▶ **Reduce vehicle miles traveled for single-occupancy vehicles** by promoting, expanding opportunities for, and incentivizing ride sharing, walking, bicycling, and public transit options.

Pennsylvania has one of the highest gasoline taxes of any state in the country. While this tax can contribute to a reduction in overall fuel use, or even changing trends in types of purchased vehicles, it is not enough to reduce VMT over the study period. In urban and suburban centers programs to incentivize alternative modes of transportation, including ride sharing, walking,

bicycling, and public transit could help reduce VMT. Pennsylvania is already in the process of updating its Bicycle and Pedestrian Master Plan (<https://www.penndot.gov/TravelInPA/RideaBike/Pages/Master-Plan.aspx>), and this update presents an opportunity for the commonwealth to become more ambitious in programs and policies to replace single occupancy trips with alternative transportation modes. The commonwealth could also consider other means for incentivizing alternative transportation modes, such as working with major companies and employers to provide expanded or new incentives for using public transportation (such as incentives provided in New Jersey (<http://www.transoptions.org/employers-pretax-commuter-incentives>)), or car or van pooling, building on efforts already going on such Commute PA (<https://pacommuterservices.org/commutepa/>) or Vanpooling (<https://pacommuterservices.org/vanpool/>). Penalties are also a mechanism which could be used to discourage single occupancy vehicle trips and encourage carpooling, such as expanding on the use of high occupancy vehicle lanes like the ones implemented by the Pennsylvania Department of Transportation (PennDOT) on I-279 (<https://www.penndot.gov/RegionalOffices/district-11/Pages/HOV.aspx>) or the newly installed on-demand toll charging for I-66 (<http://www.transform66.org/splash.html>) in Virginia during rush hour, a main artery from Virginia into DC. HOV lane requirements could also be expanded upon, such as increasing the required number of passengers from 2 to 3 (e.g., as done on parts of I-95 and offshoots of it (<http://www.virginiadot.org/travel/hov-novasched.asp#I-495%20Express%20Lanes>)). These changes would be implemented by PennDOT and operators of tolls and systems (e.g., the Pennsylvania Turnpike Authority). Additionally, incentives for public and private sector telecommuting, including business tax incentives and encouragement for setting schedules for telecommuting for individuals and teams is another mechanism that can be used to reduce VMT during the work week.

In Pennsylvania, there are 37 urban and rural fixed transit agencies and 26 agencies that only provide community/demand response transportation. Many of the fixed route agencies also provide community/demand response transportation. These agencies also play a vital role in VMT reduction and transportation demand planning and response.

- ▶ **Implement a strategic plan and incentives for increasing electric vehicle use** in line with the DEP’s EV Roadmap (PA DEP 2018a). Tactics might include: encouraging workplace charging; incentivizing the purchase of alternative, low, and zero emissions vehicles through financial mechanisms or programs; and expanding electrification for off-road applications, including vehicles, construction, and materials handling equipment. More specifics for implementing this action can be referenced in the EV Roadmap once released.
- ▶ **Increase the use of clean public transportation through electric municipal bus fleets.**

Now is the right time for Pennsylvania and its local governments to assess the role of electric municipal bus fleets – according to a May 2018 Bloomberg New Energy Finance Research article (<https://about.bnef.com/blog/e-buses-surge-even-faster-evs-conventional-vehicles-fade/>): “The electrification of road transport will move into top gear in the second half of the 2020s, thanks

to tumbling battery costs and larger-scale manufacturing, with sales of electric cars racing to 28%, and those of electric buses to 84%, of their respective global markets by 2030.” The same article also states that: “The advance of e-buses will be even more rapid than for electric cars, according to BNEF’s analysis. It shows electric buses in almost all charging configurations having a lower total cost of ownership than conventional municipal buses by 2019.” Most of the responsibility for increasing the use of electric buses in municipal fleets falls to cities, municipalities, or local transit authorities (e.g., the Southeastern Pennsylvania Transit Authority (SEPTA)). In the populated urban and suburban areas of Pennsylvania, great strides are already being made to electrifying bus fleets. For example,

- SEPTA will soon have the largest fleet of electric buses on the East Coast, with 25 electric buses scheduled to be delivered (PA DEP 2018a).
- The Port Authority of Allegheny County will buy its first electric bus with a federal grant to test the technology for potential use on its BRT route opening in 2020 (PA DEP 2018a).
- Berks Area Regional Transportation Authority In 2013, the Berks Area Regional Transportation Authority received the first 2 electric paratransit buses in the country—Ford E-450-based buses with a 100-mile range (PA DEP 2018a).

There are opportunities at the state-level to help amplify local efforts. For example, the Pennsylvania legislature and DEP could choose to expand programs such as AFIG to make larger amounts of funding available to municipal authorities, or offer additional support to these municipal authorities in completing AFIG applications. See also information in DEP’s EV Roadmap (PA DEP 2018a).

The above actions in **bold** are reflected in the quantified key metrics below. Other actions leaders can take include:

- ▶ Develop people-mover⁶ systems, such as West Virginia University’s Personal Rapid Transit system.⁷
- ▶ Continue and expand efforts to assess climate risks to transportation and land use planning, and incorporate expected future conditions into capital planning, project design, and routine operations, maintenance, and inspection practices.
- ▶ Improve preparedness for increased frequency of extreme events by improving coordination between agencies and other stakeholders and by improving real-time monitoring of flooding, traffic, and other conditions.
- ▶ Prioritize and provide guidance to local governments on transportation and land use planning that promotes efficient use of public resources, reduces congestion, and minimizes greenhouse

⁶ People movers are small scale automated guideway transit systems.

⁷ <https://transportation.wvu.edu/prt>

gas emissions through multi-modal transportation networks and compact, transit-oriented development that uses smart growth practices and complete streets.

- ▶ Educate citizens and business on the benefits of transportation demand-side management measures and clean and efficient transport options.
- ▶ Increase adoption of people-powered transportation options such as walking school buses⁸ or commuter bicycle paths.
- ▶ Reduce non-CO₂ emissions (hydrofluorocarbons) from truck and stationary refrigeration systems.
- ▶ Participate in the Transportation Climate Initiative, and help develop and implement regional market-based policies that would both reduce carbon pollution from the transportation sector and fund clean transportation investments.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Implementing sustainable transportation planning and practices can:

- Help the transportation network avoid or recover quickly from disruptions due to extreme events.
- Improve the reliability of the transportation network. Providing alternative transportation routes, modes, and fuels can increase the nimbleness of the transportation sector overall to transport goods and people even if an extreme event disrupts some parts of the system.
- Reduce Pennsylvania's dependence on gasoline-based transportation, thereby reducing citizen exposure to potential future increases in global oil prices.
- Reduce transportation system disruptions due to flooding and extreme events because transportation system planning accounts for expected climate change impacts.

Environmental Benefits & Costs

In addition to the benefits quantified in this report, sustainable transportation can create other beneficial effects, such as reduced noise and reduced congestion particularly in urban areas. To the extent that such strategies reduce total road area, they can also reduce the environmental effects associated with paving materials, and with water runoff from impervious surfaces.

Economic Benefits & Costs

The economic benefits and costs of this strategy will vary depending on the specific actions taken. Many of the actions to integrate climate risk into existing processes can be implemented at very low cost. Strategies to change the design of a specific transportation asset may be costlier, and cost effectiveness should be assessed on a case-by-case basis. Job benefits can be substantial: a recent study showed that clean vehicle businesses employ almost 7,000 people in Pennsylvania (E2 2018). Sustainable transportation can also create social equity benefits, to the extent that economically-disadvantaged

⁸ Walking buses are where parents walk from house to house and pick up kids on the way to a neighborhood school, in lieu of using a bus.












populations would have greater mobility, bringing increased access to employment and other opportunities.

Strategies to increase the resilience of the transportation system to flooding would have up-front capital costs, but also represent an opportunity for economic savings if the strategies can reduce flood-related damage and disruptions. PennDOT, for example, has spent over \$190 million in state and federal funds since 2006 to recover from flood-related disasters (PennDOT 2017). These costs do not capture the economic costs of transportation service disruptions.

Key Metrics

Net Present Value: \$20,396 Million^a

Cost-per-ton of GHG Reduced: \$71/MTCO₂e

	2025	2050		2025	2050
	GWh Electricity Consumption Increased			BBtu Fossil Fuel Consump. Reduced^b	
	1,330	42,412		21,387	465,152
	BBtu Biodiesel Consumption Reduced				
	12	283			
	MTCO₂e GHG Emissions Reduced		MT Air Pollutant Emissions Reduced		
	1,061,309	24,968,921	NO _x	1,606	7,210
			SO ₂	956	14,950
			Hg	0.02	0.20
	Capital Expenditures (\$ Million)			Public Expenditures (\$ Million)^c	
	\$2,078	\$6,374		\$151	\$695
	Maint. & Repair Cost Savings (\$ Million)				
	\$302	\$2,876			
	Number of Jobs Supported			Impact on GSP (\$ Million)	
	-4,015	8,394		-\$262	\$1,561
	Change in Disposable Personal Income Per Household (\$/Household)			Energy Expenditure Savings (\$Million)^d	
	-\$41	\$131		\$286	\$4,383

^aNet Present Value for this strategy includes capital expenditures, energy savings, and maintenance and repair cost savings.

^bThis strategy affects natural gas, distillate fuel oil, and motor gasoline consumption.

^cPublic Expenditures a

re the subset of capital expenditures associated with electric vehicle supply equipment (EVSE) expected to be funded by the commonwealth. These expenditures are also included in Capital Expenditures.

^d Energy Expenditure Savings in this strategy represent savings on natural gas, diesel fuel, motor gasoline, and electricity expenditures.

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU. Negative cost-per-ton represents net cost savings.

Key Analysis Assumptions:

- Quantified metrics reflect the policies, programs, and actions in **bold** above.
- Overall vehicle miles traveled (VMT) are reduced 3.4 percent by 2030 and 7.5 percent of total VMT from BAU by 2050. This estimate is based on the draft Pennsylvania Energy Assessment Report prepared in 2018, 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 (AEO) 2018, and Federal Highway Administration VMT projections (EIA 2018, FHWA 2018).
- EVs are 31 percent of the light-duty market share by 2030, rising to 88 percent by 2050. The target is based on a review of the U.S. EIA’s AEO 2018 national-level projections, as well as the Pennsylvania DEP report Pennsylvania Electric Vehicle Roadmap, with consideration for the current market share (EIA 2018, DEP 2018a).
- 25 percent of new municipal transit bus purchases are zero emission buses, using battery electric technology, by 2030, increasing to 60 percent by 2050. This projection is based on zero emission transit bus market penetration projections from CALSTART as well as various state targets (CALSTART 2015).

Other Key Performance Indicators

In addition to the metrics listed above, example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Number of people using public transportation/biking/walking
- Bicycle and pedestrian mode share (bicycle/pedestrian trips divided by total trips) /level of service
- Vehicle miles traveled per capita
- Carbon intensity (transportation CO₂ emissions per capita)
- Transit productivity (Average transit boarding per vehicle revenue hour, passenger miles traveled per vehicle revenue mile)
- Fuel saved with fuel-efficient vehicles (including EVs)
- Number of EVs registered in Pennsylvania
- Percent of fleet with fuel-efficient vehicles/percent of miles driven/CO₂ emissions averted
- Bus/rail/road recovery in number of days
- Change in transportation speed
- Change in travel time over time/change in volume over time
- Portion of employees using smart commuting, active transportation programs, etc.

What You Can Do to Implement Sustainable Transportation Planning and Practices
Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Choose alternative forms of transportation when possible, including public transit, carpooling, walking or biking.
- ▶ Purchase a more fuel-efficient or low-emission vehicle (e.g., a battery electric vehicle) and/or combine trips to save money and reduce greenhouse gas emissions.
- ▶ Maximize the fuel economy of your vehicle by performing proper maintenance and ensuring tires are correctly pressurized.
- ▶ Support sustainable transport by participating in transportation planning processes with your local government or metropolitan planning organization.

What Businesses Can Do to Implement Sustainable Transportation Planning and Practices

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Purchase fuel-efficient or low-emission vehicles (including fleets) to save money and reduce GHG emissions.
- ▶ Support sustainable transport by participating in transportation planning processes with your local government or metropolitan planning organization.
- ▶ Provide incentives to employees for smart commuting practices and allow for teleworking, where feasible.

Develop, Promote, and Use Financing Options to Encourage Energy Efficiency

Upfront costs can be a major barrier to implementing clean energy or energy efficiency projects. An important goal of efficiency policies and programs is to help minimize these upfront project costs, encouraging owners to invest in energy efficiency improvements and retrofits. Several financing strategies are available to pursue this goal.

Leadership Actions

The Commonwealth of Pennsylvania could advance this strategy by pursuing a selection of the following policies, programs, and actions:

- ▶ Expand use of performance contracting.
- ▶ Create state and local clean energy tax incentives.
- ▶ Establish/expand residential energy efficiency loan programs similar to Keystone HELP.
- ▶ Engage in public-private partnerships (P3) to leverage private capital for infrastructure investment.
- ▶ Encourage/require utilities to provide on-bill financing or repayment.
- ▶ Fund a state green bank (e.g., New York, Connecticut Green Banks).

- ▶ Encourage broad local government implementation of recent state commercial PACE legislation.
- ▶ Explore residential PACE program options within federal policy constraints.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Clean energy financing options, while they don't create benefits by themselves, can be important enabling mechanisms to help advance clean, distributed energy, which in turn can create the following benefits:

- Reduce the frequency or length of power outages from extreme events due to the distributed nature of clean energy. Communities and businesses experience substantial losses during power outages.
- Protect vulnerable communities from loss of critical services due to extreme events.
- Reduce strain on the energy grid through energy efficiency measures.
- Lower long-term energy costs.

Environmental Benefits & Costs

Financing, while it does not produce environmental effects directly, can help accelerate clean energy technology investment, thus providing indirect environmental benefits.

Economic Benefits & Costs

Financing can supplement the economic benefits of a range of clean energy technologies, by providing the capital needed to increase market activity. To the extent that financing increases total market uptake of a given technology, it indirectly helps increase total investment, total employment, and the other benefits described elsewhere in this report. Financing also provides direct employment benefits by increasing job opportunities for loan officers, underwriters, and servicing entities.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Total rebates or incentives received
- Number of customers who participate in on-bill financing programs or in incentive or rebate programs
- Number of clean energy projects that use financing options Strategy Benefits and Costs

What You Can Do to Develop, Promote, and Use Clean Energy Financing Options

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Apply for available utility rebates or tax incentives for energy efficiency or renewable energy projects.
- ▶ Request utilities to allow on-bill financing or repayment to streamline financing of energy efficiency projects.

What Businesses Can Do to Develop, Promote, and Use Clean Energy Financing Options

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Develop public-private partnerships with local or state government agencies to develop business opportunities and help entities finance clean energy projects.
- ▶ Utilize the new commercial PACE financing mechanism, when implemented in your locality, to help pay for energy efficiency and renewable energy projects.

Energy Production

Pennsylvania is the third-largest energy producing state in the U.S. behind Texas and Wyoming (EIA 2017b). Pennsylvania is the third-largest coal-producing state in the nation as well as second in electricity generation from nuclear power (EIA 2017a).

In the past, coal and nuclear were the predominant fuels for generating electricity. However, Pennsylvania's significant growth in natural gas production is steadily replacing coal-fired electricity generation. This shift has occurred, in part, because technological advancements in hydraulic fracturing made it possible to develop natural gas resources that were previously uneconomic, thus driving down the price of natural gas. Now, Pennsylvania is the nation's second-largest natural gas producer (EIA 2017a). This rapid increase also placed Pennsylvania among the top three largest exporters of electric power in the U.S., with approximately one third of the electricity generated in the state being consumed elsewhere (PA DCED).

Meanwhile, renewable and alternative energy production is experiencing its own boom in the commonwealth. The largest driver behind this boom is the existing AEPS in Pennsylvania, which was established in 2004 and requires that electric distribution companies and electric generation suppliers ensure that by 2021 a minimum of 18% of total electric supply is from qualified renewable and alternative energy resources. Decreasing costs of renewable energy are also helping drive the increases in renewable power generation.

Climate Change Impacts

The expected impacts of climate change on energy production in Pennsylvania (Shortle et al. 2015) include:

- Increased strain on the energy sector to produce reliable supplies, particularly for power generation facilities that require cooling water, due to increased seasonal variations in freshwater and higher peak electricity demand. This could result in potential disruptions to power for citizens and businesses, and increases to the cost of energy.
- Reduced energy delivery reliability, damaged infrastructure, or equipment failures due to extreme weather events such as floods, severe storms, or extreme temperatures.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Energy Production sector, DEP has identified four main strategies to reduce emissions and adapt to climate impacts:

- ▶ **Increase use of clean, distributed electricity generation resources**
- ▶ **Create a diverse portfolio of clean, utility-scale electricity generation**
- ▶ **Reduce upstream impacts of fossil fuel energy production**
- ▶ **Increase production and use of alternative fuels**

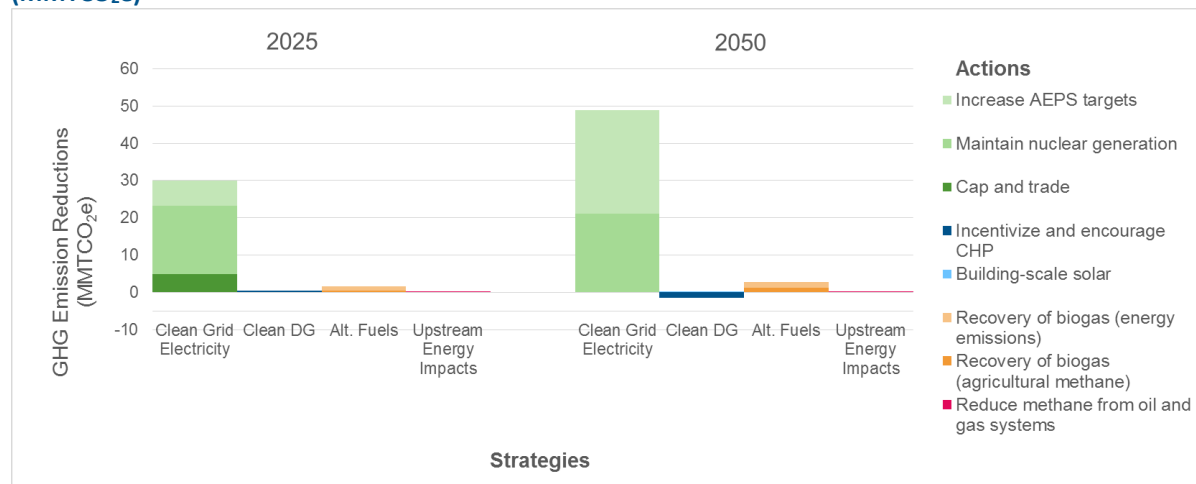
Each strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

In addition, these Energy Production strategies include seven actions that the team quantitatively analyzed (see Table 6 below). Together, these seven actions are expected to result in:

- ▶ Annual GHG reductions in 2025: **31,391,440 MTCO₂e** (12% reduction in energy consumption emissions and 6% reduction in energy production emissions from 2005 levels of 262,602,782 MTCO₂e and 18,678,372 MTCO₂e, respectively)⁹
- ▶ Annual GHG reductions in 2050: **48,858,287 MTCO₂e** (19% reduction in energy consumption emissions and 7% reduction in energy production emissions from 2005 levels 262,602,782 MTCO₂e and 18,678,372 MTCO₂e, respectively)

GHG reductions and cost per ton of GHG reduced (a measure of cost-effectiveness), by strategy and individual action, are presented in Figure 10 and Table 6 below.

Figure 10. Annual GHG Reductions from BAU Through 2050 for Energy Production Strategies and Actions (MMTCO₂e)



⁹ Emission reductions from strategies that affect the electricity generation fuel mix (e.g., utility scale renewable generation, nuclear generation, cap and trade) are accounted for in the energy consumption sector based on the reduction in the electricity consumption emission factor (i.e., a reduction of carbon intensity of the grid). Distributed renewable electricity generation is also accounted for as reductions to energy consumption emissions. Thus, emissions from these strategies are compared to the BAU emissions from energy consumption. Emissions reductions from coal mine methane capture and upstream oil and natural gas are accounted for in the energy production sector, so these are compared to the BAU emissions from energy production.

Table 6. Annual GHG Reductions in 2025 and 2050 and Cost per Ton of GHGs Reduced for Energy Production Strategies and Actions

Strategies and Actions Included in Higher-Level Strategy Quantitative Modeling	Annual GHG Reductions in 2025 (MTCO ₂ e)	Annual GHG Reductions in 2050 (MTCO ₂ e)	Cost per Ton of GHG Reduced (\$/ton of CO ₂ e)
Increase use of clean, distributed electricity generation resources	544,502	-1,512,918	NA^a
Invest in and promote building-scale solar	NA ^a	48,210	-\$285
Incentivize and increase use of combined heat and power	544,502	-1,561,128	NA ^b
Create a diverse portfolio of clean, utility-scale electricity generation	30,015,060	48,792,751	\$29
Increase Alternative Energy Portfolio Standard(AEPS) Tier 1 targets, and further increase in-state generation and use of renewables	6,703,719	27,639,941	\$27
Implement policy to maintain nuclear generation at current levels	18,412,115	21,152,811	\$26
Limit carbon emissions through an electricity sector cap and trade program	4,899,227	NA ^c	\$55
Reduce upstream impacts of fossil fuel energy production	104,879	29,598	\$19
Implement policies and practices to reduce methane emissions across oil and natural gas systems	104,879	29,598	\$19
Increase production and use of alternative fuels	1,673,531	2,796,683	-\$20
Increase recovery and use of gas from coal mines, agriculture, wastewater, and landfills for energy	1,673,531	2,796,683	-\$20

^a There is sufficient building scale solar in 2025 in the BAU to meet the 6% solar carve out assuming 90% is utility scale and 10% is building scale, so there are no GHG reductions from BAU in 2025. We see non-zero savings starting in 2026.

^b Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use. Note: the team looked primarily at the impacts from new natural gas combustion in new CHP systems and did not quantify the potential from using CHP to capture waste heat from existing combustion systems.

^c The GHG emission reductions from expanding AEPS requirements and maintaining nuclear generation are projected in this modeling analysis to meet the cap in 2050 without a cap and trade program.

Increase Use of Clean, Distributed Electricity Generation Resources

Clean, distributed electricity generation refers to renewable energy, such as solar and wind, that generate electricity on-site where it is used. These systems reduce reliance on fossil fuels and provide climate resilience benefits, including reduced reliance on centralized power. They also offer the opportunity to save money on electricity costs by installing on-site renewable energy and also reduce power lost through transmission and distribution.

Leadership Actions

State and local governments can support the use of clean, distributed electricity through incentives and policy. For example, governments can:

► **Invest in and promote building-scale solar energy.**

Separate efforts from DEP through the *Finding Pennsylvania's Solar Future Plan* (PA DEP 2018b) have specifically focused on outlining steps Pennsylvania needs to take to advance the use of solar in the commonwealth. Distributed solar PV strategies to be undertaken include:

- Give customer-generators the opportunity to use virtual net metering
- Identify and remove the barriers to the deployment of community solar systems in Pennsylvania
- Ensure alternative ratemaking is addressed in a manner that does not create a disincentive for solar deployment
- Encourage municipalities to offer PACE programs
- Accelerate use of smart inverters to manage over-voltage concerns on low voltage distribution lines and avoid unnecessarily adding costs on small solar distributed generation projects

Steps for implementing these strategies, and examples of where they have been successfully implemented in other jurisdictions are outlined in the *Finding Pennsylvania's Solar Future Plan* (PA DEP 2018b).

► **Incentivize and increase use of combined heat and power (CHP) for large campuses, hospitals, infrastructure, mass transit, and industry (e.g., through streamlining and best-practices sharing).¹⁰**

¹⁰ Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use. This projection does not consider the other benefits of CHP, or specific technologies such as waste heat recovery-based CHP, which could show different results. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use: as grid carbon intensity declines, it reaches a point where reducing electricity use by increasing natural gas use begins to increase net CO₂ emissions. In this modeling analysis, that point occurs during the 2040s.

In April 2018 the Pennsylvania Public Utility Commission (PUC) adopted a policy statement geared toward helping advance the development of CHP technology (http://www.puc.state.pa.us/utility_industry/natural_gas/chp_cogeneration.aspx). The PUC has since been focusing research and efforts to examine the viability of increased implementation of CHP through research and consultation with industry experts, including those from the private sector and DOE, among others. It is expected that the PUC (through its CHP Working Group) will determine what policies will make CHP more accessible to interested parties while balancing the needs and interests of all stakeholders. One issue that has already been identified by the PUC through their CHP workgroup is standby rates as an impediment to CHP – which would need to be addressed by the PUC. This active work will be critical to help pave the way for increased CHP use in Pennsylvania.

The above actions in **bold** are reflected in the quantified key metrics below. Other actions leaders can take include:

- ▶ Support community solar legislation and develop model local ordinances (e.g., to streamline community solar development).

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of clean, distributed electricity production include:

- Increase reliability of power grids by providing more generation sources with more diverse contributions to generation capacity, the ability to reduce transmission congestion, and reduced risk of outages.
- Increased energy reliability for key facilities and microgrids during extreme events by planning for and providing least impact backup power supply on-site, reducing operational or security disruptions.











Environmental Benefits & Costs

In addition to its measured benefits and cost, clean, distributed energy can have other environmental benefits, including reduced strain on water resources, and reduced thermal pollution from powerplant cooling water. Such strategies can also reduce the environmental effects associated with fuel extraction and transportation.

Economic Benefits & Costs

In addition to the macroeconomic benefits quantified in this report, clean distributed energy investments can create social equity benefits to the extent that resources are developed as greater total numbers of projects, distributed across a greater total number of jurisdictions. This can bring economic benefits to more Pennsylvania communities. Additionally, Pennsylvania citizens and businesses can save money on electricity costs by installing on-site renewable energy and also reduce power lost through transmission and distribution.

Key Metrics
Net Present Value: \$7,785 Million^a
Cost-per-ton of GHG Reduced: NA^b

	2025	2050		2025	2050
	GWh Electricity Consumption Reduced			BBtu Nat. Gas Consumption Increased	
	7,855	17,861		42,448	95,191
	GWh Renewable Electricity Generation Increased				
	0	243			
	MTCO_{2e} GHG Emissions Reduced^c			MT Air Pollutant Emissions Reduced^c	
	544,502	-1,512,918	NO _x	619	-1,848
			SO ₂	5,695	6,256
			Hg	0.10	0.08
	Capital Expenditures (\$ Million)			Maintenance & Repair Costs (\$ Million)	
	\$327	-\$2		\$104	\$233
	Number of Jobs Supported			Increase in GSP (\$ Million)	
	3,609	15,126		\$22	\$712
	Increase in Disposable Personal Income Per Household (\$/Household)			Energy Expenditure Savings (\$Million)^d	
	\$20	\$178		\$578	\$1,217

^a Net Present Value for this strategy includes capital expenditures, energy savings, fuel subsidies, and maintenance and repair costs.

^b Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use: as grid carbon intensity declines, it reaches a point where reducing electricity use by increasing natural gas use begins to increase net CO₂ emissions. In this modeling analysis, that point occurs during the 2040s.

^c Negative “reductions” indicate increases from BAU.

^d Energy Expenditure Savings in this strategy represent energy bill savings on natural gas and electricity.

Key Analysis Assumptions:

- Quantified metrics reflect the policies, programs, and actions in **bold** above.
- Building-scale solar is 10 percent of total solar development, as outlined in the Finding Pennsylvania’s Solar Future Plan (PA DEP 2018b) Scenario B, and building-scale solar capacity is split evenly between residential and commercial.

- *Efficient combined heat and power (CHP) systems are assumed to receive a preferential retail natural gas rate of \$5 per MMBtu, escalating according to BAU natural gas growth rates through 2050. ICF's proprietary Combined Heat and Power Database is used to identify potential CHP sites; all CHP high load factor sites are assumed to have economic potential.*

Other Key Performance Indicators

In addition to the metrics listed above, example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Installed capacity
- Production as share of sector consumption and production
- kW of installed renewable energy
- Investments made in renewable energy
- Alternative Energy Credits earned or awarded
- Customers purchasing renewable energy credits

What You Can Do to Increase Use of Clean, Distributed Electricity Generation Resources

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Invest in rooftop solar electric and water heating systems on your home.

What Businesses Can Do to Increase Use of Clean, Distributed Electricity Generation Resources

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Install on-site renewable energy generation and participate in the Pennsylvania Alternative Energy Credit Program.
- Implement combined heat and power at appropriate facilities.

Create a diverse portfolio of clean, utility-scale electricity generation

A diverse and clean electricity grid that relies on a mix of fuels makes the most of Pennsylvania's energy resources. Reducing the overall carbon intensity of the electricity generated in Pennsylvania affects every electricity grid customer in the commonwealth, making it one of the most critical strategies for reducing GHG emissions.

Leadership Actions

The Commonwealth of Pennsylvania plans to advance this strategy by pursuing a selection of the following policies, programs, and actions:

- ▶ **Increase Alternative Energy Portfolio Standard (AEPS) Tier 1 targets, and further increase in-state generation and use of renewables** (utility-scale solar), if possible, through actions in line with Solar Future through 2030.^{11,12}

The existing AEPS in Pennsylvania was established in 2004 and requires that electric distribution companies and electric generation suppliers ensure that by 2021 a minimum of 18% of total electric supply is from qualified alternative energy resources. This is being achieved through a mix of resources, including solar PV, wind, low impact hydro, waste coal, etc. This action focuses on expanding the AEPS, both in terms of its total percentage requirements, and in terms of the more specific tiered requirements by resource type.

- ▶ **Implement policy to maintain nuclear generation at current levels.**

Two large nuclear power plants are expected to go offline in Pennsylvania in the next few years. Three Mile Island and Beaver Valley are expected to be closing for financial reasons in 2019 and 2021, respectively, as their owners have found that low wholesale market prices have made them uneconomic. Keeping these plants online would both save jobs (approximately 1,500 jobs between both plants) and ensure zero emissions sources of baseload electricity are maintained in the commonwealth. Given how quickly the expected closures are approaching, the Pennsylvania legislature would need to act swiftly to implement this action. This is a problem that has been faced in other states such as New York (Spector 2018), New Jersey, Illinois, New York, and Wisconsin; it could be solved through a number of options that the Pennsylvania legislature could consider, including:

- Establishing a Zero Emissions Credit (ZEC) program (done in New Jersey, Illinois and New York) where generators get paid per MWH of zero emissions electricity generated at their facility. To create this mechanism, the legislature would need to enact legislation that sets the price, timeframe, and other details of the credit mechanism, or directs a state agency to so do. Other states have placed time limits on the credits and defined other key details such as adjusting the value of the ZECs over time based on specific indicators.
- Incorporating nuclear in the AEPS. The legislature could create a new and separate tier for nuclear power within the AEPS structure; it would define a specific percentage of electricity sales that electric distribution companies would have to purchase from Pennsylvania nuclear plants. Another approach would be to add nuclear to an existing AEPS resource tier, with a specific “carve-out” for nuclear, similar to the current solar carve-out. In this latter approach, the total tier resource requirement would need to be increased by at least the amount of the nuclear carve-out.

¹¹ To strengthen the AEPS over time, a periodic review process with an eye toward further strengthening the goals as technology allows could be used.

¹² Increasing the AEPS will also further incentivize DG as well as utility-scale electricity generation.

These options and what has worked in various states are described further in the National Conference of State Legislatures' report *State Options to Keep Nuclear in the Energy Mix*: http://www.ncsl.org/Portals/1/Documents/energy/StateOptions_NuclearPower_f02_WEB.pdf.

Maintaining the current nuclear generation levels in Pennsylvania will ensure that 18,412,115 MTCO₂e of GHG emissions are reduced in 2025 and 21,152,811 MTCO₂e of GHG emissions are reduced in 2050.

► **Limit carbon emissions through an electricity sector cap and trade program.**

To implement this action, the state legislature, or the Governor, could enact new policy that authorizes the state to establish a state-wide emissions trading program that addresses the electricity sector. If enacted, DEP would conduct a rulemaking effort to establish the framework and auction participation rules and requirements.

Many other states have already gone through this effort in the Northeast and other parts of the country, and America's Pledge *America's Low-Carbon Future: A "Bottom-Up" Opportunity Action Agenda for Climate Action in the United States* (America's Pledge 2018a) outlined state coalitions for carbon pricing as one to their top ten action areas for states to act on climate change. In creating the rules for the cap and trade program lawmakers and DEP could look at what other states have done as models, including Virginia and New Jersey (see <https://www.deq.virginia.gov/Programs/Air/GreenhouseGasPlan.aspx> and <https://www.state.nj.us/dep/aqes/rggi.html>) who are both working towards joining the Regional Greenhouse Gas Initiative (RGGI). This recommendation is also consistent with Proposed Strategy 4 of the *Finding Pennsylvania's Solar Future Plan* (PA DEP 2018).

Establishing the cap and trade program should require a carbon cap equal to a 30 percent reduction from 2020 CO₂ emissions levels by 2030. DEP would promulgate rules for the cap and trade program, establish roles and responsibilities for the program (e.g., for the auction of allowances), and clearly define what is to be done with auction revenues (e.g., a carbon revenue recycle program where payments get made back to consumers which is what is modeled for this report, or investments in energy efficiency or other programs). The GHG emission reductions from expanding AEPS requirements and maintaining nuclear generation are projected in this modeling analysis to meet the cap in 2050 without a cap and trade program.

The above actions in **bold** are reflected in the quantified key metrics below. Other actions leaders can take include:

- Establish a workgroup to help optimize siting of renewables, and to review and streamline permitting and regulations at the state and local levels (e.g., to address high value implementable actions and technologies such as community choice aggregation and battery storage).

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Create a diverse portfolio of clean, utility-scale electricity generation can:

- Reduce power outages due to extreme events.
- Reduce dependency on single fuels and sensitivity to price changes.

Environmental Benefits & Costs

In addition to the GHG and criteria air pollution metrics quantified above, clean utility-scale generation can reduce water use for powerplant cooling as well as environmental effects of fuel extraction and transportation. Some clean power technologies have their own environmental effects, such as wind power's potential impacts to birds and bats, or the embodied effects of materials used in manufacturing certain technologies.










Economic Benefits & Costs

Clean energy supply technologies already employ about 13,000 people in Pennsylvania, including renewable energy, grid modernization, and related businesses (E2 2018); the employment effects modeled in the 2018 Plan update are additional to this estimate.

Key Metrics

Net Present Value: -\$33,188 Million^a

Cost-per-ton of GHG Reduced: - \$29/MTCO₂e

	2025	2050		2025	2050
	GWh Renewable Energy Generation Increased			MW Renewable Energy Capacity Increased	
	13,867	58,725		6,496	24,486
	MTCO₂e GHG Emissions Reduced^b			MT Air Pollutant Emissions Reduced	
	30,015,060	48,792,751	NO _x	31,987	58,821
			SO ₂	58,317	112,542
			Hg	1.32	2.45
	Capital Expenditures (\$ Million)			Maintenance & Repair Costs (\$ Million)	
	\$1,949	\$1,127		\$691	\$1,2923
	Number of Jobs Supported			Decrease in GSP (\$ Million)	
	-2,493	-6,205		\$261	\$187
	Energy Expenditure Savings (\$Million)^c			Decrease in Disposable Personal Income Per Household (\$/Household)	
	-\$31	\$1,825		\$24	\$68

^a Net Present Value for this strategy includes capital expenditures, energy savings, and maintenance and repair costs

^b This represents the GHG emission reductions counted toward meeting Pennsylvania's GHG emission reduction target (i.e., those associated with electricity that is consumed within the commonwealth and not those associated with electricity that is exported).

^c *Energy Expenditure Savings in this strategy represent savings on fuels purchased for electricity generation at the utility scale.*

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU. Negative cost-per-ton represents net cost savings.

Key Analysis Assumptions:

- *Quantified metrics reflect the policies, programs, and action in **bold** above.*
- *The AEPS requirements will increase from eight percent Tier I renewables by 2020 (2020-2021 year) to 30 percent Tier 1 by 2030 and 50 percent by 2050 with a six percent solar carve out phased in linearly to 2030. The six percent solar carve out is in line with the Finding Pennsylvania’s Solar Future Plan (PA DEP 2018b).*
- *While Beaver Valley and Three Mile Island nuclear plants will close in 2021 and 2019 respectively in the BAU Scenario, these plants will be brought back online or kept open as part of this strategy and all other levels of nuclear generation in Pennsylvania will remain constant through 2050. Prices used in this analysis represent what would be needed to pay to the nuclear facilities to keep the existing nuclear running.*
- *A carbon emission limit for each year is established, using a 30 percent reduction from 2020 CO₂ levels by 2030. Post-2030 the emissions cap is stringent enough to phase out most remaining coal generation other than waste coal by 2050. The carbon emissions limit in each year is first met through the expansion of the AEPS and nuclear generation and then by ramping up natural gas generation and displacing coal generation, then by reducing coal generation further through a reduction in exports.*
- *For the cap and trade program carbon prices are designed to achieve the cap selected for modeling purposes (see above); the carbon price is high enough to reduce the cost-competitiveness of coal relative to natural gas, which is the incremental step beyond the AEPS that is needed to meet carbon limits and overall GHG reduction targets used for this modeling exercise.*

Other Key Performance Indicators

In addition to the metrics listed above, example indicators that Pennsylvania could use to measure progress toward this strategy include:

- AECs generated or purchased
- Compliance with the AEPS
- Portion of electricity generation driven by clean energy policies
- Generation levels from specific low-emission sources
- Carbon intensity of the electricity grid
- Number of communities or businesses using community choice aggregation

What You Can Do to Create a Diverse Portfolio of Clean, Utility-Scale Electricity Generation

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Urge elected officials to expand the AEPS to provide greater access to clean energy options.
- ▶ Urge the Pennsylvania legislature to require increases in clean electricity generation.
- ▶ Promote renewable energy customer choice with your utility and purchase clean power through PA Power Switch.
- ▶ Support community choice aggregation to aggregate customer buying power and increase cleaner energy purchasing.

- ▶ Choose to buy renewable energy through competitive electricity markets.

What Businesses Can to Create a Diverse Portfolio of Clean, Utility-Scale Electricity Generation

Pennsylvania **businesses** can support this strategy by taking the same actions listed above for citizens.

Pennsylvania **utilities** can support this strategy by taking the following actions:

- ▶ Collaborate with regulators, customers, and power suppliers to develop clean energy resources while maintaining grid safety and reliability.
- ▶ Support community choice aggregation.
- ▶ Support financing strategies for clean energy sources.

Reduce Upstream Impacts of Fossil Fuel Energy Production

The fossil fuel industry has historically been, and continues to be, one of the largest economic drivers in Pennsylvania. The recent rise in natural gas production from the Marcellus and Utica Shale formations has reaffirmed the importance of fossil fuels to Pennsylvania's economy. However, oil and natural gas production pose several environmental risks, not the least being the release of methane to the atmosphere throughout the production, transmission, storage, and distribution processes. There are many cost-effective operational changes and technologies for reducing methane emissions in these processes that could be deployed to improve the industry's overall net benefits by reducing one of its larger environmental costs.

Leadership Actions

The Commonwealth of Pennsylvania can advance this strategy by **implementing policies and practices to reduce methane emissions across oil and natural gas systems** (e.g., from well heads, abandoned wells, leakage in distribution systems). These policies and practices are reflected in the quantified key metrics below.

Pennsylvania has a long history of being one of the largest fossil fuel producers in the country and is therefore at the forefront of state action for reducing methane emissions from the oil and natural gas sector. These reductions can be achieved through both mandatory and voluntary reductions, an approach which has proven to be effective in the past. This year, Pennsylvania moved on a number of fronts to reduce methane emissions from the oil and natural gas sector, which will go a long way to helping achieve this action. Governor Tom Wolf has launched a Methane Reduction Strategy (<https://www.dep.pa.gov/Business/Air/Pages/Methane-Reduction-Strategy.aspx>) designed to reduce emissions from natural gas well sites, compressor stations and along pipelines and protect the environment, reduce climate change, and help businesses reduce the waste of a valuable product. To help achieve this goal, DEP released the revised general permits GP-5 for Natural Gas Compression Stations, Processing Plants, and Transmission Stations; (DEP 2018d) and new GP-5A for Unconventional

Natural Gas Well Site Operations and Remote Pigging Stations; (DEP 2018e) as well as related technical resources for operators. In addition to the action already being taken, DEP could set a regular schedule for GP review and updates to continue to further drive reductions. Additionally, DEP encourages in-state producers to participate in voluntary programs like the EPA Natural Gas STAR Program to help to further drive reductions.

Additionally, steps outlined in the 2015 Climate Action Plan continue to be relevant for this strategy (PA DEP 2015), including:

- Expand verification of methane emission data reported to DEP by operators.
- Continue to investigate and quantify methane emissions from plugged and abandoned wells, including wells plugged by DEP, through partnerships between DEP, academia, and citizen-science groups.
- Expand the use of remote-sensing technologies to identify fugitive and non-fugitive emission sources throughout the present and historical areas of operating, abandoned, and plugged oil and natural gas wells. This may include vehicle or aircraft-mounted methane detection equipment, as well as hand-held methane detection equipment, such as FLIR cameras.
- As a result of these surveys and results, develop a source emissions inventory and recommendations for developing and enhancing programs to minimize and eliminate methane emissions, expanding on what DEP already includes in the state GHG inventory.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

No identified climate resilience benefits or costs.

Environmental Benefits & Costs

In addition to the metrics quantified in this report, reducing upstream effects of fossil fuel production can create additional environmental benefits. To the extent that increasing the focus on “cleaner” upstream practices improves overall industry performance, such strategies could reduce the risks of groundwater and surface water contamination, the health risks associated with methane and other hydrocarbon emissions in nearby communities, and the safety risks associated with combustible fuels and byproducts.

Reducing methane emissions will also have other environmental benefits such as reducing the formation of ozone by reducing emissions of volatile organic compound emissions, local air pollutants, and odors, all of which have negative effects human health (e.g., in the form of smog) and ecosystems (EPA 2016c).







Economic Benefits & Costs

The metrics below constitute the relevant benefits and costs related to this strategy.

Key Metrics

Net Present Value: \$59 Million^a

Cost-per-ton of GHG Reduced: \$19/MTCO₂e

	2025	2050		2025	2050
	MTCO₂e GHG Emissions Reduced				
	104,879	29,598			
	Capital Expenditures (\$ Million)			Maintenance & Repair Costs (\$ Million)	
	\$2.51	\$5.49		\$0.52	\$1.23
	Number of Jobs Supported			Impact on GSP (\$ Million)	
	13	-13		\$0.00	-\$1.70
	Decrease in Disposable Personal Income Per Household (\$/Household)				
	\$0.08	\$0.34			

^a Net Present Value for this strategy includes capital expenditures, revenues from recovered natural gas, and maintenance and repair costs.

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU. Negative cost-per-ton represents net cost savings.

Key Analysis Assumptions:

- Quantified metrics reflect the policies, programs, and action in **bold** above.
- Emission reductions are for both conventional and unconventional sources and consider regulatory drivers at the federal-level (New Source Performance Standards, in BAU) and state-level (current Exemption 38(c) control standards to existing sources starting in 2020 and General Permit 5-A).
- Activity and emissions rely on the U.S. EIA AEO (EIA 2018), internal calculations and data from DEP, and an Environmental Defense Fund Tool for Evaluating Options for Reducing Methane Emissions in Pennsylvania.

Other Key Performance Indicators

In addition to the metrics listed above, example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Volatile Organic Compound (VOC) emissions
- Instances of water contamination in proximity to natural gas or oil production systems

What You Can Do to Reduce Upstream Impacts of Fossil Fuel Energy Production

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Support public policies to reduce upstream impacts that damage the environment and health.

What Businesses Can Do to Reduce Upstream Impacts of Fossil Fuel Energy Production

Pennsylvania **oil and natural gas businesses** can support this strategy by taking the following actions:

- ▶ Join the EPA Natural Gas STAR program to benefit from public recognition, information sharing, and peer networking by transparently reporting voluntary methane emissions reductions activities.
- ▶ Invest in methane leak detection to reduce emissions and safety hazards.
- ▶ Update control technology and implement best management practices to control methane emissions at well sites, in addition to properly plugging abandoned wells.
- ▶ Recover 10% of total methane emissions from coal mining through various technologies and techniques before, during, and after extraction.

Increase Production and Use of Alternative Fuels

Alternative fuels are a critical aspect of the AEPS in Pennsylvania, and are also currently incentivized or mandated in the transportation sector through the AIFG program and House Bill 1202 which requires that 2 percent of in-state diesel fuel production be biodiesel. There are a number of facilities already active in Pennsylvania that are producing alternative fuels or using them to generate electricity or energy, but there is opportunity for further development.

Leadership Actions

The Commonwealth of Pennsylvania can promote the production and use of alternative fuels by pursuing policies, programs, and actions, such as the following:

- ▶ **Increase recovery and use of gas from coal mines, agriculture,¹³ wastewater, and landfills for energy.**

Multiple national voluntary programs run by the U.S. EPA including the Landfill Methane Outreach Program, the Coalbed Methane Outreach Program, Ag Star, and the Global Methane Initiative offer industry the technical assistance needed to implement methane recovery and reuse for energy projects. These programs also provide recognition and other incentives (e.g., grants and cooperative agreements) for voluntary action and involvement. DEP could expand outreach efforts to help broaden participation in these effective programs to increase the development and use of alternative energy projects in Pennsylvania.

Additional recent action within Pennsylvania to make general permits amenable and streamlined for the beneficial use of landfill gas (LFG) (e.g., GP-26; reciprocating engines using LFG) and other energy uses of recovered gas (e.g., Waste Management General Permit

¹³ A key barrier to use of agricultural biogas is lack of transparency and access to data about the distribution network until the interconnection application stage.

WMGM042 for using food waste in anaerobic digester) can be built upon to continue to encourage and expand the use of alternative energy projects.

Similarly, Pennsylvania, through its various economic development arms, should encourage co-locating industrial and institutional facilities and commercial business centers to facilitate the utilization of waste heat from landfill-gas-to-energy projects and waste-to-energy facilities. Such efforts would offset consumption of fossil fuels, and would also provide additional revenue to these facilities. Generally, the focus should be on promoting co-development at waste-to-energy facilities, which have higher waste heat loads and more centrally located facilities.

The above action in **bold** is reflected in the quantified key metrics below. Other actions leaders can take include:

- ▶ Increase biofuel production in Pennsylvania (e.g., expand on biodiesel requirements outlined in Pennsylvania House Bill 1202 of 2008).
- ▶ Finalize the draft air general permit (reciprocating engines using LFG), which incentivizes increased beneficial use of landfill gas, and reduces downtime due to maintenance at existing projects.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Increasing the production and use of alternative fuels can:

- Reduce sensitivity to fuel price shocks or fuel scarcity.
- Keep facilities with on-site fuel production or storage operational during extreme events.

Environmental Benefits & Costs

Using alternative fuels, such as landfill gas, to produce electricity not only burns methane that could be released to the atmosphere, it also destroys most hazardous air pollutants and VOCs that are present in landfill gas. This reduces health risks and risks to the ecosystem.



Economic Benefits & Costs










The alternative fuels industry already employs about 1,400 people in Pennsylvania (E2 2018); the employments effects modeled in the 2018 Plan update are additional to this base.

Key Metrics

Net Present Value: \$1,504 Million^a

Cost-per-ton of GHG Reduced: - \$20/ MTCO₂e^b

	2025	2050		2025	2050
	GWh Electricity Consumption Reduced			GWh Renewable Electricity Generation Increased	
	331	876		331	876
	BBtu Nat. Gas Consumption Reduced			BBtu Biogas Consumption Increased	

	1,413	3,772		3,598	9,522
	MTCO₂e GHG Emissions Reduced		MT Air Pollutants Emissions Reduced^c		
	1,673,531	2,796,683	NO _x	-797	-2,230
			SO ₂	197	193
	Capital Expenditures (\$ Million)			Maintenance & Repair Costs (\$ Million)	
	\$37	\$0.24		\$9	\$20
	Number of Jobs Supported			Increase in GSP (\$ Million)	
	230	4,018		\$14	\$129
	Energy Expenditure Savings (\$Million)^d			Increase in Disposable Personal Income Per Household (\$/Household)	
	\$45	\$132		\$0.00	\$0.04

^a Net Present Value for this strategy includes capital expenditures, energy savings, revenues, and maintenance and repair costs.

^b Negative cost-per-ton indicates cost savings.

^c Emission factors for Hg emissions from biogas consumption were not readily available. Negative reductions indicate an increase compared to BAU.

^d Energy Expenditure Savings in this strategy represent energy bill savings on natural gas and electricity as well as revenues from selling electricity produced from landfill gas and captured coal mine methane.

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU. Negative cost-per-ton represents net cost savings.

Key Analysis Assumptions:

- Quantified metrics reflect the policies, programs, and action in **bold** above.
- For coal mine methane, full economic potential, estimated in the draft Pennsylvania Energy Assessment Report prepared in 2018, is realized each year through 2050 and then emission reductions are calculated with the Coal Module from EPA’s SIT.
- Agriculture Waste, Landfill Gas, and Wastewater methane use is expected to increase based on information in ICF’s CHP Database and considers support of the expanded AEPS through 2050 (see above).

Other Key Performance Indicators

In addition to the metrics listed above, example indicators that Pennsylvania could use to measure progress toward this strategy include:

- VOC emissions
- Hazardous air pollutant emissions
- Number of alternative energy projects in Pennsylvania
- Volume of biofuel production in Pennsylvania

What You Can Do to Increase Production and Use of Alternative Fuels

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Purchase “flex-fuel” labeled vehicles, which can burn E85 fuel.
- ▶ Advocate for greater alternative fuel infrastructure
- ▶ Convert personal vehicle to be capable of operating on alternative fuels.

What Businesses Can Do to Increase Production and Use of Alternative Fuels

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Take advantage of Pennsylvania’s AFIG program to purchase or convert business vehicle fleet to be capable of burning biofuels or compressed natural gas (CNG) or other alternative fuels.
- ▶ Capture methane emissions and convert to energy.

Agriculture

According to the Census of Agriculture, there are nearly 60,000 farms and ranches on more than 7.7 million acres of land in Pennsylvania (USDA 2012). In fact, 27% of all land use in Pennsylvania represents agricultural land.

Agriculture is a major driver of the state’s economy, accounting for approximately \$83.8 billion in direct economic output, including \$22.8 billion in value-add (PDA 2018). This industry generates approximately \$135.7 billion in total economic impact each year and supports 579,000 jobs with \$26.9 billion in earnings (PDA 2018).

Pennsylvania ranks number one in the nation for mushroom production, growing over half of the mushrooms in the United States and providing nearly \$530 million in sales a year (Whetstone 2014). The state is also a leader in export grade hardwood. Other unique crops where Pennsylvania ranks among the top 5 producers in the nation include poultry egg-layers, milk from cows, Christmas trees, and the nursery, greenhouse, floriculture, and sod sectors (PDA 2018). Conventional commodities such as corn, soybeans, and wheat are also commonly grown in the state.

Specific areas that affect emissions in this sector include enteric fermentation, manure management, and agricultural soil management as well as fuel combustion emissions.

Climate Change Impacts

Overall, climate change will alter growing conditions and growing seasons for agriculture. The exact effects on specific crops are uncertain, but the overall expected impacts of climate change on agriculture in Pennsylvania (Shortle et al. 2015) include:

- Changes in agricultural productivity and profitability or shifts in ideal crop ranges that could require farmers to adjust practices (e.g., irrigation, fertilization) or switch to new crops. Example agricultural products that could be affected include dairy and field crops.

- Indirect effects on food prices, increasing financial risks for farmers and citizens.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Agriculture sector, the analysis team has identified two main strategies to reduce emissions and adapt to climate impacts:

- ▶ **Use agricultural best practices**
- ▶ **Provide resources and technical assistance to farmers to adapt**

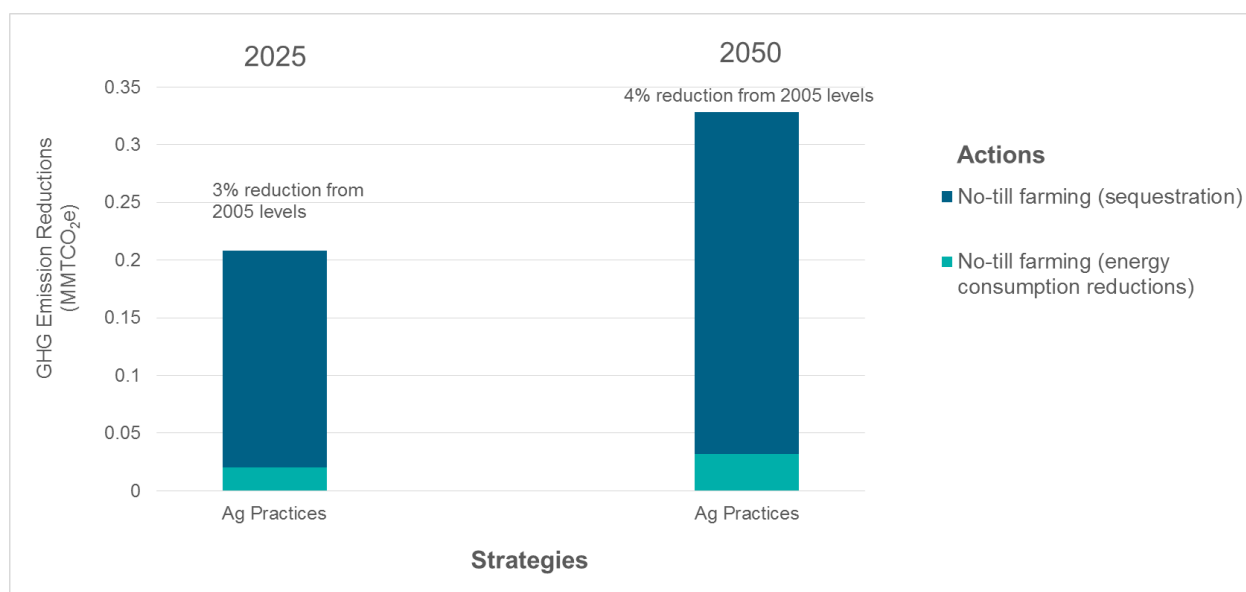
Each strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

In addition, these Agriculture strategies include one action that the team quantitatively analyzed (see Table 7 below). This action is expected to result in:

- ▶ Annual GHG reductions in 2025: **208,331 MTCO₂e** (3% reduction from 2005 levels of 7,566,296 MTCO₂e)¹⁴
- ▶ Annual GHG reductions in 2050: **328,070 MTCO₂e** (4% reduction from 2005 levels of 7,566,296 MTCO₂e)

GHG reductions and cost per ton of GHG reduced (a measure of cost-effectiveness) are presented in Figure 11 and Table 7 below.

¹⁴ This includes some emission reductions from energy consumption due to changes in fuel consumption by agricultural equipment.

Figure 11. Annual GHG Reductions from BAU Through 2050 for Agriculture Strategies and Actions (MMTCO₂e)

Table 7. Annual GHG Reductions in 2025 and 2050 and Cost per Ton of GHGs Reduced for Agriculture Strategies and Actions

Strategies and Actions Included in Higher-Level Strategy Quantitative Modeling	Annual GHG Reductions in 2025 (MTCO ₂ e)	Annual GHG Reductions in 2050 (MTCO ₂ e)	Cost per Ton of GHG Reduced (\$/ton of CO ₂ e)
Use agricultural best practices	208,331	328,070	-\$22
Implement and provide training for no-till farming practices	208,331	328,070	-\$22

Use Agricultural Best Practices

Agricultural best practices will allow farmers to maintain or increase productivity sustainably into the future while also accounting for expected climate changes.

Leadership Actions

Policies, plans, and government activities can encourage the adoption of best practices. State and local leaders can:

- **Implement and provide training for no-till farming practices**, especially those that sequester carbon in soils and plants. To take this action, the Pennsylvania Department of Agriculture should build upon existing programs, such as the Workforce Development initiative which has the intent of promoting and expanding the state's agriculture education opportunities, as well as career and technical education programs. In establishing education materials and trainings for no-till farming, the Department of Agriculture should look to partner with the PennState

Extension to utilize the training resources that have already been developed and are in use. For example, a four-part video series which highlights knowledge and experience from farmers in Pennsylvania already using no-till practices is already available online: <https://extension.psu.edu/no-till-farmer-to-farmer-introduction-to-the-series>. They should also look to use other resources that are out there at the federal level from the United States Department of Agriculture when looking to establish training programs and education materials. These programs and materials should focus on sharing best practices between farmers and on educating farmers on the benefits (economic and environmental) of no-till farming practices.

The above action in **bold** is reflected in the quantified key metrics below. Other actions leaders can take include:

- ▶ Expand integrated farm management and conservation planning, including:
 - Energy conservation and renewable energy generation such as digesters for methane capture and recovery, energy efficiency, and the production and use of renewable energy (e.g., biofuels, solar, wind).
 - Best practices to manage flooding, including agriculture that is compatible with periodic flooding, establishment or restoration of riparian buffers, wetland easements for marginal and flood-prone agricultural lands, switchgrass planting programs for soil and bank stabilization, and research on the benefits of periodic fallowing for active floodplain acres.
 - Best practices related to runoff and nutrient management such as runoff reduction strategies; pesticide, herbicide, fertilizer, and nitrogen reduction programs; and efforts to ensure that manure is land-applied only at agronomic rates.
 - Advanced irrigation systems such as GIS, GPS, and satellite crop and soil moisture sensing systems.
 - Plant drought-tolerant hybrid species in upland areas to reduce need for irrigation.
- ▶ Expand regional planning initiatives, especially in agricultural areas, focusing on agricultural security zones and local food security.
- ▶ Revise / update existing conservation and agricultural measures to see how they could further support resilience to climate change, and modify where necessary.
- ▶ Provide financial incentives and support for agricultural best practices, such as:
 - Sales or property tax exemptions, rebates, and reduced agricultural insurance rates.
 - Agricultural insurance requirements to factor climate risk reduction benefits of management best practices in rates.
 - Economic and cooperative structures that transfer risk away from the bank and farmer, such as Community Supported Agriculture (CSA).
 - Pricing systems that reward conservation (e.g., seasonal pricing).

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Encouraging and adopting agricultural best practices can offset some of the negative impacts of increased temperatures, pests and diseases, and changing precipitation patterns. Agricultural best practices can result in:

- Increased or maintained agricultural productivity, allowing farmers to take advantage of opportunities presented by climate change.
- Improved sustainability of agricultural practices to cope with changing climatic conditions.
- Reduced erosion and improved soil quality across the state.
- Improved water quality which will be negatively impacted by changing precipitation patterns and increased runoff, thereby protecting the health of Pennsylvania's citizens.
- Conserved water resources, which are expected to be increasingly strained.

Environmental Benefits & Costs

Several of the aforementioned climate resilience benefits are also environmental benefits, including reduced erosion, improved soil quality, improved water quality, and water resource conservation. Agriculture can be a carbon sink, and proper management reduces the GHG emissions as well (Agriculture and Agri-Food Canada 2000). Good soil management reduces erosion and soil degradation, which can be damaging for the agricultural sector and for waterways impacted by sedimentation (McRae, Smith, and Gregorich 2000). Reducing runoff also lowers the amount of nitrate runoff from agricultural land, which contributes to water pollution and eutrophication. Also, water conservation in irrigation will help preserve groundwater and surface water resources.



Economic Benefits & Costs







Agricultural best practices can promote economic stability for farmers by increasing or maintaining agricultural productivity. This adds to the GSP and creates or maintains local jobs. Additionally, as shown below, fuel costs are reduced, offering savings for farmers.

Key Metrics

Net Present Value: \$162 Million^a

Cost-per-ton of GHG Reduced: - \$22 / MTCO₂e^b

	2025	2050		2025	2050
	BBtu Fossil Fuel Consumption Reduced^c				
	294	462			
	MTCO₂e GHG Emissions Reduced			MT Air Pollutants Emissions Reduced^d	
	208,331	328,070	NO _x	-18	27
			SO ₂	-0.2	-0.3

	Capital Expenditures (\$ Million)			Maintenance & Repair Savings (\$ Million)	
	\$14	\$22		\$12	\$19
	Number of Jobs Supported			Impact on GSP (\$ Million)	
	470	-495		\$0.00	-\$12
	Energy Expenditure Savings (\$Million)^e			Change in Disposable Personal Income Per Household (\$/Household)	
	\$6	\$12		\$0.24	-\$5

^a Net Present Value for this strategy includes capital expenditures, energy savings, lost revenues, and maintenance and repair costs.

^b Negative cost-per-ton indicates cost savings.

^c This strategy affects natural gas, distillate fuel oil, liquefied petroleum gas (LPG), kerosene, and motor gasoline consumption. Note that there is a small amount of biodiesel blended into the distillate fuel oil that was not estimated in this strategy.

^d Emission factors for Hg emissions from LPG and kerosene consumption were not readily available. Negative reductions indicate increases compared to BAU.

^e Energy Expenditure Savings in this strategy represent energy bill savings on natural gas, distillate fuel oil, LPG, kerosene, and motor gasoline.

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU. Negative cost-per-ton represents net cost savings.

Key Analysis Assumptions:

- Quantified metrics reflect the policies, programs, and action in **bold** above.
- No-till total acres planted in Pennsylvania will increase by approximately 2 percent annually based on the U.S. Department of Agriculture (USDA) Pennsylvania Tillage Survey statistics for 2013 and 2014 (USDA 2014).
- Planted acres of crops stay consistent over time through 2050 and conventional tillage acres will transition to reduced tillage acres, and reduced tillage acres will transition to no-tillage acres.
- Emission reductions and yield changes by crop/tillage practice are estimated using Northeast data from USDA’s report Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States (USDA 2013).
- Fuel savings are in line with USDA regional estimates of fuel consumption (\$/acre) for various tillage practices to the projected estimates of conventional, reduced, and no-till acres in Pennsylvania

Other Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Yield
- Land use intensity
- Share of agricultural land enrolled in agricultural preserve programs
- Food production per unit of GHG emissions
- Share of farm area with agricultural GHG emissions management practices

- Share of irrigated cropland with efficient irrigation practices in place
- Share of agricultural land affected by soil erosion
- Share of arable land under soil conservation practices/conservation agriculture
- Fertilizer applied per unit of arable land
- Pesticide use per unit of cropland
- Sustainable nitrogen management index

What You Can Do to Increase Use of Agricultural Best Practices

- ▶ Support sustainable farming in personal purchasing decisions (e.g., subscribe to a CSA).
- ▶ Reduce personal food waste through improved storage methods and planning.
- ▶ Participate in community composting programs that provide farmers with fertilizer.

What Businesses Can Do to Use Agricultural Best Practices

Pennsylvania **farmers** can support this strategy by taking the following actions:

- ▶ Protect crops from heat and drought, including:
 - Diversify cropping systems including planting drought-tolerant varieties to reduce water consumption and defend against drought.
 - Adjust the selection of planting dates (e.g., earlier planting and harvesting dates to avoid arid late-summer conditions).
 - Integrate agro-forestry practices into cropping systems.
- ▶ Sustainably manage soil and protect water resources, including:
 - Use soil conservation techniques and conservation tillage methods (e.g., no-till, mulching, strip till) to increase water infiltration and soil organic matter.
 - Protect environmentally sensitive agricultural land through enrollment in the Conservation Reserve Program or other, similar programs.
 - Use intensive/rotational grazing as opposed to cropping and feeding animals indoors.
 - Use cover crops and water-holding crops to enhance soil water retention, reduce erosion, and improve water quality.
 - Improve water use efficiency in agricultural buildings and processing facilities.
 - Deploy a nutrient management plan and manage manure responsibly
 - Use carefully prescribed pesticide and nutrient application practices, such as no winter nutrient application and application at agronomic rates.
- ▶ Employ organic farming techniques and increase chemical-free forms of pest control.

Provide Resources and Technical Assistance to Farmers to Adapt

Many farmers lack access to climate data or do not know how to change their practices to reduce risk from climate change. Providing technical assistance and other support can help farmers make better decisions about sustainable farm management and how to protect their crops.

Leadership Actions

Actions under this strategy fall into two main categories: (1) Actions to improve monitoring and data dissemination, and (2) actions to fill research needs and disseminate results.

Having access to accurate and timely weather and climate information allows farmers to make better decisions about their crops and planting cycles. Actions to improve monitoring and data dissemination in the near-term include:

- ▶ Establish a network of agro-meteorological stations statewide to collect climate observations, including estimates of evapotranspiration, to support research and development of agricultural practices.
- ▶ Expand the collection and dissemination of local weather information for irrigation planning.
- ▶ Improve the accuracy of existing real-time weather warning and forecasting systems for drought and extreme events.
- ▶ Develop and disseminate seasonal climate forecasts.
- ▶ In addition, several of the long-term impacts of climate change in Pennsylvania are not well understood. State leadership can take action to fill those research gaps and disseminate the results to the agricultural community, including the following actions:
- ▶ Conduct or sponsor research to understand topics such as climate change effects on weeds, insects, and diseases; best practices for agricultural emergency response plans; conservation best practices; and methods for maintaining the genetic diversity of crops.
- ▶ Facilitate information sharing networks for farmers and the agricultural research community to share experiences and best practices.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Providing technical assistance will provide farmers with the resources they need to make informed decisions about how to manage changing climatic conditions. This has the benefits of:

- Reduced crop and animal product losses due to heat stress or changing precipitation, thereby preventing economic losses.
- Maintained and improved soil health that will help maintain crop yields over time.
- Reduced damages and costs from pests and diseases.

Environmental Benefits & Costs

As described under the previous strategy, actions to mimic natural pest management systems and sustainable farming practices can improve soil and water quality, and preserve ecosystem health. If used responsibly, integrated pest management will have insignificant environmental impacts. However, if

chemicals are not handled or dispersed properly, they could negatively affect wildlife, including bees (CDC 2017b).

Economic Benefits & Costs

All of the aforementioned climate resilience benefits can result in preserved economic activity from the agricultural sector. In addition, technical assistance and the resulting resilience benefits can result in economic benefits for individual farmers and the 280,500 people directly employed in agriculture within the state (PA Department of Agriculture 2018).

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Number of farmers involved in technical assistance networks
- Number of persons assisted/trained through outreach programs
- Investment in research and development
- Number of family farms
- Number of crop insurance claims/year
- Yield of key crops and animal products

What You Can Do to Support Resources and Technical Assistance to Farmers to Adapt

Pennsylvania citizens can support this strategy by buying local farm products to support local farmers, and encouraging businesses (e.g., restaurants and grocers) to do the same.

What Businesses Can Do to Use and Support Resources and Technical Assistance to Farmers to Adapt

Pennsylvania **farmers** can support this strategy by taking the following actions:

- ▶ Work with state and local leadership to communicate observed climate impacts and needs for technical support.
- ▶ Participate in technical assistance programs.
- ▶ Make use of information and technical assistance resources provided by state agencies and other sources.
- ▶ Monitor trends in weather and productivity to inform future decision-making.
- ▶ Increase adoption of techniques that replicate natural systems' mechanisms for pest control and disease management.
- ▶ Consider diversifying or supplementing crops with solar panels to counterbalance climate-related crop risks.

In addition, **restaurants** and **grocers** can procure local produce to support local farmers.

Ecosystems and Forestry

Pennsylvania's ecosystems include forests, wetlands, and coastal ecosystems.

The dominant ecosystem in the Commonwealth of Pennsylvania is the forest. Pennsylvania has 17 million acres of forested land, covering 59 percent of its total land base and is the largest single cover type. Common trees present in Pennsylvania forests are oak, maple, and cherry. These trees provide economically important products for the state's economy such as lumber and maple syrup.

Furthermore, forests support diverse plant and animal life and protect the state's watershed. The Plan also recognizes the importance of GHG sinks in climate change mitigation: while no quantitative goals have been set for sinks, afforestation, reforestation, sustainable agriculture, and other natural-system improvements can provide significant reductions in net emissions by removing GHGs from the atmosphere. Pennsylvania's forests serve as one of these important carbon sinks, and in 2018 state forests are projected to sequester 5.14 million tons of carbon, while storing 158 million tons above ground (PA DCNR 2015, DCNR, personal communication).

Conserving forest land, maintaining forest health, planting trees, and promoting a vibrant wood products industry are effective, low-cost contributions that mitigate the impacts of climate change while also offering many additional social and environmental benefits (PA DCNR 2015).

Wetlands are another important ecosystem in Pennsylvania. These are areas which are saturated with water and can occur in floodplains along rivers and streams, in swamps or marshes, and along the edges

of lakes. Wetlands are vital breeding and spawning grounds for many animals such as fish and amphibians. In fact, these ecosystems are home to some of Pennsylvania’s threatened and endangered species, like the American bittern (Sothorn 2017).

A coastal ecosystem is found where the lands meets the sea. In Pennsylvania there are two coastal areas: 77 miles of coastline along Lake Erie and 112 miles of coastline along the Delaware Estuary (PA DEP). These zones encompass a diverse set of habitat types that include both terrestrial and marine areas. The uniqueness of coastal ecosystems gives them large social, economic, and biological value. Many people in Pennsylvania rely on the provisioning services of coastal zones for their food supply and livelihoods and this ecosystem contributes to several economic sectors such as fisheries and tourism.

Climate Change Impacts

The expected impacts of climate change on ecosystems and forestry in Pennsylvania (Shortle et al. 2015) include:

- Shifts of suitable habitat to higher latitudes and elevations; species inhabiting decreasingly suitable habitat could become stressed due to warmer temperatures.
- Threats to ocean resources, particularly in the tidal freshwater portion of the Delaware estuary, due to increases in dissolved oxygen concentrations.
- Damage to coastal wetlands due to sea level rise and salinity intrusion. Coastal wetlands provide many environmental benefits, including flood protection, erosion control, improved water quality, and fish and wildlife habitat.
- Reduced stream and wetland community health due to temperature increases and precipitation changes.
- Reduced suitable habitat for fish and wildlife.

Healthy ecosystems and forestry provide for flood protection, clean water for drinking and swimming, healthy fish populations for recreational fishing, enjoyable environments for outdoor recreation, and many other benefits to Pennsylvanians.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Ecosystems & Forestry sector, DEP has identified two main strategies to reduce emission and adapt to climate impacts:

- ▶ **Improve protection and optimize ecosystems**
- ▶ **Monitor, identify, and remove ecosystem vulnerabilities**

Each strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

The team did not quantitatively analyze actions within Ecosystems & Forestry strategies.

Improve Protection of and Optimize Ecosystems

Ecosystems within Pennsylvania provide significant value through ecosystem services, natural resources, and recreational opportunities. Maintaining healthy ecosystems capable of supporting fish and wildlife populations, as well as preserving ecosystem function and recreational use, is critically important, especially as the ecosystems are under increasing stress due to climate change.

Leadership Actions

Pennsylvania can protect green spaces and ecosystems upon which wildlife, fish, and recreation depend through actions such as the following:

- ▶ Conserve and enhance areas representing the full range of wildlife and fish habitats and promote connectivity (e.g., using land exchanges, conservation easements, leases; by removing barriers) to allow species to migrate to suitable habitat.
- ▶ Promote forest conservation, growth, and adaptation, as well as urban trees (e.g., by establishing a carbon banking and trading system that pays landowners to plant and manage working forests on both private and public land).
- ▶ Restore wetlands and riparian areas, expand or revise current minimum riparian buffer zones, and implement living shoreline programs to provide natural flood abatement, breeding habitat, and improved stream conditions (including improved thermal conditions).
- ▶ Preserve and create open spaces, parks, and trails that allow people to continue to engage in outdoor activities and maintain connectivity to natural resources. Protect wildlife and fish habitat and species that support recreational opportunities like hunting, fishing, and wildlife viewing.
- ▶ Educate recreational land users about the importance of climate change impacts on ecosystems and the dangers of illegal hunting and fishing, pollution, and development.
- ▶ Retrofit existing parks and trails and create new parks and trails to strengthen the community, improve habitat connectivity, provide more water sources for human users recreating in higher temperatures, enhance natural stormwater and flood management, and connect paths to schools, workplaces, and retail centers to promote pedestrian use.
- ▶ Promote alternatives to mowing, including meadows, native plants, and trees.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of protecting ecosystems and promoting optimal use include:

- Protected resources and ecosystem services for recreation, fishing, and drinking water.
- Improved habitat for wildlife, including allowing populations to shift to adapt to increased temperatures.
- Maintenance of key migration routes for vulnerable species.
- Improved water quality.
- Reduced temperatures in stream and wetland ecosystems, which protects fish populations from heat stress and productivity loss.

- Reduced damage to aquaculture, fisheries, and recreation by protecting fish populations from habitat destruction and cutting off migration.
- Reduced heat island effects caused by rising temperatures, which will reduce heat stress and health impacts due to climate change.
- Reduced impacts from flooding in urban areas caused by more intense precipitation by providing stormwater management.
- Continued outdoor recreation opportunities despite rising temperatures, providing benefits for health and the tourism industry.

Environmental Benefits & Costs

Environmental benefits of effective ecosystem management include improved water quality, reduction of runoff, healthier habitats, and healthier wildlife and fish populations.

The GHG emission reduction benefits of ecosystem protection include:

- Reduced atmospheric carbon dioxide through protected and restored carbon stocks.
- Reduced carbon and other air emissions when people hike or bike on trails instead of driving their vehicles.
- Reduced atmospheric greenhouse gas and pollution impacts due to carbon sinks.

Urban and suburban areas receive multiple benefits from increased forest cover, some of which include improved air quality, greater natural beauty (and property values), and added value to the ecosystem. In addition to removing carbon and other greenhouse gases from the atmosphere, well-placed trees offer benefits, such as energy savings for property and vehicle owners, groundwater filtration, and reduced runoff and flooding, just to name a few (PA DEP 2015).

Economic Benefits & Costs

Trees that are placed in close proximity to a home can also help to reduce the owner's energy costs by as much as 30 percent. During the summer, the shade that trees provide is a natural way to keep energy bills low, as it prevents the sun from heating the home and lessens the energy required to maintain a cool temperature. Properly placed trees also serve as windbreaks during the winter and shield homes from icy winds that would otherwise result in increased heating costs (PA DEP 2015).

Efforts to plant more trees in Pennsylvania are well underway, in large part because of TreeVitalize, a public-private partnership established by DCNR. The program aims to restore tree cover in Pennsylvania communities by providing technical and financial assistance on tree planting, tree improvements, and urban tree canopy assessments; training citizens on how to select, plant, and maintain trees in their local areas; and publicizing the numerous benefits of tree planting through partnerships with local sports teams and public radio stations.

Since its inception in 2004, more than 461,627 TreeVitalize trees have been planted in urban and suburban areas throughout the commonwealth. As of 2018 this provided a reduction in 1.6 billion gallons of stormwater and a savings of \$12.8 million; a reduction of 41,611 pounds of nitrogen; sequestration of 235 million pounds of carbon; and a 41 million kWh decrease in electricity consumption and \$5.7 million in savings, among other things (PA DCNR, 2018, personal comm.).

Possible actions within this strategy range from low to high cost. For example, a low-cost action is choosing native plants for gardens or landscaping. A higher cost action is installing fish ladders at hydroelectric dams. The cost of a fish ladder is proportional to the height of the dam and may cost \$10,000-30,000 per foot (Connecticut River Watershed Council 2000).

The economic benefits of these actions include improved ecosystem services that provide recreation, flood protection, drinking water, and food sources. Outdoor recreation is enjoyed by 56% of residents each year and brings in \$29.1 billion in customer spending and directly employs 251,000 people (PA DCNR 2017).

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Number of endangered or threatened species
- Percentage of stocks overfished/degree of overfishing
- Amount of buffer zone protected
- Number of park visitors
- Area and percent of forest land managed primarily for protective functions, e.g. watersheds, flood protection, riparian zones, and using management protocols certified sustainable by The Sustainable Forest Initiative, Forest Stewardship Council, TreeFarm USA, or other third-party organizations.
- Total forest ecosystem biomass and carbon pool, and if appropriate, by forest type, age class, and successional stages
- Area and percent of forest land managed for general recreation and tourism, in relation to the total area of forest land

What You Can Do to Improve Protection of and Optimize Ecosystems

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Choose native plants for your garden to conserve water and protect habitat.
- ▶ Follow local hunting and fishing regulations to protect vulnerable species.
- ▶ Participate in local conservation activities.
- ▶ Support parks and trails in your area by using recreation areas.
- ▶ Protect open spaces, parks, and trails by cleaning up parks, preventing littering, and acting respectfully.

What Businesses Can Do to Improve Protection of and Optimize Ecosystems

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Support local conservation organizations and activities.
- ▶ Choose native plants for landscaping to conserve water and protect habitat.
- ▶ Allow fish to safely pass around hydroelectric dams (e.g., using fish ladders).
- ▶ Use green infrastructure and water management features that promote infiltration and reduce runoff.

- ▶ Minimize construction in key habitat areas.
- ▶ Increase and maintain access points (e.g., walking trails) in and around lake and river recreation areas to be resilient to climate impacts.
- ▶ Relocate or redesign docks, boat launch sites, boardwalks, and other at-risk infrastructure as water levels change, taking potential future climate impacts, best management practices, and green infrastructure principles into account.
- ▶ Maintain dirt biking trails and educate riders to minimize the environmental impacts of additional trail usage.

In addition, **farmers** can also play a role by taking the following actions:

- ▶ Use best management practices (BMPs) on agricultural lands and barnyards to limit polluted runoff that might damage ecosystems.

Monitor, Identify, and Remove Ecosystem Vulnerabilities

Developing better research on how climate change may affect Pennsylvania’s ecosystems and green spaces is necessary to manage them more sustainably. It is also important to continue to monitor environmental impacts to these areas to establish adaptive thresholds.

Leadership Actions

State and local leaders can take action to identify and study key ecosystems to better understand the vulnerabilities they could face. Actions include:

- ▶ Develop a central database to store relevant ecosystem data.
- ▶ Establish a statewide monitoring and research network of academics, civil society, and citizen scientists to establish baseline conditions and monitor ecosystem factors, such as physical changes, species distribution (including invasive species), weather conditions, disease outbreaks, and general ecological conditions.
- ▶ Identify and prioritize species, habitat, and ecosystems most vulnerable to climate change and other stressors to better target protection and management actions.
- ▶ Review existing legal, regulatory and policy frameworks that govern protection and restoration of wildlife and fisheries habitats, and identify opportunities to improve their ability to address climate change impacts.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of monitoring and research on ecosystem vulnerabilities to climate change, and removing those vulnerabilities include:

- Better informed management to reduce threats to habitat.
- Improved ecosystem protection to provide key ecosystem services.

Environmental Benefits & Costs

This strategy promotes long-term environmental health and ecosystem services. Monitoring and identifying vulnerabilities enables the state or individuals to respond when a problem is detected and protect natural resources through adaptive management approaches.

Economic Benefits & Costs

This strategy is a low-cost way to prepare today so that Pennsylvania is able to respond appropriately over time to protect key ecosystems and economies. For example, healthy hardwood forests account for about 58% of the state's land cover and contribute to a strong forest products industry, which employs more than 86,000 people (Pennsylvania Forest Products Association 2003). Having the right information to appropriately manage forests under changing climatic conditions can help protect jobs and industry. In addition, better information can help to manage species migration that could negatively affect hunting, fishing, and wildlife watching activities, which are a small, but important part of the state's economy. In 2011, in-state hunting and fishing expenditures totaled around \$1.5 billion and wildlife watching activities totaled around \$1.3 billion (U.S. Department of the Interior and U.S. Department of Commerce 2013).

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Trees planted in urban or community areas
- Number of species included in monitoring activities
- Habitat extension, size, and representativeness
- Spatial connectivity
- Population density of target species
- The status (threatened, rare, vulnerable, endangered, or extinct) of forest dependent species at risk of not maintaining viable breeding populations, as determined by legislation or scientific assessment

What You Can Do to Monitor, Identify, and Remove Ecosystem Vulnerabilities

Pennsylvania citizens can support this strategy by participating in "citizen science" programs to monitor changing ecological conditions over time.

What Businesses Can Do to Monitor, Identify, and Remove Ecosystem Vulnerabilities

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Sponsor and participate in "citizen science" programs to monitor changing ecological conditions over time.
- ▶ Partner with research institutions as appropriate to support monitoring and research efforts.

Outdoor Recreation and Tourism

Pennsylvania's 120 state parks, over 5,000 miles of rivers and streams, and 2.2 million acres of state forests attract visitors from all over the globe and foster outdoor activities such as hiking, skiing, biking, bird watching, and kayaking (Wilgus 2014).

Outdoor recreation brings visitors to an area and the communities reap the economic benefits when visitors buy food, stay overnight in hotels, buy or rent equipment, and pay for travel costs. For this reason, Pennsylvania's abundant tourism opportunities at treasured destinations have caused the travel and tourism sectors to be critically important for the residents as well as the economy of the state. Outdoor recreation is among the nation's largest economic sectors. In Pennsylvania, outdoor recreation generates \$29.1 billion in consumer spending annually as well as provides 251,000 direct jobs (Outdoor Industry Association 2017). Overall, tourism supports 6.5% of jobs in the state, which includes almost 319,700 direct jobs, and nearly \$4.1 billion of state and local taxes (Tourism Economics 2015). Tourism has also been growing more quickly than the state's broader economy.

Climate Change Impacts

The expected impacts of climate change on outdoor recreation and tourism in Pennsylvania (Shortle et al. 2015) include:

- Longer outdoor recreation seasons and an overall increase in outdoor recreation participation.
- Potentially increased demand for water-based recreation due to higher summer temperatures.
- Increased participation in indoor recreation due to longer summer seasons and rising temperatures.
- Potentially increased participation in recreational fishing due to a longer season, offset by potential declines in fish populations due to reduced summer streamflow, reduced water quality, and increased potential for eutrophication.
- Increased costs and decreased profits for winter recreation. For example, ski resorts will experience shorter seasons, higher snowmaking costs, and lower profits.
- Increased adverse health effects associated with outdoor recreation such as from heat or ticks.

These changes could alter the nature of a major economic sector in Pennsylvania.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Outdoor Recreation and Tourism sector, the analysis team has identified one main strategy to reduce emission and adapt to climate impacts:

- ▶ Help the outdoor tourism industry manage shifting climate patterns.

The strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

This strategy does not include actions that the team quantitatively analyzed.

Help the Outdoor Tourism Industry Manage Shifting Climate Patterns

The outdoor tourism industry is an important pillar of the Pennsylvania economy that is expected to experience changes—both positive and negative—as a result of climate change. Providing assistance and support to the industry to understand and manage anticipated impacts will help the industry maximize the benefits and minimize the negative impacts of climate change.

Leadership Actions

State and local leaders can build strategic collaborative partnerships to engage citizens and communities in adapting and conserving special places within Pennsylvania in the face of climate change. For example, leaders can:

- ▶ Establish a formal climate change working group building on existing partnerships, comprised of commonwealth agencies, federal agencies, academic institutions, the business community, and environmental NGOs.
- ▶ Explore developing new collaboratives with surrounding states.
- ▶ In addition, state and local leaders can provide technical assistance, education, and other resources to help the private sector respond to climate changes. For example, leaders can:
 - Create a business ombudsman or technical assistance center for affected recreational industries and establish a source of grant funding or tax incentives to help industry and municipalities transition from winter to summer activities.
 - Educate facilities about diversification opportunities for more warm-weather or cold-weather activities (e.g., ski slopes can maintain mountain bike trails for warm weather) with consideration of environmental impacts.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of building networks and helping the outdoor tourism industry adapt include:

- Reduced economic impacts to snow-based winter tourism due to increased temperatures.
- Reduced public health impacts due to changing climatic conditions.
- Higher economic activity in locations that can capitalize on more favorable conditions for outdoor recreation or a longer outdoor recreation season.

Environmental Benefits & Costs

Helping outdoor tourism providers plan for shifting climate patterns and manage changes will reduce the burden placed on natural resources environmental services. Working with industry can provide additional opportunities for conservation. For example, a ski resort adapting to shifting patterns can reduce water consumption for manufactured snow and take advantage of off-season revenue opportunities. Additionally, using native plants in landscaping or golf courses will reduce the need for watering, thereby conserving water resources and protecting ecosystem health. Some of these solutions may also improve habitat quality.

Economic Benefits & Costs

This strategy is intended to support the outdoor recreation industry, which contributes \$29.1 billion to the state economy annually (Outdoor Industry Association 2017). Actions can help the industry maximize the benefits and minimize the negative impacts of climate change. For example, seasonal tourist destinations could increase their revenue by attracting year-round or multi-seasonal tourists.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Revenue from outdoor recreation, winter and summer
- Participation rates in outdoor recreation, by season
- Parks and recreation facilities with water conservation mechanisms
- Snow produced for recreation
- Number of facilities reached through education programs
- Number of collaborative programs with other states

What You Can Do to Help the Outdoor Tourism Industry Manage Shifting Climate Patterns

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Participate in public participation processes related to helping the outdoor recreation industry adapt to climate change.
- ▶ Use native plants and landscaping techniques to decrease water consumption, lessen impacts on groundwater and nearby streams, and decrease fertilizer use and carbon emissions from lawn maintenance.

What Businesses Can Do to What You Can Do to Help the Outdoor Tourism Industry Manage Shifting Climate Patterns

Outdoor activity providers can support this strategy by taking the following actions:

- ▶ Use native plants and landscaping techniques to decrease water consumption, lessen impacts on groundwater and nearby streams, and decrease fertilizer use and carbon emissions from lawn maintenance.
- ▶ Adapt golf course management towards increased water conservation and use of more native plants to decrease water consumption and lessen impacts on groundwater and nearby streams.
- ▶ Augment fishing and boating access, adapt for longer seasons, and provide more dock slip space.
- ▶ Manage water on-site at all parks and recreational centers using green infrastructure and conservation mechanisms.

Pennsylvania **ski resorts** can play a role by taking the following actions:

- ▶ Promote and market summer activities at ski resorts.
- ▶ Raise awareness for how citizens and visitors can exploit larger, infrequent snowfalls, such as through snow tubing, cross-country skiing, snowshoeing, and snowmobiling.

- ▶ Strategically plant and retain trees to capture moving snow and to shade ski slopes to reduce snowmelt, thereby reducing snowmaking needs.
- ▶ Retain snow by using snow breaks and fences, as well as improve snowmaking capabilities.
- ▶ Use more efficient equipment to reduce revenue losses and strain on energy and water resources.

Waste Management

Waste consists of any unwanted or unusable material that is discarded. It can be divided into several main categories such as municipal, industrial, and hazardous waste. Waste management refers to the collection, transportation, treatment, and disposal of these waste materials.

GHG emissions in the waste management sector come from landfill gas, solid waste combustion, and wastewater treatment, as well as from waste transportation. Landfill gas is generated by the decomposition of solid waste within a landfill. The waste that is instead combusted in waste-to-energy plants avoids the production of methane in a landfill but results in the release of carbon dioxide.

Currently, Pennsylvania operates 43 municipal waste landfills, 3 construction and demolition waste landfills, 6 resource recovery facilities using waste-to-energy combustion, 95 material recovery facilities, approximately 260 composting facilities, and 14 permitted digesters for manure and food waste (PA DEP 2015). The municipal waste industry in Pennsylvania collects, hauls, and disposes of 8.6 million tons of municipal solid waste annually (Econsult Solutions 2013).

Statewide recovery rate of recyclables from the waste stream is 35%. The amount of materials recycled has grown from 4.8 million tons in 2006 to 5.85 million tons in 2011, a 20% increase. Of this, 30% is exported as recycled commodities (Econsult Solutions 2013). Recent changes in China's plastic waste import policies may impact plastic recycling in the commonwealth as waste management companies adjust to lower commodity prices.

In addition to the income received from resource recovery, the waste sector can have positive economic impacts, such as generating about \$250 million in taxes and fees to state and local governments in addition to direct annual operating expenditures (Econsult Solutions 2013). Overall, the municipal waste industry in Pennsylvania has a total economic impact of more than \$4.2 billion a year and provides an array of job opportunities supporting more than 26,000 jobs (Econsult Solutions 2013).

Climate Change Impacts

The expected impacts of climate change on waste management in Pennsylvania (EPA 2017f) include:

- Larger quantities of waste resulting from natural disasters.
 - Difficulties in segregating disaster-related wastes for proper disposal.
 - Increased need for transportation of disaster-related wastes.
 - Insufficient waste management capacity to handle surges in these types of wastes.
- Direct impacts to waste management facilities.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Waste sector, DEP has identified one main strategy to reduce emissions and adapt to climate impacts:

▶ **Reduce waste sent to landfills, and expand beneficial use of waste**

The strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

The team did not qualitatively analyze actions included in this strategy.

Reduce Waste Sent to Landfill, and Expand Beneficial Use of Waste

As noted above, reducing the amount of waste sent to landfills, or beneficially using it (e.g., through recycling programs) can provide economic benefits for the commonwealth. Continuing to build on the efforts already in place to reduce and reuse waste is a necessary part of Pennsylvania's sustainable economy.

Leadership Actions

The Commonwealth of Pennsylvania plans to advance this strategy by pursuing a selection of the following policies, programs, and actions.

- ▶ Implement programs to encourage citizens and business to reduce waste (including food waste) and use recycling and composting programs through reduce, reuse, and recycle actions.
- ▶ Encourage the use of digesters for methane capture and recovery.
- ▶ Support solar projects on landfill land.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

Reducing waste sent to landfills and expanding beneficial use of waste sent to landfills can:

- Capture methane to use as an alternative energy source, which reduces stress and can increase reliability of the energy grid.
- Utilize surfaces on landfills for solar panels, which will offset energy used from traditional fuels and lower requirements for traditional power production.

Environmental Benefits & Costs

Reducing waste has several environmental benefits, including:

- Reduced GHG emissions, particularly methane from landfills, and overall lifecycle GHG emissions (e.g., for transporting waste to landfill sites).
- Reduced pollution through reuse/recycle.
- Reduced environmental degradation caused by landfills.
- Using recycled products requires less energy use than manufacturing using raw materials, resulting in less GHG emissions and air pollutants.

- Recycling paper products results in the need for fewer trees to be cut down, offering more carbon sequestration potential.

Additionally, landfill gas offers an additional alternative energy resource, which offers environmental benefits as described in the Increase Production and Use of Alternative Fuels Section of this Plan.

Economic Benefits & Costs

As indicated in the beginning of this Sector discuss, reducing and reusing waste offers economic benefits and costs for Pennsylvania, such as:

- Revenue streams and taxable activity from use of recycled materials or gas for energy.
- Personal income savings from only buying what you need and repairing as opposed to buying new (which is often cheaper).
- Job creation to handle and use recycled materials.

A recent EPA study, the *Recycling Economic Information (REI) Report*, indicates that in 2007, the United States recycling industry resulted in 757,000 jobs (1.57 jobs for every 1,000 tons of materials recycled), \$36.6 billion in wages; and \$6.7 billion in tax revenues (EPA 2016d).

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Number of landfill gas to energy and waste to energy projects
- Quantity of recycled materials in Pennsylvania
- Number of illegal dump sites
- Number of companies/jobs in the recycling/waste minimization sector
- Number of alternative-fueled trash trucks
- Gallons of diesel used to collect waste

What You Can Do to Reduce Waste Sent to Landfills and Expand Beneficial Use of Waste

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Reduce personal production of waste through informed personal consumption decisions.
- ▶ Reuse or repair products to minimize waste; avoid purchasing single-use products.
- ▶ Recycle all recyclable waste via curbside pick-up or community recycling centers.
- ▶ Resell or donate items that are still in good condition but are no longer needed.
- ▶ Buy used items, goods made from recycled materials, and durable goods.
- ▶ Participate in community composting programs.
- ▶ Support solar energy and methane gas-to-energy projects at landfills.
- ▶ Do not dump illegally or burn waste.

What Businesses Can Do to Reduce Waste Sent to Landfills and Expand Beneficial Use of Waste

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Reduce waste used in business operations, such as reducing packing materials or transitioning from single-use materials to recyclable materials.
- ▶ Recycle all recyclable waste materials.
- ▶ Introduce an office recycling program.
- ▶ Offer repair services of consumer products.
- ▶ Implement Environmental Management System that includes a waste reduction component, such as ISO14000
- ▶ Offer refurbished goods to customers at discounted prices.
- ▶ Analyze collection routes to reduce miles traveled and switch to alternative-fueled collection vehicles
- ▶ Use LFG for transportation and electricity generation or straight-piping to nearby industries.

Water Resources

Pennsylvania's surface water resources comprise nearly 2.5 trillion gallons of water with around 86,000 miles of rivers and streams that flow through the state, more than 4,000 lakes, reservoirs and ponds, and 120 miles of coastal waters (Penn State Agriculture and Environment Center 2017). Thirty times more water lies below the surface in groundwater aquifers that rely on 40-plus inches of precipitation a year to be replenished (Abdalla and Blunk 2007). The commonwealth depends on these resources for drinking water, water for agriculture and industry, habitat for aquatic species, and recreational activities.

Pennsylvania's water resources are already subject to high demand from several user groups, such as thermoelectric power generators (70%), industrial and mining operations (13.6%), domestic and commercial customers (16%), and agricultural users (0.4%). The total withdrawal of surface and ground water in the state is around 10 billion gallons per day (Abdalla and Blunk 2007).

Many users in Pennsylvania, especially farmers and rural residents, depend on private wells for their water supply; for them, groundwater is the only option. More than one million private wells serve about 3.5 million people, about one quarter of the total population, and about 20,000 new wells are drilled each year in Pennsylvania (Swistock et al. 2009). Only Michigan has a larger population served by private wells. Studies have documented various water contaminants in private water systems, finding that 15-50 percent of private water systems fail at least one safe drinking water standard (Swistock et al. 2009). Contamination of groundwater wells can occur from failing septic systems, manure and fertilizer applications, oil and natural gas drilling, mining, or other land uses.

Climate Change Impacts

The expected impacts of climate change on water resources in Pennsylvania (Shortle et al. 2015) include:

- Increased saltwater intrusion due to rising sea levels, especially in the Delaware Estuary. This can alter habitats.
- Decreased water quality due to runoff from extreme precipitation events, urbanization, and increasing water temperature. This could result in higher water treatment costs.

- Reduced groundwater aquifer recharge, when precipitations occurs in more extreme events and a greater fraction runs off rather than infiltrating.
- Increased flood potential due to more extreme precipitation, and associated infrastructure impacts.
- Amplified risks to water resources associated with decreased snowpack, decreased water quality, urban flooding, and irrigation. This could result in higher water supply costs.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Water sector, DEP has identified two main strategies to reduce emissions and adapt to climate impacts:

- ▶ **Use stormwater best management practices**
- ▶ **Promote integrated water resources management and water conservation**

Each strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

These Water strategies do not include actions that the team quantitatively analyzed.

Use Stormwater Best Management Practices

With changing precipitation patterns, stormwater management is critical for reducing the likelihood and impact of floods.

Leadership Actions

State and local leadership can develop and enforce new policy requirements, revise existing policies, and provide incentives for improving stormwater management. These actions can include the following:

- ▶ Require mandatory compliance with PA DEP's *Stormwater Best Management Practices Manual*.
- ▶ Provide incentives for the installation and use of gray water and rainwater harvesting and consider existing international guidelines for increased reclaimed, recycled, and gray water use for non-potable applications (e.g., irrigation, toilet flushing).
- ▶ Revise stormwater regulations to accommodate increases in precipitation and run-off.
- ▶ Promote green infrastructure by instituting laws, regulations, and local ordinances requiring implementation of green infrastructure with new development or substantial redevelopment and revising the State Revolving Fund (SRF) state ranking criteria to require a thorough analysis and maximization of the use of green infrastructure, where appropriate.
- ▶ Reduce impervious surfaces by requiring installation of permeable surfaces, buffers, and vegetated filters for all transportation-related projects; developing and enforcing a stormwater retention standard for new development and redevelopment; and/or implementing a fee for impervious surfaces.

- ▶ Promote, preserve, and manage natural features that treat, infiltrate, and hold runoff, such as riparian zones, estuaries, wetlands, floodplains, forests, and related landscapes.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of improved stormwater management include:

- Reduced flooding due to extreme precipitation events.
- Reduced heat island effect—which are exacerbated by higher temperatures—and associated health and air quality impacts.
- Protection of groundwater resources that are being depleted, particularly due to seasonal precipitation changes and reduced infiltration due to development.
- Reduced contamination of runoff, protecting the health of citizens and wildlife.

Environmental Benefits & Costs

In addition to the environmental benefits identified above, stormwater best management practices can capture carbon dioxide from the air and improve air quality through the use of natural infrastructure. Natural infrastructure solutions are low-impact, often no-regrets options that mimic natural systems. Primarily, natural infrastructure can improve water quality, mitigate flooding, and build habitat.

Additionally, natural infrastructure provides emission reduction benefits from reduced carbon dioxide emissions, carbon sequestration, reductions in water treatment and pumping energy requirements, and reductions in energy use due to cooling qualities of green roofs.

Economic Benefits & Costs

Additional modeling would be needed to quantify economic benefits, but improved stormwater management reduces the frequency and severity of urban flooding, which can result in significant economic benefits. Studies have shown that natural infrastructure helps avoid capital costs for gray infrastructure, with a lower marginal cost (EPA 2014). Also, improved stormwater management will reduce the amount of runoff diverted to wastewater treatment plants, thereby reducing treatment costs.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Incentives provided for gray water and rainwater harvesting
- Investment in green infrastructure
- Amount of water reclaimed, recycled, and captured
- Water balance
- Area of impervious vs. permeable surface
- Total annual runoff
- Forest area replanted in watershed area
- Water quality (pH, phosphorous, nitrates, turbidity, conductivity, fecal coliform)
- Acres of open space created/amount of wildlife habitat created
- Gallons of stormwater entering combined sewer systems

- Value of reduced flood damage

What You Can Do to Promote Stormwater Best Management Practices

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Reduce impervious surfaces on your property.
- ▶ Install a rain barrel, rain garden, or other means to capture and use rainwater from roofs, driveways, and sidewalks.
- ▶ Plant vegetation on your property to slow and absorb runoff.

What Businesses Can Do to Promote Stormwater Best Management Practices

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Maximize retention and ground infiltration of stormwater on-site at existing developed sites.
- ▶ Use bushes, mulch, rain gardens, permeable hardscape, or curb cuts in parking lot islands or in the areas between sidewalks and the roadway.
- ▶ Establish urban forests or plant street trees to reduce stormwater volume and pollutants.
- ▶ Develop erosion control and stormwater management plans for all construction sites.

Promote Integrated Water Resources Management and Water Conservation

Integrated water resources management involves coordinated development and management of water, land, and other resources to maximize economic and social wellbeing without compromising the environment. Pennsylvania can take a holistic approach to protecting water resources from the impacts of climate change, through planning and practices such as managing water quality, quantity, and use.

Leadership Actions

To implement informed water management policies and practices, leaders can:

- ▶ Support additional research on climate change impacts on water supply and basin hydrology, including with hydrologic models to project changes in surface runoff and groundwater.
- ▶ Assess the impact of climate change on critical water supply and wastewater infrastructure, and encourage the development of facility-specific adaptation plans.
- ▶ Include climate change projections and modeling results in water supply and water quality planning to enhance reliability, improve quality, and improve instream flows and fish passage.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of integrated water resource management include:

- Ensured long-term reliability of water supplies for drinking, agriculture, and other uses in the commonwealth.

- Improved water quality that could be degraded due to runoff from extreme precipitation events, resulting in reduced health risks of water-borne diseases and reduced environmental contamination.

Environmental Benefits & Costs

The climate resilience benefits associated with this strategy are also environmental benefits. Additionally, better water conservation practices often go hand-in-hand with energy conservation, sometimes leading to reduced environmental impacts from reduced energy usage.

Economic Benefits & Costs

Water conservation and efficiency is inexpensive compared to developing new water supplies, and treatment and distribution operations. For example, using a metering program allowed a utility in Gallitzin, Pennsylvania to identify leaks and initiate a leak repair program. Within four years of implementing the program, the city was saving \$5,000 annually in chemical costs and \$20,000 on power costs, which was significant for a system with approximately 1,000 connections (EPA 2002). Additionally, demand management can lower the operating and maintenance costs such as pumping and chemical costs for utilities (EPA 2016a).

This strategy will also reduce residential and commercial water bills. Just by fixing leaks, homeowners could save 10 percent of their water bill (EPA 2018b).

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Average/median gross water demand
- Average residential water demand
- Percentage of buildings with water meters
- Non-residential average water use
- Infrastructure Leakage Index rating
- Percentage water loss
- Seasonal water use
- Water savings from measure implementation
- Percentage per capita water demand reduction achieved
- Cost of conservation programs/person served
- Non-Revenue Water

What You Can Do to Promote Integrated Water Resources Management and Water Conservation

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Reduce household indoor water use by using water-efficient showerheads, faucets, and appliances (see EPA's WaterSense program for more information, available at <https://www.epa.gov/watersense>).
- ▶ Reduce outdoor water use, including by:
 - Plant native plants and drought-tolerant plants that don't require watering

- Installing drip irrigation systems.
- Setting sprinklers to keep the water on the landscape and off the pavement.
- Managing sprinkler schedules to save water and money, updating schedules to align with the seasons.
- Avoiding watering in the middle of the day when the sun will evaporate much of the water.
- Contacting your local water utility to find out how much and when you should be watering outdoor plants.
- ▶ Set your pool water level several inches below the edge of the pool and plug the overflow line when the pool is in use or when adding water to avoid water loss from splashing.
- ▶ Use rain barrels or cisterns to harvest rainwater for irrigation and other outdoor water uses.
- ▶ Reuse household wastewater, called gray water, from bathroom sinks, showers, bathtubs, and clothes washers for landscape irrigation. Implement gray water reuse systems to divert water to a storage tank for outdoor watering use.
- ▶ Capture runoff on your property with rain gardens.

What Businesses Can Do to Promote Integrated Water Resources Management and Water Conservation

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Install water-efficient technologies and better water-saving practices, such as toilets, faucets, laundry equipment, commercial ice machines, combination ovens, steam cookers, steam kettles, wok stoves, dipper wells, pre-rinse spray valves, food disposals, commercial dishwashers, and wash-down sprayers.
- ▶ Use non-potable water sources or reclaimed water for non-potable uses (e.g., industrial cooling, landscape irrigation) with adequate public health safeguards.
- ▶ Increase water recycling in industrial processes.
- ▶ Install smart water meters that allow different rates to be charged when overall system demand is higher.
- ▶ Monitor water use and educate facility staff, building occupants, employees, and visitors about water use and water management.
- ▶ Ensure that your facilities have leak detection and repairs performed regularly.
- ▶ Use soil moisture sensors that water plants based on their needs by measuring the amount of moisture in the soil and tailoring the irrigation schedule accordingly.
- ▶ Use rainfall shutoff devices and rain sensors to decrease water waste by turning off the sprinklers in rainy weather.
- ▶ Use natural or constructed means (e.g., green roofs, rain barrels, cisterns) to harvest rainwater.

In addition, **water utilities** can play a role by taking the following actions:

- ▶ Assess the vulnerability of water systems (e.g., pipes, culverts, treatment plants) to extreme events and more intense precipitation.
- ▶ Price water to reflect its true cost.
- ▶ Consider rate structures based on water usage to encourage conservation.

Human Health

Climate change can directly and indirectly affect vital determinants of health such as clean air, safe drinking water, sufficient food as well as secure shelter. This can include impacts from increased extreme weather events such as heat, droughts, and floods, wildfire, decreased air quality, and illnesses transmitted by food, water, and disease carriers such as mosquitoes (National Climate Assessment 2014). Some existing health threats will intensify, and new health threats will emerge.

Climate change is expected to cause around 250,000 additional deaths per year globally between 2030 and 2050 (WHO 2018). This includes deaths from malnutrition, malaria, diarrhea, and heat stress. There are additional direct damage costs to health from climate change, which is estimated to be around \$2-4 billion per year by 2030 (WHO 2018). Taking actions such as preparedness and prevention, can help protect people from some of the impacts of climate change.

Climate Change Impacts

The expected impacts of climate change on human health in Pennsylvania (Shortle et al. 2015) include:

- Increased heat-related illness and mortality due to higher temperatures, particularly during intense heat waves affecting older populations and those with existing conditions such as asthma and heart disease.
- Increased distribution and prevalence of Lyme Disease, West Nile Virus, and Zika Virus due to changing distribution of pests due to changing temperature and precipitation. Uncertain impacts on vectors and tick-borne diseases and life cycles are factors.
- Increased respiratory and heart disease rates due to declining air quality.
- Increased health risks due to contact with polluted water, since higher temperatures, algal blooms, and other factors could reduce water quality in streams and lakes.
- Increased risk of injury and death due to extreme weather events (e.g., non-tropical extreme rainfall, flooding, etc.) exacerbated with climate change.
- Increased allergens due to changing temperatures and seasonality.

Opportunities to Reduce Emissions and Adapt to Climate Change

In the Human Health sector, DEP has identified two main strategies to reduce emission and adapt to climate impacts:

- ▶ **Improve reliability and accessibility of public information about climate-related health risks**

► **Bolster emergency preparedness and response**

Each strategy description below includes leadership, citizen, and business actions that support the strategy; a summary of strategy benefits and costs; and key performance indicators.

The team did not quantitatively analyze these actions.

Improve Reliability and Accessibility of Public Information about Climate-related Health Risks

Research is limited on exactly how climate change may affect human health in Pennsylvania. Additional information is needed to better understand climate-related health trends, and ensure that the public has the information it needs to take necessary precautions.

Leadership Actions

It is important to improve the understanding of climate impacts to health in Pennsylvania through monitoring and data collection. For example, leaders can:

- Support efforts to develop new surveillance databases and increase data quality and availability, especially for climate-sensitive morbidity.
- Update Community Health Assessments to include climate change and health tracking metrics.

Working with medical professionals will help contextualize these issues, and determine and communicate the risks facing public health. Leaders can:

- Increase interdisciplinary collaboration among medical and health professionals and other environmental and social scientists to better understand the linkage between climate change and disease.
- Help local health departments assess their capacity to respond to health threats and to integrate climate preparedness into their hazard response plans and daily operations.
- Enhance education of health-care professionals to understand the health risks of climate change, including diagnosis and treatment for health outcomes that may become more prevalent.

Additionally, state and local leaders can inform the public about the potential health risks due to climate change. Leaders can develop a web-based resource hub to provide information and technical resources, incorporate climate change and public health messages into existing education and outreach efforts, and expand public outreach and education efforts about climate-related health risks.

Climate impacts to health are likely to have disproportionate impacts on vulnerable communities. State and local governments must recognize these impacts and act to reduce these impacts. For example, leaders can:

- Work locally with vulnerable groups to assist at-risk communities with the development, adoption, practice, and evaluation of response, evacuation, and recovery plans.

- ▶ Regularly map locations of vulnerable populations and use the information to focus interventions and outreach.
- ▶ Review occupational health and safety standards to identify occupations at significant risk due to climate change, and revise as necessary.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of improved reliability and accessibility of public information about climate-related health risks include:

- Reduced illness and mortality associated with heat, vector-borne diseases, and water-borne diseases
- Increased capacity to manage the incidence of vector-borne disease
- Protection of vulnerable communities from disproportionate climate impacts

Economic Benefits & Costs

Additional modeling would be necessary to quantify benefits, but reductions in morbidity and mortality provide a significant economic benefit. In addition, improved data reliability and awareness of climate-related health risks could increase the quality or efficiency of health care services and reduce costs in the healthcare sector. For example, it could increase the number of patients able to seek early treatment, or improve physicians' ability to diagnose and care for patients with climate-related ailments.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Heat-stress related emergency department visits
- Hospitalizations due to climate-related impacts
- Heat-related mortality
- Visits to web-based resources
- Participation in public outreach and education events
- Number of community cooling spaces
- Cases of Lyme Disease and other vector-borne illnesses
- Injuries and deaths from extreme weather events

What You Can Do to Improve Reliability and Accessibility of Public Information about Climate-related Health Risks

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Know the symptoms of heat-related illness and take care to stay cool on hot days – wear loose-fitting, light-colored clothing, minimize direct exposure to the sun, and stay hydrated.
- ▶ Check the local news for health and safety updates. Subscribe to local heat alert systems, such as AlertPA.
- ▶ Use air conditioning or spend time in air-conditioned places, such as cooling centers, malls, and libraries when outdoor temperatures are extremely high.

- ▶ Use electric fans to provide comfort when the temperature is below 95 degrees F. Fans can improve evaporation to help heat leave the body. However, above 95 degrees F, fans are insufficient.
- ▶ Get involved in workplace, schools, and organizations to ensure that committees are in place to develop a heat response plan and take proper measures for those participating in outdoor work or activities.
- ▶ Shorten work periods and increase rest periods as temperature and humidity rises. Choose shaded rest areas (find more details on heat-related adaptation strategies for workers from the Occupational Safety and Health Administration (OSHA) available at: https://www.osha.gov/SLTC/heatillness/heat_index/work_rest_schedules.html).
- ▶ Prevent mosquito bites to protect yourself from mosquito-borne diseases, such as Zika, West Nile Virus, malaria, etc. (see CDC Guidance available at <https://www.cdc.gov/zika/prevention/prevent-mosquito-bites.html>).
- ▶ Prevent tick bites to protect yourself from tick-borne illnesses, which might become more prevalent due to climate change (see CDC Guidance available at <https://www.cdc.gov/zika/prevention/prevent-mosquito-bites.html>).

What Businesses Can Do to Improve Reliability and Accessibility of Public Information about Climate-related Health Risks

The Pennsylvania **healthcare industry** can support this strategy by taking the following actions:

- ▶ Expand analytical laboratory capacity to support essential environmental monitoring, disease surveillance, and outbreak investigation and control activities.
- ▶ Enhance prevention (e.g., vaccination) and treatment capabilities.
- ▶ Assign more medical staff at places where people congregate and recreate in hot weather and may suffer heat stress.

Bolster Emergency Preparedness and Response

Climate change is expected to increase the frequency and intensity of extreme events, including floods, extreme heat, and disease outbreaks. Pennsylvania can reduce the impacts of these events by continuously improving its preparedness for emergency situations and developing thorough response plans that take climate impacts into account.

Leadership Actions

Pennsylvania leaders can prepare for emergency situations by incorporating climate change considerations into planning. For example, leaders can:

- ▶ Review existing emergency response, preparedness, evacuation, and management plans to ensure that events that will become more likely with climate change are adequately addressed; to address the most updated estimates of likely levels of precipitation, flooding, and extreme storm events; and to include coordination and communication among critical stakeholders, such

as community organizations, local businesses, local health departments, hospitals, and other health-care delivery facilities, utilities, and local government.

- ▶ Expand the scope of the state hazard mitigation plan to factor in expected vulnerabilities from climate change impacts.

Additionally, state and local leaders can prepare communities to deal with disasters by evaluating current practice, establishing early warning systems, improving response capability, and conducting outreach. Specific actions include the following:

- ▶ Evaluate and improve the adequacy, effectiveness, accuracy, and technological capabilities of forecasting, early-warning, and emergency-preparedness systems.
- ▶ Foster collaboration between communication service providers and agencies to provide reliable communications in times of power outages and emergencies.
- ▶ Establish heat advisories, increase availability of cooling stations, invest in efficient HVAC systems at targeted Recreation Centers which are provided with renewable energy backup systems, and implement other preventive measures to reduce the impact of extreme heat events.
- ▶ Evaluate the capacity of existing disease prevention programs, enhance surveillance of disease and disease-causing agents, and enhance the capacity of public health programs that control disease-causing agents.
- ▶ Restructure disaster-recovery policies to ensure that redevelopment efforts strive to reduce long-term risk.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of bolstering emergency response include:

- Improved capacity to respond to emergency situations.
- Reduce injury and mortality risk due to extreme weather events.
- Reduced heat-related morbidity and mortality.
- Reduced impacts of vector-borne diseases which are expected to become more commonplace due to climate change.

Environmental Benefits & Costs

Emergency preparedness and response can help protect the environment from negative impacts, including pollution. During extreme events, wastewater treatment plants, chemical plants, and oil and natural gas facilities may experience flooding. If not prepared, these floodwaters can produce leaks and flows of toxic materials into waterways, presenting a health risk for ecosystems and humans. In the past, power outages due to extreme events have contributed to the discharge of raw sewage, which often contains disease-causing organisms, heavy metals, and excessive nutrients (EPA 2018a, NEIWPCC 2016). Wastewater is hazardous to the environment, particularly water quality and soil contamination (NH DES

2015). Oil and natural gas operations, both extraction and processing, could be impacted by extreme weather events and preparedness can help mitigate negative environmental impacts of these events.

Economic Benefits & Costs

A National Institute of Building Sciences study of federally funded disaster mitigation grants found that every dollar invested in disaster mitigation saves the country six dollars in future disaster costs (National Institute of Building Sciences 2017). Between 2012 and 2016, Pennsylvania spent \$17,462,000 on natural disaster programs (PEW 2018). Due to storms and flooding in 2016, Pennsylvania experienced damages to roads and bridges equivalent to \$33,202,883 and received a grant for \$27,323,547 from the Federal Emergency Management Agency (FEMA) for recovery efforts (FEMA 2016). Bolstering disaster preparedness and response will help avoid costs due to damaged infrastructure, loss of life, and human injuries.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Number/percentage of people signed up for emergency alerts
- Number of people reached through emergency-related communications and stakeholder outreach
- Facilities with least impact backup power generation, and if needed, how many of these systems worked
- Drills and simulation exercises held to test emergency protocol
- Inventory system for essential supplies and equipment
- Time required for emergency response

What You Can Do to Bolster Emergency Preparedness and Response

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Subscribe to emergency text alert services from government officials.
- ▶ Ensure a supply of water in the house, in case of emergency. FEMA recommends keeping a three-day supply of water available in case clean water is not available.
- ▶ Keep extra batteries and a car charger for your mobile devices. This will allow you to stay up-to-date on news reports and use your phone to stay in touch with friends and family. If you use your car to charge your devices, make sure it's in a well-ventilated place.
- ▶ Keep a physical list of emergency, family, and work contacts. In case your phone battery dies, you could find a landline to check on friends and loved ones.
- ▶ Know the location of flashlights and a radio. Make sure these things are easy to access in case of power loss, and that you have extra batteries to keep them running.
- ▶ During extreme events, conserve your cell phone battery. Reduce the brightness of your screen, place your phone in airplane mode, and close unused apps that draw power.
- ▶ Prevent overloaded circuits. Switch off all unnecessary lights and appliances to prevent overloaded circuits when power is restored.

- ▶ Keep your car tank at least half full. Gas stations rely on electricity to power their pumps.

What Businesses Can Do to Bolster Emergency Preparedness and Response

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Ensure that your business has an emergency response plan.
- ▶ Prepare employees to evacuate and respond in the case of an emergency.
- ▶ Install least impact backup power generation capacity to maintain critical operations.

Cross-Cutting Opportunities to Reduce Emissions and Adapt to Climate Change

Pennsylvania has several opportunities to adapt to climate change that are not limited to a single sector. These cross-cutting opportunities span all activities in the commonwealth, and fall into two high-level strategies:

- ▶ **Lead by example in commonwealth and local government practices and assets**
- ▶ **Incorporate historical and projected climate conditions into siting and design decisions for long-term infrastructure**

Lead by Example in Commonwealth and Local Government Practices and Assets

The commonwealth and local governments can take a leading role in developing a more sustainable and resilient Pennsylvania by taking action and demonstrating best practices in government operations and projects.

Leadership Actions

Below are examples of the ways in which state and local governments can demonstrate the importance and feasibility of climate adaptation and reducing emissions, showing that they are committed to climate action and setting an example for the rest of the commonwealth.

- ▶ Establish a strategic energy management plan for public facilities that includes benchmarking and specific energy, water, and transportation emissions reductions targets and goals.
- ▶ Maximize onsite renewable energy generation and purchase additional renewable power through renewable energy certificates (RECs) or direct purchasing.
- ▶ Implement a state-wide benchmarking strategy and platform (such as EnergyStar's Portfolio Manager) for energy and water consumption. Engage the PUC and PA's gas, electric and water utilities to automate billing and utility data input into the selected benchmarking platform, and encourage others (businesses, industry, schools, and municipalities) to implement similar programs to establish their baseline consumption patterns.

- ▶ Establish a state-wide Governor’s Sustainability Council and/or interagency workgroup dedicated to the implementation of leadership actions listed in the CAP, as well as actions in department-level plans.
- ▶ Incorporate climate change considerations into decision making processes and criteria. For example, add climate change resilience as a prioritization factor for new capital projects.
- ▶ Consider ENERGY STAR certification for existing buildings, and Architecture 2030, LEED, net-zero designs, and climate resilience design guidelines to drive higher performance in new construction and major renovation projects in public buildings.
- ▶ Inventory and benchmark state and local government buildings’ energy use patterns, using tools such as Portfolio Manager and supporting analytics, to identify savings opportunities.
- ▶ Implement emissions reduction and climate resilience activities in public facilities, including distributed generation, backup power generation, water efficiency, climate resilient vegetation, and proper tree maintenance.
- ▶ Require energy efficient and alternative fuels use in fleet vehicles and equipment.
- ▶ Conduct more training, education, and outreach on energy efficiency, clean energy, climate resilience, and related skills for facility managers and the facility management workforce.
- ▶ Ensure that key government operations plan for and provide least impact energy backups to protect important security features in the case of more frequent or prolonged blackouts. For example, the Pennsylvania Army National Guard is building a solar farm on its largest military base to have its own backup power.
- ▶ Highlight climate action already occurring in Pennsylvania and learn from best practice examples within and outside the commonwealth.

Strategy Benefits and Costs

Resilience Impacts

Benefits of leading by example in adaptation include:

- Increased resilience of public services to floods, power outages, heat waves, droughts, and other disruptive events.
- Reduced overall costs to government in the form of infrastructure maintenance, operations, energy costs, and emergency response.
- Expanded capacity of Pennsylvania citizens and businesses to increase their own resilience to such events.

Environmental Benefits & Costs

This strategy incorporates many of the aspects of other strategies identified in this report; therefore, it offers many of the same environmental benefits such as reduced GHG emissions, reduced air pollution, and reduced health risks.

Economic Benefits & Costs

This strategy incorporates many of the aspects of other strategies identified in this report; therefore, it offers many of the same economic benefits such as reduced energy expenditures.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Adaptation and mitigation strategies implemented by the government
- Government operation GHG emissions
- LEED, ENERGY STAR, and other certified buildings owned or leased by the government
- Share of the government fleet that is alternative fuel or zero emission vehicles
- Reduction in VMT by government fleets
- Number of government owned or leased buildings that are energy audited and/or benchmarked
- Energy efficiency guidelines met by new construction, or number of net zero energy buildings
- Climate resilience design guidelines met by new infrastructure projects
- Renewable energy generation capacity implemented at public facilities
- Water and energy consumption reduced through conservation and efficiency
- Audience reached with highlights of Pennsylvania adaptation efforts

Incorporate Historical and Projected Climate Conditions into Siting and Design Decisions for Long-term Infrastructure

When new infrastructure is built, the choice of location and design have large implications for how the system will hold up under future conditions. Given the long lifespans of some infrastructure, including buildings, bridges, roads, and power plants, it is important to consider the climatic conditions throughout the life of the project and how to ensure that the asset will remain functional and protected.

Leadership Actions

The commonwealth can use funding and regulatory tools to ensure that long-term infrastructure is built in locations that will be stable for the long-term and incorporate planning and design elements that will make them more resilient to climate impacts. For example, leaders can:

- ▶ Establish statewide design guidelines for incorporating climate change, similar to New York City's design guidelines (NYC Mayor's Office of Recovery and Resiliency 2018).
- ▶ Integrate climate change considerations into agency-level capital planning processes and seek to ensure that state investments in infrastructure and development projects (direct or indirect) reflect potential climate change impacts, especially future risk projections. For example, require project sponsors to self-identify vulnerabilities to climate change and incorporate climate change impacts into the return on investment calculations.
- ▶ Implement new or modified policies (e.g., zoning regulations, tax incentives, and rolling easements) that encourage appropriate land use and reduce repetitive losses.

- ▶ Develop or update floodplain mapping using the best available science and accounting for the impacts of climate change.
- ▶ Adopt insurance mechanisms and other financial instruments, such as catastrophe bonds, to protect against financial losses associated with infrastructure losses.
- ▶ Encourage owners and operators of critical energy infrastructure to evaluate vulnerability to the impacts of climate change, including the risk of damage; the potential for disruptions and outages from flooding, sea level rise, extreme heat, drought, erosion and other extreme weather events; and the impacts of new climate change weather data on energy demand.

Strategy Benefits and Costs

Climate Resilience Benefits & Costs

The climate resilience benefits of incorporating climate considerations into siting, design, and system planning include:

- Reduced exposure of infrastructure to extreme events and flooding, which reduces costs associated with recovery from repetitive losses and ensures continued infrastructure services (e.g., energy, water, and transportation) even during climate extremes.
- Ensured reliability of critical systems (e.g., transportation, energy, water, and communications) into the future.
- Ensured continuity of operations for the numerous businesses, individuals, and activities dependent on critical services (e.g., transportation networks, electric power).
- Reduced costs to energy utilities and consumers.

Environmental Benefits & Costs

Incorporating climate projections into infrastructure design can help reduce the impact of flooding and damage related to severe weather events. Landslides, mudslides, erosion, and sedimentation, to name a few, can result from extreme weather events that lead to damages to roads, bridges, and other infrastructure. In the case of severe weather, infrastructure debris could become pollutants in the environment, such as bridge components washed downstream. Also, there is an environmental cost associated with rebuilding. Extreme events could also contribute to destruction of wildlife habitat and species kills, such as stocked fish being swept downstream in a storm.

Economic Benefits & Costs

Overall economic benefits and costs of this strategy are unknown. Some changes to infrastructure design to accommodate expected climate change could increase the upfront costs of capital projects. However, ignoring the climate changes could potentially result in much higher costs, in the form of higher operating costs, business disruptions, or infrastructure damage. Individual projects should consider the future frequency of extreme events in their estimates of the return on investment for that project.

Key Performance Indicators

Example indicators that Pennsylvania could use to measure progress toward this strategy include:

- Design standards incorporating climate projections

- Length of infrastructure service disruptions

What You Can Do to Incorporate Historical and Projected Climate Conditions into Siting and Design Decisions for Long-term Infrastructure

Pennsylvania citizens can support this strategy by taking the following actions:

- ▶ Understand risks to your property.
- ▶ Consider purchasing flood insurance, even if you are not required to do so.
- ▶ Encourage your state and local leaders to invest in climate-resilient public infrastructure.
- ▶ Encourage leaders to incorporate climate change into energy, transportation, and communications system planning.
- ▶ Participate in long-range planning processes with your local government or public utility commission.

What Businesses Can Do to Incorporate Historical and Projected Climate Conditions into Siting and Design Decisions for Long-term Infrastructure

Pennsylvania businesses can support this strategy by taking the following actions:

- ▶ Understand risks to your property.
- ▶ Ensure sufficient availability of least impact backup power at all critical sites.
- ▶ Conduct vulnerability assessments of potential and existing critical infrastructure at risk of climate impacts including higher temperatures, water scarcity, and sea level rise.
- ▶ Protect critical, vulnerable infrastructure as appropriate based on vulnerability assessments, and, when necessary, relocate.

Engineers and Architects can support this strategy by taking the following actions:

- ▶ Stay abreast of industry guidance on how to create climate-resilient infrastructure.
- ▶ Consider climate conditions over the lifetime of the asset when designing new infrastructure.
- ▶ Design buildings to be more flexible. For example, use modular buildings that can be moved, renovated, and deconstructed easily. Design buildings for passive survivability (without external power).

Utilities can support this strategy by taking the following actions:

- ▶ Develop and implement drought-resistant cooling technologies to reduce the curtailments drought could cause at nuclear, coal, and natural gas power plants, potentially affecting electric grid reliability.
- ▶ Explore opportunities to coordinate water treatment and energy generation. For instance, locating power plants next to wastewater treatment facilities could partly displace freshwater needs for cooling purposes.
- ▶ Develop operational contingency plans for critical infrastructure, including energy supply and distribution networks.
- ▶ Enhance the climate resilience of electric grid and communications infrastructure (e.g., towers, lines) in coastal and inland flood zones.

- ▶ Monitor and model temperature and precipitation patterns to understand how changing weather patterns will affect hydropower generation in both drought and flood situations. Monitor instream flows in basins with thermal and hydropower generation facilities.
- ▶ Seek to reduce water use in energy production by considering alternative technologies since peak water use in energy production often coincides with periods of high heat and low water availability.
- ▶ Review equipment specifications to ensure adequacy under future climate conditions.
- ▶ Replace outdated turbines and generators with more efficient equipment at hydropower facilities to generate more electricity per unit of water and generate more efficiently across a range of flow conditions.
- ▶ Alter the timing of hydropower generation to more closely mimic a river's natural ebb and flow.

Recommendations for Further Research

Many climate change-related topics are complex and evolving, requiring more in-depth analysis to inform further decision making.

Leadership Actions

The Commonwealth of Pennsylvania will need to further research several topics over time to inform decision making. For example, leaders can:

- ▶ Conduct a statewide comprehensive climate change risk assessment that builds off the current climate impacts assessment, but allows for prioritization across sectors, geographies, and strategies.
- ▶ Assess the potential impacts of policies and programs that make carbon dioxide and other GHGs as tradable commodities in more detail than the analysis underlying this report.
- ▶ Identify and evaluate specific policy options for maintaining and/or restoring nuclear electric power capacity.
- ▶ Study the potential impacts of the use of carbon capture, utilization, and sequestration on the commonwealth.

4 Benefits and Costs for Modeled Strategies and Actions

This section summarizes the benefits and costs of the 15 quantitatively analyzed actions within the seven quantified strategies. Notably, these actions represent only a subset of the potential actions under a subset of the identified strategies. In other words, the benefits and costs in this section do not comprehensively account for all the strategies and actions identified in this Plan due to resource and time constraints. If Pennsylvania pursues actions and strategies beyond those that were quantitatively assessed, there would be additional benefits and costs that are not quantified in this analysis from reducing GHG emissions and adapting to climate change. In addition, if the commonwealth pursues the quantified strategies and actions in a different way than the team's assumptions, the benefits and costs will differ from this analysis.

Figure 12 illustrates how each of the seven strategies, grouped by sector (Energy Consumption, Energy Production, and Agriculture) contributes to progress towards reaching the GHG reduction targets selected for modeling in this Plan.

- ▶ Total annual GHG reductions in 2025 resulting from the quantified strategies are **39,435,490 MTCO₂e**, which, when combined with the decreasing trend in annual BAU emissions, results in a 21 percent reduction from 2005 levels. This falls short of the target set forth for modeling purposes: a 26 percent reduction from 2005 GHG emission levels by 2025. In 2025 GHG reduction contributions from each sector are:
 - Energy Consumption-related annual GHG reductions are **6,889,187 MTCO₂e** (3% reduction from 2005 levels)
 - Energy Production-related annual GHG reductions are **31,391,440 MTCO₂e** (12% reduction in energy consumption emissions and 6% reduction in energy production emissions from 2005 levels)¹⁵
 - Agriculture-related annual GHG reductions are **208,331 MTCO₂e** (3% reduction from 2005 levels)¹⁶
- ▶ Total annual GHG reductions in 2050 resulting from the quantified strategies are **87,439,278 MTCO₂e**, which, when combined with the decreasing trend in annual BAU emissions, results in a

¹⁵ Emission reductions from strategies that affect the electricity generation fuel mix (e.g., utility scale renewable generation, nuclear generation, cap and trade) are accounted for in the energy consumption sector based on the reduction in the electricity consumption emission factor (i.e., a reduction of carbon intensity of the grid). Distributed renewable electricity generation is also accounted for as reductions to energy consumption emissions. Thus, emissions from these strategies are compared to the BAU emissions from energy consumption. Emissions reductions from coal mine methane capture and upstream oil and natural gas are accounted for in the energy production sector, so these are compared to the BAU emissions from energy production.

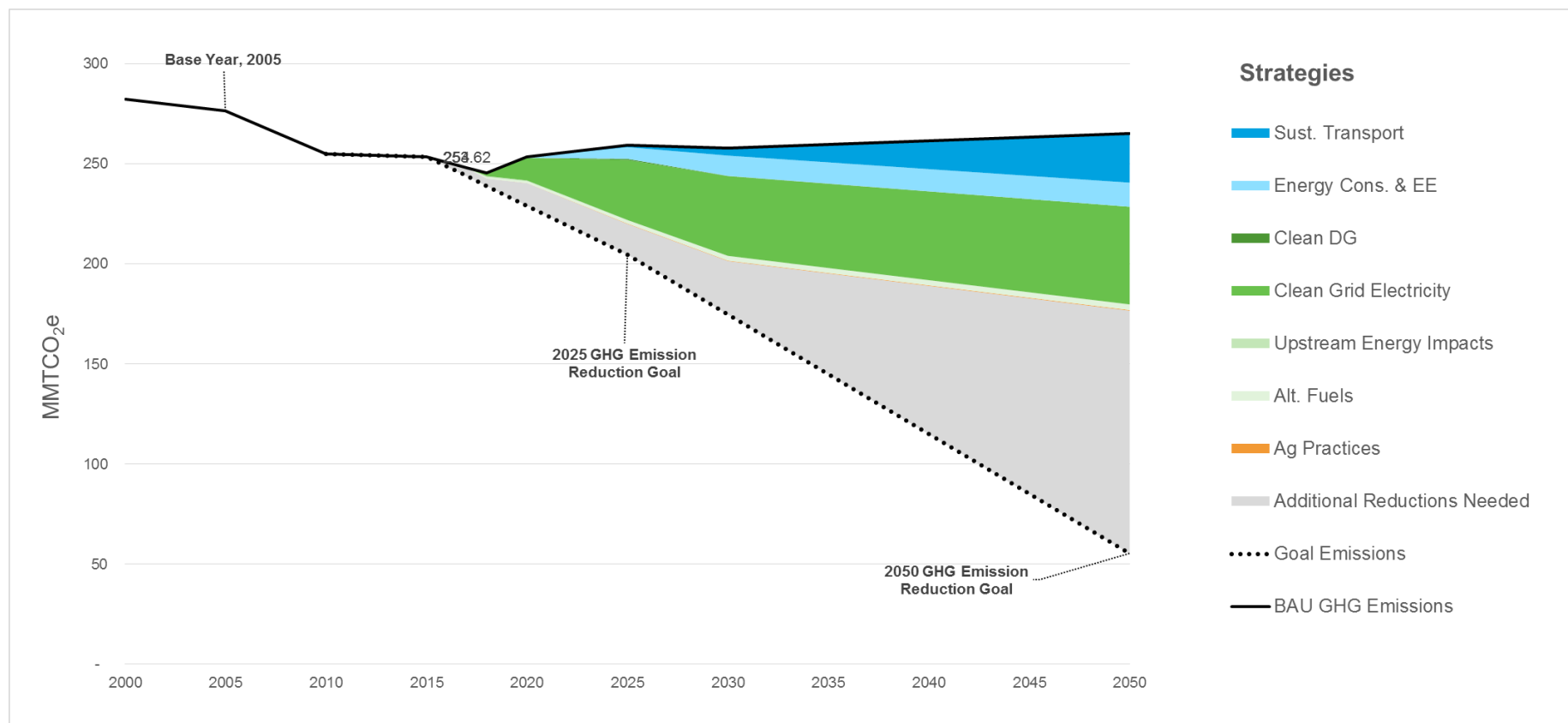
¹⁶ This includes some emission reductions from energy consumption due to changes in fuel consumption by agricultural equipment.

36 percent reduction from 2005 levels. This does not meet the target set forth for modeling purposes: an 80 percent reduction from 2005 GHG emission levels by 2050. In 2050 GHG reduction contributions from each sector are:

- Energy Consumption related annual GHG reductions are **37,005,093 MTCO₂e** (14% reduction from 2005 levels)
- Energy Production-related annual GHG reductions are **48,858,287 MTCO₂e** (19% reduction in energy consumption emissions and 7% reduction in energy production emissions from 2005 levels)
- Agriculture-related annual GHG reductions are **328,070 MTCO₂e** (4% reduction from 2005 levels)

The results for 2025 and 2050 fall short of meeting the modeling targets of 26 percent (2025) and 80 percent (2050) relative to 2005 GHG emissions. However, these findings are consistent with what other jurisdictions are seeing—actions with large GHG reduction potential, such as those quantified for this Plan, are not quite enough to meet 2025 or 2050 targets, when taken alone. For example, the America’s Pledge report, *Fulfilling America’s Pledge: How States, Cities, and Businesses are Leading in the United States to a Low Carbon Future*, shows that implementation of ten key climate actions—which are, for the most part, similar to what was modeled for this Plan—will likely result in a 21 percent reduction of annual GHG emissions in 2025 as compared to 2005 levels for America’s Pledge, U.S. Climate Alliance, and Climate Mayors participants (America’s Pledge 2018b). This finding further emphasizes the need for more ambitious and quick climate action from all actors, including leadership, businesses, and citizens. This is particularly relevant for 2025 where there is less uncertainty than 2050 and more visibility into potential implementable actions.

Figure 12. GHG Reductions Through 2050 for All Strategies, By Sector (MMTCO₂e)



Note: Blue shading indicates emission reductions from strategies within the Energy Consumption sector; green shading indicates emission reductions from strategies within the Energy Production sector; and orange shading indicates emission reductions from strategies within the Agriculture sector. For wedges that are relatively smaller in size, Figure 13 and Figure 14 provide a different graphical representation of reductions.

Figure 13 and Figure 14 show the GHG emissions reductions of each quantified action within the seven quantified strategies in both 2025 and 2050, respectively. As seen, the strategy to create a diverse portfolio of clean, utility-scale electricity generation has the most significant emission reduction impacts in both 2025 and 2050. Large GHG reductions are seen for energy conservation and efficiency measures in both 2025 and 2050, while the benefits of sustainable transportation measures do not really come into play until after 2025. While relative reductions from the other strategies are smaller, they still play a vital role in overall GHG reductions that could be achieved by implementing this Plan.

Other key conclusions in considering these GHG results are:

- ▶ Existing clean energy and climate program policies are already driving reductions in the near-term, as evidenced by the decreasing trend in BAU GHG emissions through 2025, a 6 percent (17,376,468 MTCO₂e) reduction from 2005 levels. However, without additional action GHG reductions under the BAU will slow in later years as existing policies and programs phase out; in 2050 BAU GHG emissions are 4 percent (11,318,853 MTCO₂e) lower than 2005 levels.
- ▶ The 15 actions within the seven strategies quantitatively analyzed for this Plan significantly reduce GHG beyond the reductions in the BAU. As indicated above and in Figure 12, these strategies result in Pennsylvania falling short of the target selected for modeling in 2025 and are not enough for the commonwealth to reduce GHG emissions 80 percent by 2050. In considering these results, it is important to keep in mind:
 - As highlighted above, due to resource and time constraints, the modeling conducted for this report only focuses on a subset of strategies and actions that could reduce GHG emissions in Pennsylvania. Additional strategies and actions qualitatively addressed in this report would likely result in additional GHG reductions. For example, sequestration of carbon through forests offers a lot of potential for GHG reductions in Pennsylvania. Effective conservation and management of forests through programs such as the Nature Conservancy's Working Woodlands program can help accelerate and maintain forests as carbon sinks. This program has protected over 62,000 acres and accelerated restoration on 5,000 acres in Pennsylvania alone, with the result that almost 3.5 million tons of carbon will be sequestered over the life of the projects.
 - The results do not consider new or updated federal policies that reduce GHG emissions.
 - There are high levels of uncertainty associated with forecasting GHG emissions through 2050. Although this analysis provides single estimates of GHG emissions reductions from the quantified strategies, it would be useful to conduct sensitivity analyses that examine a range of aggressiveness for underlying modeling assumptions (e.g., market penetration rates or costs of certain technologies).

Figure 13. Annual GHG Reductions Compared to BAU in 2025 for All Quantified Strategies and Actions (MMTCO₂e)

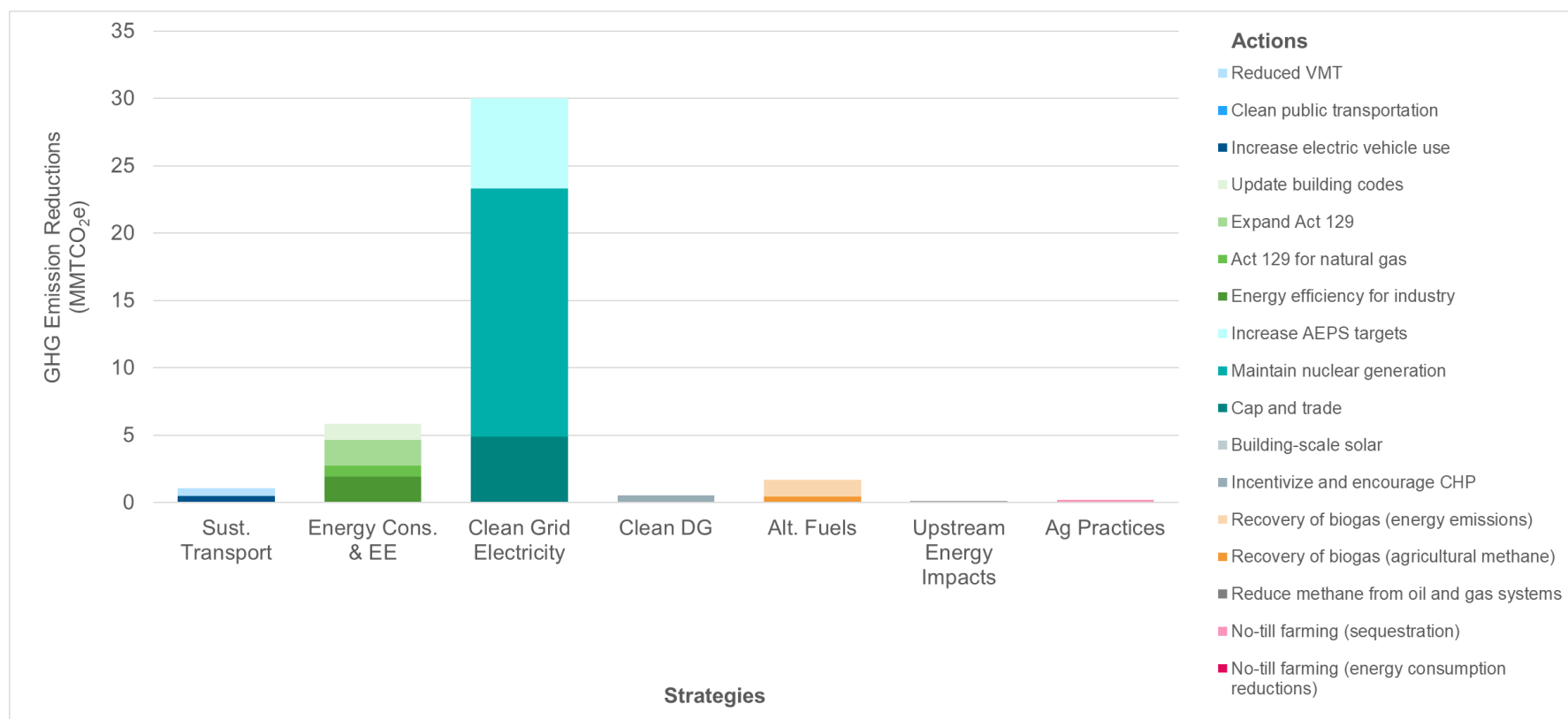
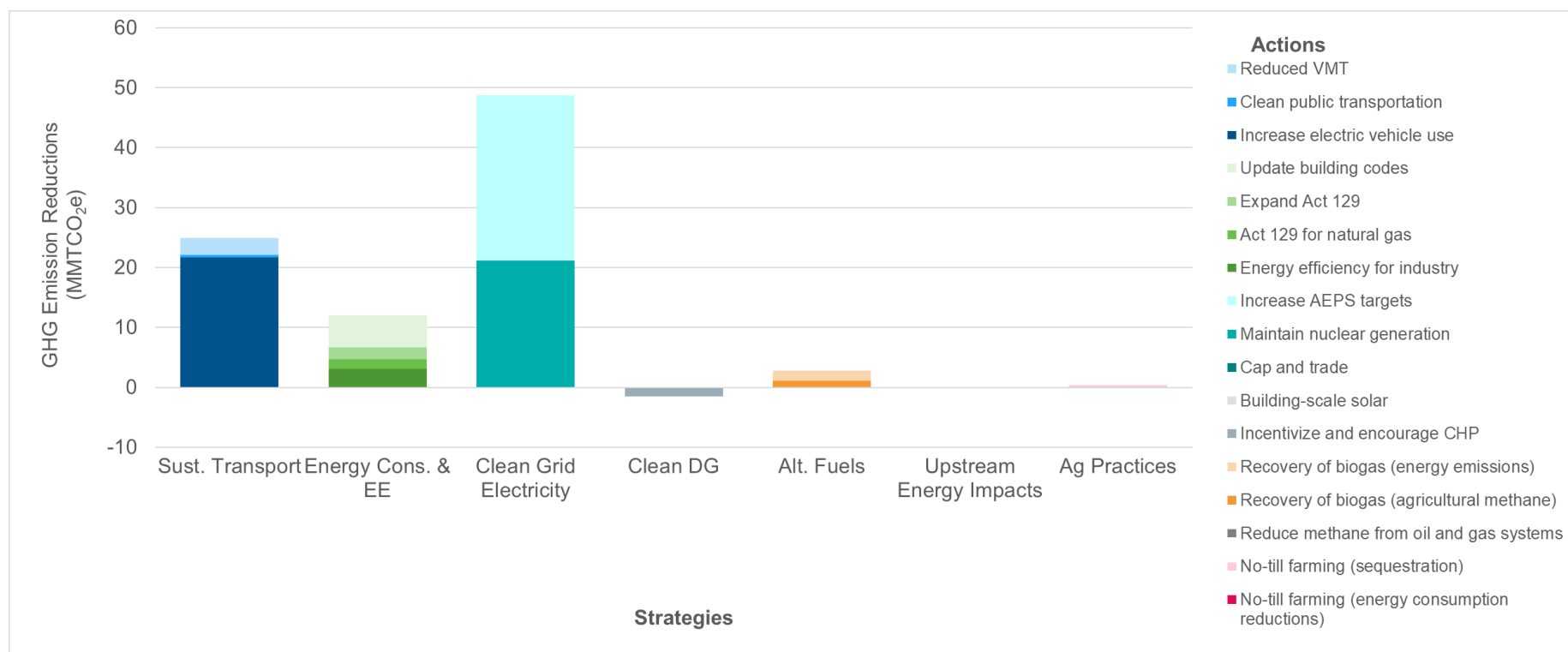


Figure 14. Annual GHG Reductions Compared to BAU in 2050 for All Quantified Strategies and Actions (MMT_{CO₂e})



Summary of Strategy-Specific Economic Benefits and Costs

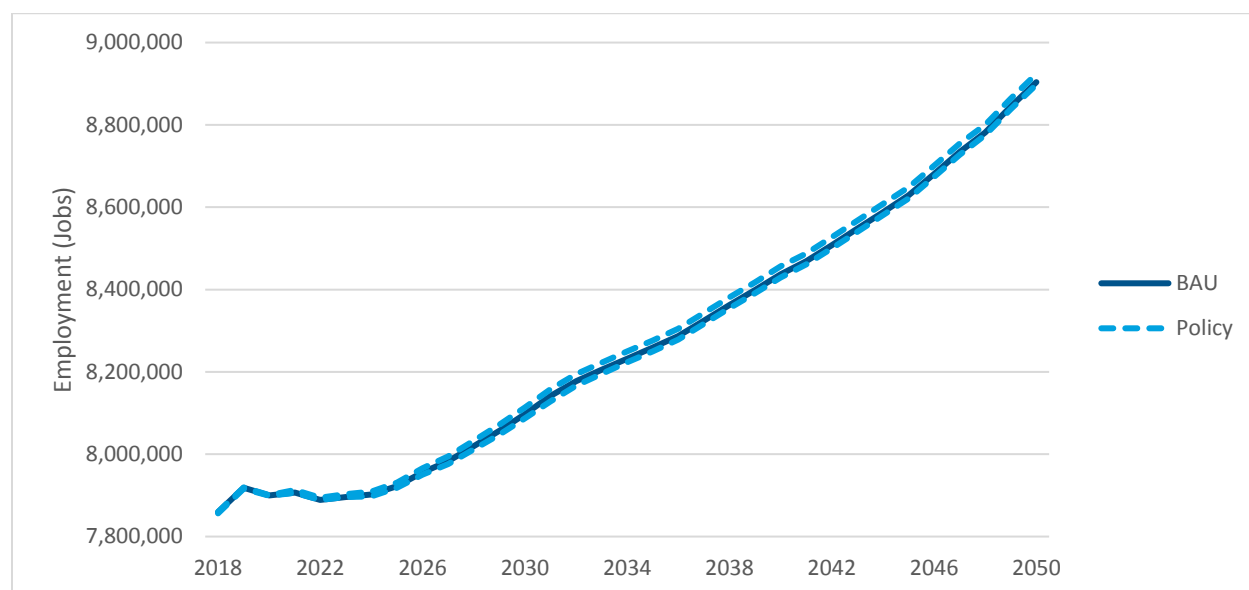
To assess cost-effectiveness of the strategies presented in this report (a requirement of Act 70), DEP and the analysis team looked at multiple factors which, when considered together, can be used to understand the cost-effectiveness of a strategy. Cost-effectiveness measures assessed include:

1. **Net present value (NPV)**, provided for each strategy action, which is a narrow analysis of direct costs and benefits, and uses zero NPV as a benchmark. This is useful as a simple microeconomic perspective. NPV does not include externality costs, such as those of GHGs or other emissions. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action.
2. **Cost per ton of CO₂e**, provided for each strategy action, which uses the social cost of carbon as a benchmark. Anything that falls below the benchmark could be considered cost-effective based on one perspective. This is useful as a climate policy perspective (see Figure 19).
3. **Macroeconomic factors** (described below), which captures multiple benefit and cost effects, including employment, gross state product, and personal income. This is useful as a richer set of indicators.

To better understand the macroeconomic impacts of the Climate Action Plan (CAP), DEP and the analysis team examined the strategies in greater detail, by estimating the impacts on employment, gross state product (GSP), and personal disposable income for commonwealth residents. As discussed in How this Plan was Developed, the analysis team utilized the REMI model to estimate these macroeconomic impacts by using individual action-level inputs to model the CAP strategies. Snapshot results from 2025 and 2050 are provided in the chapters above; this section provides a more detailed look at the macroeconomic trends.

The overall impacts of CAP strategies on the Pennsylvania economy are positive, though small in absolute magnitude.

Figure 15 shows the range of variation in total employment impacts using the largest and the smallest estimated impacts from individual strategies as the benchmarks, over the BAU projections. The trend lines appear to overlap because the total employment impacts of the CAP are small when compared to the statewide economy. While these impacts may be small, the net impacts of the CAP are positive (see Table 8 and Table 9, and net impact trend lines of Figure 16, Figure 17, and Figure 18). The transitions from strategies modeled for this Plan are not disruptive for the overall economic trajectory of the state, and offer potential additional economic benefit to the commonwealth over the BAU scenario.

Figure 15. Overall BAU Employment Compared to Policy Case Employment in Pennsylvania¹


¹ Employment data are from REMI. These REMI data may differ from other employment figures and projections (e.g., employment data from the Bureau of Labor Statistics) because REMI includes part time jobs in employment figures.

Strategy-specific benefits and costs of each of the seven strategies are summarized quantitatively analyzed below. Table 8 and Table 9 provide an overall summary of strategy-level net economic impacts, both as annual averages and as cumulative impacts over the entire modeling period.

Table 8. Annual (2025 and 2050) and Cumulative (2018-2050) Number of Jobs Supported

Strategies Included in Quantitative Modeling	Annual Number of Jobs Supported (2025)	Annual Number of Jobs Supported (2050)	Cumulative Number of Job-Years ¹ Supported (2018-2050)
Increase end use energy conservation and efficiency	8,690 (0.11%)	19,790 (0.22%)	475,000 (0.17%)
Implement sustainable transportation planning and practices	-4,020 (-0.05%)	8,390 (0.09%)	35,380 (0.01%)
Increase use of clean, distributed electricity generation resources	3,610 (0.05%)	15,130 (0.17%)	362,910 (0.13%)
Create a diverse portfolio of clean, utility-scale electricity generation	-2,490 (-0.03%)	-6,210 (-0.07%)	-200,440 (-0.07%)
Reduce upstream impacts of fossil fuel energy production	10 (0.00%)	-10 (0.00%)	-190 (0.00%)

Strategies Included in Quantitative Modeling	Annual Number of Jobs Supported (2025)	Annual Number of Jobs Supported (2050)	Cumulative Number of Job-Years ¹ Supported (2018-2050)
Increase production and use of alternative fuels	230 (0.00%)	4,020 (0.05%)	71,290 (0.03%)
Use agricultural best practices	470 (0.01%)	-500 (-0.01%)	-8,020 (0.00%)
Net Total	6,500 (0.08%)	40,610 (0.46%)	

¹ This is the cumulative number of years newly created jobs are held through 2050.

Table 9. Annual (2025 and 2050) and Cumulative (2018-2050) Impact on Gross State Product¹ (\$ Million)

Strategies Included in Quantitative Modeling	Annual Impact on GSP (\$ Million) (2025)	Annual Impact on GSP (\$ Million) (2050)	Cumulative Impact on GSP (\$ Million) (2018-2050)
Increase end use energy conservation and efficiency	\$700 (0.08%)	\$1,560 (0.11%)	\$37,180 (0.14%)
Implement sustainable transportation planning and practices	-\$260 (-0.03%)	\$1,560 (0.11%)	\$15,860 (0.06%)
Increase use of clean, distributed electricity generation resources	\$20 (0.00%)	\$710 (0.005%)	\$14,900 (0.06%)
Create a diverse portfolio of clean, utility-scale electricity generation	-\$260 (-0.03%)	-\$190 (-0.01%)	-\$13,060 (-0.05%)
Reduce upstream impacts of fossil fuel energy production	\$0 (0.00%)	\$0 (0.00%)	-\$20 (0.00%)
Increase production and use of alternative fuels	\$10 (0.00%)	\$130 (0.01%)	\$2,540 (0.01%)
Use agricultural best practices	\$0 (0.00%)	-\$10 (0.00%)	-\$130 (0.00%)
Net Total	\$200 (0.02%)	\$3,760 (0.26%)	

¹ GSP results are discounted at 1.75%. Numbers are rounded.

Table 8 and Table 9 show that, in total, the strategies modeled for macroeconomic impacts in this analysis show small but positive effects on total Pennsylvania jobs and gross state product, growing total jobs by over 40,000 and the commonwealth's economy by almost \$4 billion. The subsections that follow provide additional detail on each strategy's modeled impacts.

Increase end use energy conservation and efficiency

Investments in end-use energy efficiency for the residential, commercial, and industrial sectors drive economic growth through several different mechanisms. Households and businesses reduce their energy consumption through the installation of energy efficient appliances, building insulation, and conservation methods. These consumption changes reduce their monthly electricity bills. Electricity bill savings correspond to more disposable income (Figure 18) for the residential sector, and lower costs of doing business and increases competitiveness for the commercial and industrial sectors.

The economic impacts from energy efficiency are often muted initially, as the upfront investments offset some of the gains, assuming a finite (constant) budget. The trend lines in the figures below show increasing positive impacts over time as the bill savings continue to accrue and energy consumers spend those savings on other goods and services generating additional economic benefits.

The employment benefits largely relate to the installation of energy efficiency equipment (e.g., demand for electricians rises), and these increases continue as more energy efficiency investments take place. The retail sector also sees an increase in demand as sales of energy efficient appliances increase.

Implement sustainable transportation planning and practices

The macroeconomic results of sustainable transportation are primarily driven by the increasing adoption of electric vehicles. The shift to electric vehicles necessitates large capital investments for the manufacturing of electric engines, batteries, and charging stations. Comparatively, bus electrification and strategies to reduce vehicle miles traveled have much lower economic impacts as investments are lower.

The initial results reflect that the cost to consumers of purchasing electric vehicles that, on average, are more expensive than their alternative vehicle options (Figure 18 displays an initial negative trend). Employment and GSP results in Figure 17 and Figure 16 show initial downward trends as entities like gas stations see some negative impacts as cars transition away from gasoline to electricity.

After 2029, these negative impacts begin to reverse. This trend reversal occurs for several reasons: (1) decline of electric vehicle costs, which decreases the negative impact on consumer budgets; (2) entities like gas stations begin to have sizable electric charging infrastructure, mitigating the need for continued investments (GSP increases in Figure 16); and (3) consumers begin to see significant savings due to electricity being a cheaper energy source than gasoline (DPI increases in Figure 18). These positive impacts begin cause this strategy to reflect positive macroeconomic impacts by 2035.

Increase use of clean, distributed electricity generation resources

The increasing attention to the use of clean distributed electricity generation will result in positive macroeconomic impacts through increased distributed solar and CHP use. The installation of distributed solar for residential and commercial customers drives the creation of construction related jobs through

capital investments. The increase in solar demand will also drive increases in retail and installation services. Similar to energy efficiency, the initial employment impacts are muted due to investment costs but can be seen to increase over the longer term in Figure 17.

Investments by households and businesses will result in large reductions in electricity bills (similar to energy efficiency), as they generate behind-the-meter electricity and avoid purchasing electricity from the grid. These impacts result in more disposable income for households and lower costs for businesses (e.g., positive trend in Figure 18).

Likewise, sectors installing CHP systems also see lower energy bills and reduced costs as heat and power is produced very efficiently behind-the-meter.

Create a diverse portfolio of clean, utility-scale electricity generation

The creation of clean utility-scale generation results in some negative net macroeconomic impacts, due to its multiple effects on Pennsylvania's generation mix and related energy industries. Because this strategy has several competing components that impact the state economy in both positive and negative ways, some parts of the energy sector gain jobs while others contract. It is also worth noting that these effects are small, less than one-tenth of one percent for total employment.

The expansion of the AEPS, through increased utility-scale solar and wind generation, initially leads to the growth in renewable energy jobs in the commonwealth. Investments in solar and wind generation spurs employment growth that can be seen in the early years of Figure 17, peaking at over 6,000 jobs in 2021. The cumulative capital investment of \$8.9 billion through 2025 is expected to increase total employment by around 46,000 jobs years through the same time span. Investments in renewable energy peak by 2030, and are projected to approach approximately \$20 billion, resulting in close to 100,000 job-years by 2030. By the end of the modeling period (2050) the cumulative investments are estimated to be over \$37 billion, and are expected to support nearly 180,000 job-years in the commonwealth for the entire time period.

Reliance on renewable energy for future expansion of the electricity sector, coupled with continued nuclear generation and the establishment of a carbon price, leads to decrease reliance on fossil generation in the commonwealth, and is expected to have a negative impact on the fossil fuel-related sectors. This movement away from fossil fuels to wind, solar, and nuclear energy is expected to negatively impact the coal and natural gas industries by leading to retirements of existing fossil fuel-burning plants and lowering demand for resource extraction related jobs. Moreover, the establishment of a carbon price is expected to lead to fuel-switching away from coal-based generation to cheaper and cleaner natural gas-based generation. This fuel-switching increases coal retirements, leading to some job losses in the commonwealth. Finally, the revenues generated by the carbon price (via projected allowance prices) are modeled to mitigate some of these impacts via rebates to energy consumers. Given the projections of relatively low allowance prices in our modeling, however, these recycled revenues are not large enough to mitigate the overall impacts on the fossil fuel-related sectors, leading to net negative economic impacts for this strategy.

Reduce upstream impacts of fossil fuel energy production

The economic impacts of this strategy are very small, and not representative of measurable economic changes.

Increase production and use of alternative fuels

The macroeconomic impacts of the increase in production and use of alternative fuels show positive trends across employment (Figure 17) and GSP (Figure 16). The job impacts are generated from the manufacturing and construction of agricultural waste digesters, water digesters, and biogas generators. These small scale and onsite biogas generator installations lead to an increase in energy savings and reduced costs of doing business.

Use agricultural best practices

The annual impacts of promoting agricultural best practices are small (see the agricultural best practices trend line hover near zero in Figure 16, Figure 17, Figure 18). However, the initial investments in new agricultural machinery will result in some slim economic benefits. On the whole, however, higher operating and maintenance costs in the long-term result in some small net negative economic impacts.

Figure 16. Impact on Gross State Product Through 2050, by Strategy (\$ Million)

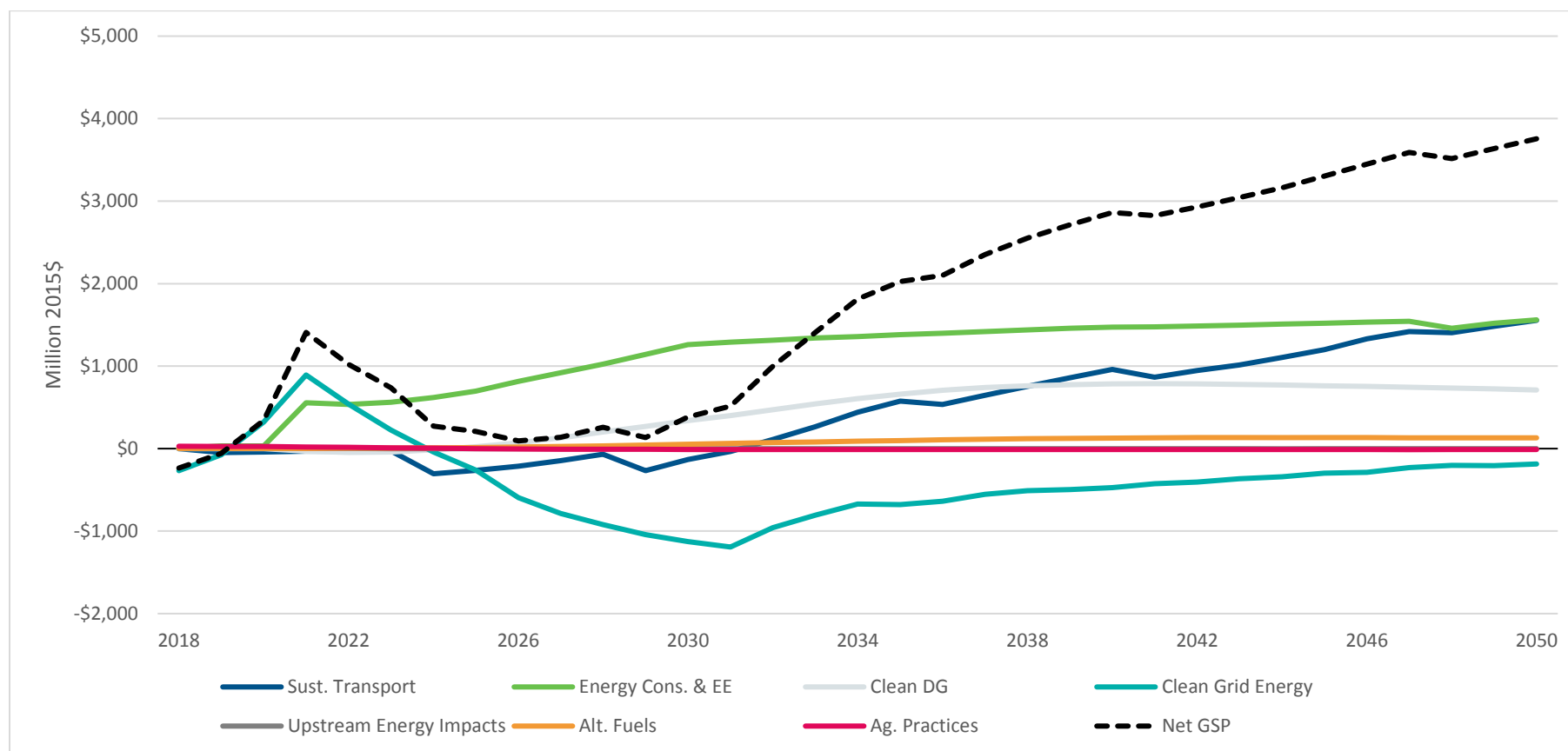


Figure 17. Number of Jobs Created Through 2050, by Strategy

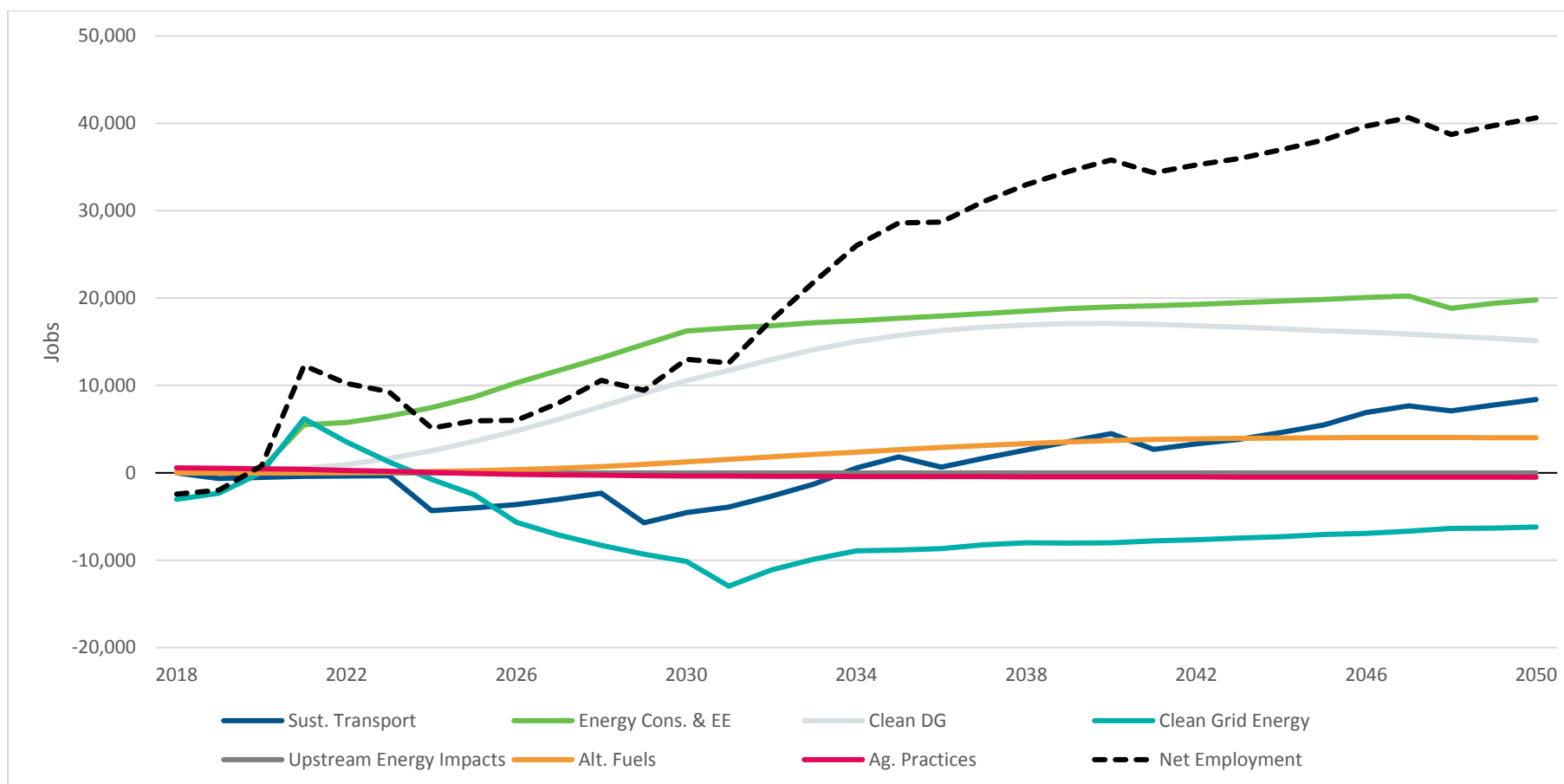
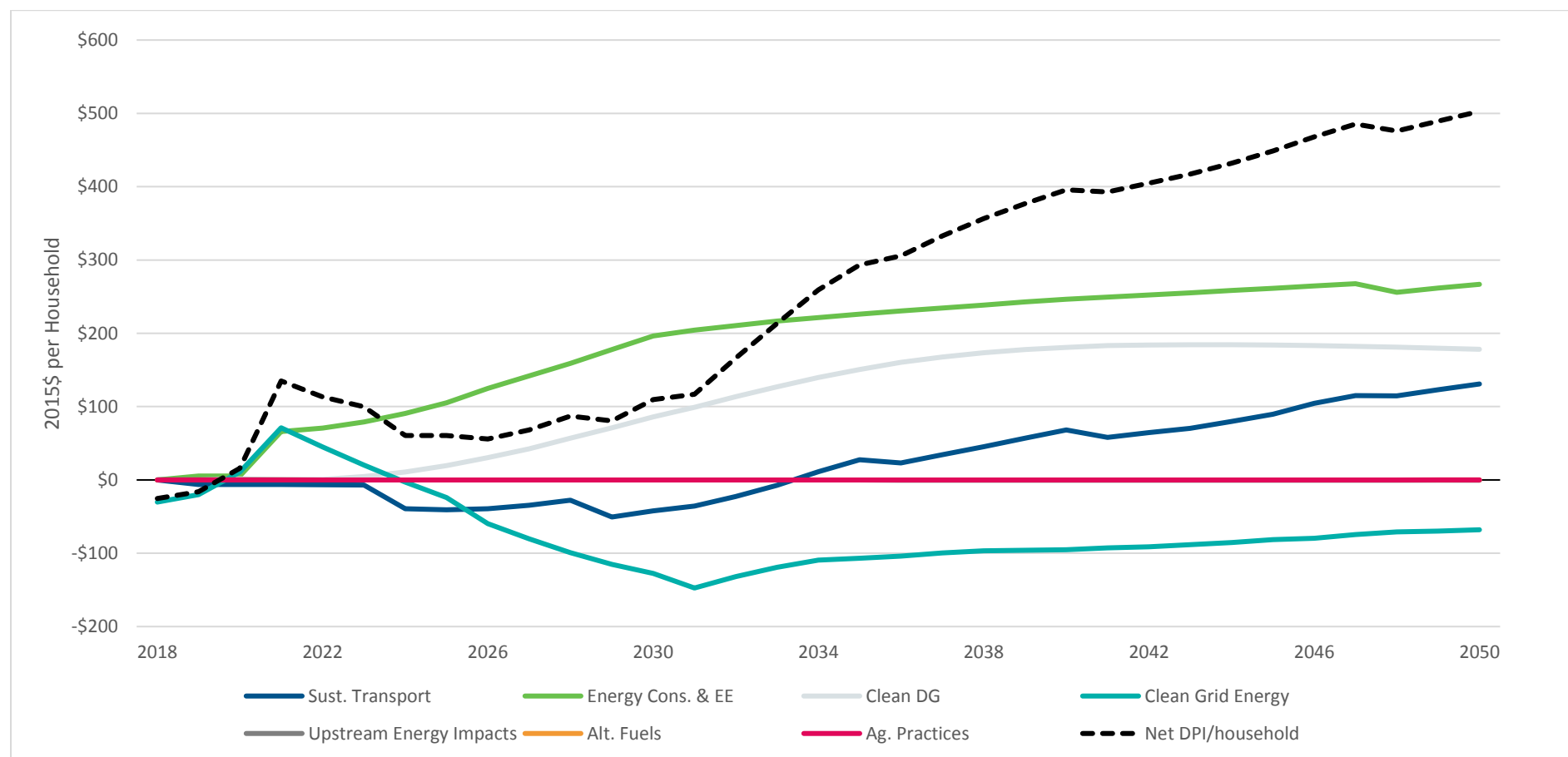
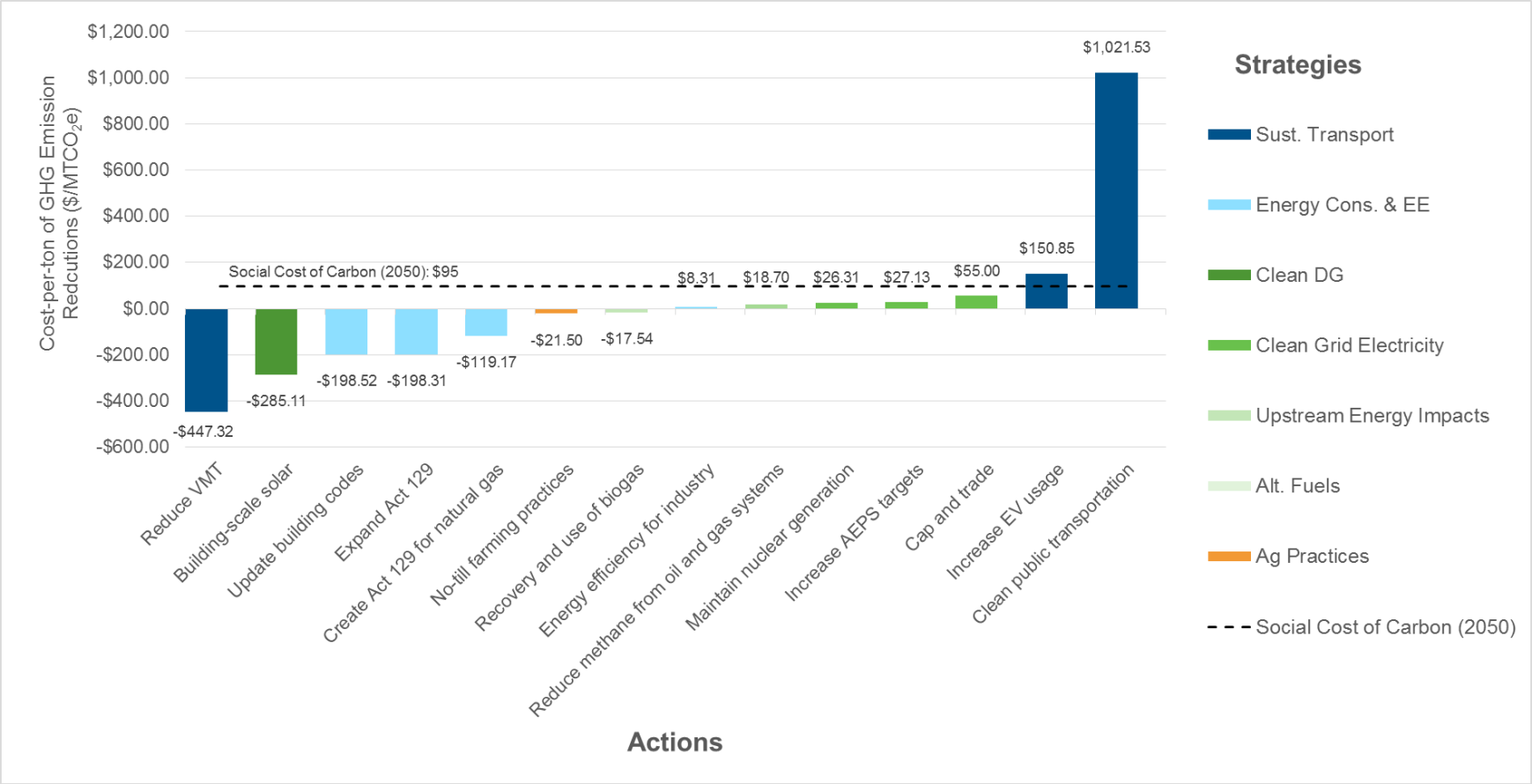


Figure 18. Change in Disposable Personal Income and in Disposable Income per Household Through 2050, by Strategy (\$/Household)



Alt. Fuels and Upstream Energy Impacts are in line with the Ag. Practices strategy line in this chart.

Figure 19. Cost per Ton of CO₂ Reduced for All Actions, By Sector (\$/MTCO₂e)



Note: Blue shading indicates emission reductions from strategies within the Energy Consumption sector; green shading indicates emission reductions from strategies within the Energy Production sector; and orange shading indicates emission reductions from strategies within the Agriculture sector.

Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use. Note: the

team looked primarily at the impacts from new natural gas combustion in new CHP systems and did not quantify the potential from using CHP to capture waste heat from existing combustion systems.

The Social Cost of Carbon (SCC) included in this chart is the 2050 SCC assuming a 2.5% discount rate (EPA 2016)

Table 10. Annual (2025 and 2050) and Cumulative (2018-2050) Change in Disposable Personal Income (\$ Million) and Change in Disposable Personal Income Per Household¹ (\$/Household)

Strategies Included in Quantitative Modeling	Annual Change in Disposable Personal Income (\$ Million) (2025)	Annual Change in Disposable Personal Income (\$ Million) (2050)	Cumulative Change in Disposable Personal Income (\$ Million) (2018-2050)	Annual Change in Disposable Personal Income Per Household (\$/Household) (2025)	Annual Change in Disposable Personal Income Per Household (\$/Household) (2050)	Cumulative Change in Disposable Personal Income Per Household (\$/Household) (2018-2050)
Increase end use energy conservation and efficiency	\$492 (0.07%)	\$1,246 (0.11%)	\$28,446 (0.13%)	\$105 (0.08%)	\$267 (0.18%)	\$6,089 (0.13%)
Implement sustainable transportation planning and practices	-\$190 (-0.03%)	\$611 (0.05%)	\$3,951 (0.02%)	-\$41 (-0.03%)	\$131 (0.09%)	\$846 (0.02%)
Increase use of clean, distributed electricity generation resources	\$92 (0.01%)	\$832 (0.07%)	\$17,001 (0.08%)	\$20 (0.01%)	\$178 (0.12%)	\$3,639 (0.08%)
Create a diverse portfolio of clean, utility-scale electricity generation	-\$113 (-0.02%)	-\$317 (-0.03%)	-\$10,833 (-0.05%)	-\$24 (-0.02%)	-\$68 (-0.05%)	-\$2,319 (-0.05%)
Reduce upstream impacts of fossil fuel energy production	\$0 (0.00%)	-\$2 (0.00%)	-\$27 (0.00%)	\$0 (0.00%)	\$0 (0.00%)	-\$6 (0.00%)
Increase production and use of alternative fuels	\$0 (0.00%)	\$0 (0.00%)	\$3 (0.00%)	\$0 (0.00%)	\$0 (0.00%)	\$1 (0.00%)
Use agricultural best practices	\$1 (0.00%)	-\$23 (0.00%)	-\$335 (0.00%)	\$0 (0.00%)	-\$5 (0.00%)	-\$72 (0.00%)
Net Total	\$283 (0.05%)	\$2,348 (0.20%)		\$61 (0.5%)	\$503 (0.35%)	

¹ Results for disposable personal income and disposable personal income per household are discounted at 1.75%. Household data is taken from the U.S. Census Bureau.

In aggregate, the suite of strategies recommended in this Plan maximize GHG reductions and are cost-effective for Pennsylvania. However, DEP, its sister agencies, and the Pennsylvania state legislature and executive branch will need to prioritize and phase strategy implementation for both the quantified and non-quantified strategies in this Plan. The year 2025 is rapidly approaching, and actions with large GHG and economic benefits, and relatively low cost and political barriers offer Pennsylvania the best short-term solutions. In parallel, initiating actions that may take more time and resources to implement and have more trade-offs to consider will help Pennsylvania maximize the potential impact of this Plan. Examples of these considerations are presented below.

Energy conservation and efficiency actions appear to be likely candidates for immediate implementation. These actions offer relatively large GHG reductions over time, provide cost savings (negative cost-per-ton of GHG reduced), and support growth in jobs. Many of the energy conservation and efficiency actions outlined in this Plan build upon existing Pennsylvania policies and programs that have widespread support, and therefore offer a low barrier for implementation. Further, many of these actions have important resilience benefits.

The case for sustainable transportation practices gets more compelling as time goes on. Most of the GHG benefits of this strategy come after 2025, positive job results are not seen until 2030, and the costs of reductions for actions under this strategy are relatively high compared to other actions. Nonetheless, state and local governments need to act now to realize the eventual benefits of this strategy and ensure infrastructure and policies are in place to drive and support market transformation. This will take time as the strategy will require public and private investment, scaling of infrastructure (e.g., bike shares and electric vehicle charging), and changes to consumer behavior to achieve the projected large climate and economic benefits through 2050.

Creating a diverse portfolio of clean, utility-scale electricity generation presents the most important trade-offs to consider. This strategy has a potentially large impact on almost every sector of the Pennsylvania economy, as well as residents, businesses, and government. This strategy drives the largest reductions in GHG emissions of all the modeled strategies. It also appears to be cost-effective when considering the cost-per-ton of GHG reduced as compared to the social cost of carbon (see Figure 19). It also has positive resilience impacts. However, some actions under this strategy may take more effort to implement. Additionally, the creation of clean utility-scale generation results in some possible negative net macroeconomic impacts, due to the multiple effects on Pennsylvania's generation mix and related energy industries.

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Appendix A. Technical Support for Strategy and Action Modeling

This appendix documents the assumptions, methods, data, and results for mitigation actions modeled for the 2018 Climate Action Plan (CAP) update. Macro-economic modeling and results are not covered in this appendix, which is in line with and underlying many of the actions and implementation information provided in the actual Climate Action Plan.

The strategies and actions discussed in this appendix are one piece of the CAP that fit into a more comprehensive plan. There are 15 actions, as part of 7 strategies, that were quantitatively analyzed. There are dozens of other actions and strategies that are qualitatively addressed in the CAP which will lead to additional GHG reductions and benefits for Pennsylvanians.

Energy, micro-economic, and environmental inputs and results are presented below. Particularly for the energy-related actions, the descriptions of assumptions, methods, and data focus mainly on energy and economic modeling. Environmental and climate benefits and costs are calculated using emission factors from a range of sources, such as the Environmental Protection Agency's (EPA's) State Inventory Tool, EPA's Emissions & Generation Resource Integrated Database (eGRID), and 2006 IPCC Guidelines for National Greenhouse Gas Inventories. The draft results presented in this document feed into macro-economic modeling being done in REMI.

Table 11. Annual GHG Reductions in 2025 and 2050, Cost per Ton of GHGs Reduced, and Net Present Value for All Strategies and Actions

Strategies and Actions Included in Higher-Level Strategy Quantitative Modeling	Annual GHG Reductions in 2025 (MTCO ₂ e)	Annual GHG Reductions in 2050 (MTCO ₂ e)	Cost per Ton of GHG Reduced (\$/MTCO ₂ e)	Net Present Value (\$ Million)
Increase end use energy conservation and efficiency	5,827,879	12,036,172	-\$127	\$37,487
Update building codes	1,164,587	5,374,682	-\$199	\$18,345
Increase adoption of energy efficiency, and expand Act 129	1,916,947	1,984,261	-\$198	\$14,916
Create an Act 129-like conservation and efficiency program for natural gas	845,010	1,567,198	-\$119	\$4,944
Expand energy assessments and provide more trainings on energy efficiency for industry	1,901,335	3,110,031	\$8	-\$718
Implement sustainable transportation planning and practices	1,061,309	24,968,921	\$71	-\$20,397

Strategies and Actions Included in Higher-Level Strategy Quantitative Modeling	Annual GHG Reductions in 2025 (MTCO ₂ e)	Annual GHG Reductions in 2050 (MTCO ₂ e)	Cost per Ton of GHG Reduced (\$/MTCO ₂ e)	Net Present Value (\$ Million)
Reduce vehicle miles traveled for single-occupancy vehicles	573,260	2,820,936	-\$447	\$20,114
Implement a strategic plan and incentives for increasing electric vehicle use	474,100	21,689,937	\$151	-\$35,983
Increase the use of clean public transportation through electric municipal bus fleets	13,948	458,048	\$1,022	-\$4,527
Increase use of clean, distributed electricity generation resources	544,502	-1,512,918	NA^{ab}	\$8,166
Invest in and promote building-scale solar	NA ^a	48,210	-\$285	\$490
Incentivize and increase use of combined heat and power	544,502	-1,561,128	NA ^b	\$7,295
Create a diverse portfolio of clean, utility-scale electricity generation	30,015,060	48,792,751	\$29	-\$27,526
Increase Alternative Energy Portfolio Standard(AEPS) Tier 1 targets, and further increase in-state generation and use of renewables	6,703,719	27,639,941	\$27	-\$13,551
Implement policy to maintain nuclear generation at current levels	18,412,115	21,152,811	\$26	-\$14,463
Limit carbon emissions through an electricity sector cap and trade program	4,899,227	NA ^c	\$55	-\$5,174
Reduce upstream impacts of fossil fuel energy production	104,879	29,598	\$19	-\$59
Implement policies and practices to reduce methane emissions across oil and natural gas systems	104,879	29,598	\$19	-\$59
Increase production and use of alternative fuels	1,673,531	2,796,683	-\$20	\$1,299
Increase recovery and use of gas from coal mines, agriculture, wastewater, and landfills for energy	1,673,531	2,796,683	-\$20	\$1,299
Use agricultural best practices	208,331	328,070	-\$22	\$162
Implement and provide training for no-till farming practices	208,331	328,070	-\$22	\$162

^a There is sufficient building scale solar in 2025 in the BAU to meet the 6% solar carve out assuming 90% is utility scale and 10% is building scale, so there are no GHG reductions from BAU in 2025. We see non-zero savings starting in 2026.

^b Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use: as grid carbon intensity declines, it reaches a point where reducing electricity use by increasing natural gas use begins to increase net CO₂ emissions. In this modeling analysis, that point occurs during the 2040s.

^c The GHG emission reductions from expanding AEPS requirements and maintaining nuclear generation are projected in this modeling analysis to meet the cap in 2050 without a cap and trade program.

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU. Negative cost-per-ton represents net cost savings

Sector: Energy Consumption

Strategies include:

- Increase end use energy conservation and efficiency
- Implement sustainable transportation planning and practices

Strategy: Increase end use energy conservation and efficiency

Actions include:

- Update building codes
- Increase adoption of energy efficiency, and expand Act 129
- Create an Act 129-like conservation and efficiency program for natural gas
- Expand energy assessments and provide more trainings on energy efficiency for industry

Action: Update building codes

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Residential
 - Energy Savings: Using ICF’s Energy Code Calculator,¹⁷ the analysis team assumes an International Energy Conservation Code (IECC) 2009 base code and then implements projected future IECC code versions every six years through 2050. This implementation timeframe is based on the actual time it took to adopt the 2015 codes in Pennsylvania.¹⁸

¹⁷ The Energy Codes calculator is a proprietary tool that estimates changes in energy use based on assumed updates to building codes for new construction.

¹⁸ 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

The team assumes 90 percent code compliance for all new construction homes with a 30-year measure life. New home projections are provided by Pacific Northwest National Laboratory¹⁹. This approach delivers both electricity and natural gas savings.

- **Costs:** The team assumes an incremental cost of \$2,561 per home for efficiency measures, which comes from PECO's Incremental Cost Database²⁰.
- **Commercial**
 - **Energy Savings:** Again, using ICF's Code Calculator, the team assumes an American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 2007 base code and implement projected future ASHRAE code versions every 6 years through 2050. The team assumes 90 percent code compliance for all new construction, renovations, and additions with a 30-year measure life. New commercial square foot projections are provided by Pacific Northwest National Laboratory²¹. This approach delivers both electricity and natural gas savings.
 - **Costs:** The team assumes an incremental cost of \$5.32 per sq. ft. for efficiency measures, which comes from Pacific Northwest National Laboratory's 2015 study *Cost-Effectiveness of ASHRAE Standard 90.1-2013 for the State of Pennsylvania*²².

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	-2,282	-14,962	-7,110
Change in Natural Gas Consumption (BBtu)	-6,590	-45,144	-21,284
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	1,164,587	5,374,682	2,976,499
SO ₂ Emission Reductions (MT)	1,476	4,355	3,061
NO _x Emission Reductions (MT)	785	2,300	1,656
Hg Emission Reductions (MT)	0.03	0.07	0.05
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$174.78	\$192.53	\$177.44

code. These changes will go into effect in October of 2018. <https://www.dli.pa.gov/ucc/Documents/rac/UCC-RAC-2015-Code-Review-Report.pdf>

¹⁹ Pacific Northwest National Laboratory. (PNNL). 2014. Utility Savings Estimator. Accessed on July 13, 2018.

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²⁰ Pennsylvania Statewide Evaluator. (SWE). 2017. PECO Combined Incremental Cost Database v 3.1

²¹ Pacific Northwest National Laboratory. (PNNL). 2014. Utility Savings Estimator. Accessed on July 13, 2018.

Available at <https://www.energycodes.gov/resource-center/utility-savings-estimators>

²² Pacific Northwest National Laboratory. (PNNL). 2015. Cost-Effectiveness of ASHRAE Standard 90.1- 2013 for the State of Pennsylvania. PNNL-25017. Accessed on July 3, 2018. Available at:

https://www.energycodes.gov/sites/default/files/documents/Cost-effectiveness_of_ASHRAE_Standard_90-1-2013-Pennsylvania.pdf

Fuel Savings (\$ Million)	\$313.10	\$2,394.67	\$1,087.51
Net Present Value (\$)			\$18,344,875,625
Cost-per-ton of GHG Emission Reductions (\$/MTCO ₂ e)			-\$198.52 ^{a,b}

Notes: Positive “changes” indicate increases from business-as-usual (BAU) values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Negative cost-per-ton represents net cost savings.

^b For this and all other actions, a discount rate of 1.75% is used and dollars are presented in as 2015 values.

Action: Increase adoption of energy efficiency, and expand Act 129

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Residential
 - Energy Savings: Using the Pennsylvania Statewide Evaluator’s (SWE) *Energy Efficiency Potential Study for Pennsylvania*²³, the analysis team applies the calculated maximum achievable potential from 2021-2050 (1.5 percent). Historically, it has been seen that this is a potential that can be achieved. The analysis team assumes a measure lifetime of 10 years.
 - Cost Savings: The team takes residential hard and soft costs documented in the SWE potential study and apply them annually from 2021-2050. This includes incentive and administrative soft costs and direct capital hard costs.
- Commercial
 - Energy Savings: Again, using the SWE’s study, the analysis team applies the maximum achievable potential from 2021-2025 (0.8 percent) followed by 1.0 percent annual incremental savings for years 2026-2050. The team assumes a measure lifetime of 10 years.
 - Cost Savings: The analysis team applies non-residential incentive, administrative, and direct capital costs from PA SWE annually from 2021-2050.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	-5,375	-9,986	-8,857
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	1,916,947	1,984,261	2,426,293

²³ 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/pdocs/1345079.pdf>

SO ₂ Emission Reductions (MT)	3,941	3,580	4,895
NO _x Emission Reductions (MT)	1,728	1,357	2,092
Hg Emission Reductions (MT)	0.07039	0.05	0.08
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$341.26	\$316.22	\$338.18
Fuel Savings (\$ Million)	\$763.09	\$1,581.64	\$1,371.61
Program Costs (\$ Million) ^a	\$276.06	\$251.45	267.54
Net Present Value (\$)			\$14,916,207.67
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			-\$198.31 ^b

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Public sector expenditures are in addition to the capital expenditures shown. This represents the administrative and incentive costs for energy efficient actions.

^b Negative cost-per-ton represents net cost savings.

Action: Create an Act 129-like conservation and efficiency program for natural gas

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Residential
 - Energy Savings: Using an American Council for an Energy-Efficient Economy (ACEEE) Energy Efficiency Resource Standard (EERS) policy brief²⁴, the analysis team applies the Massachusetts EERS target of 1.1 percent annual incremental natural gas savings from 2020-2025 followed by 1.0 percent from 2026-2050. The team assumes a measure lifetime of 10 years.
 - Cost Savings: The team applies a \$0.35/therm levelized cost of saved energy (CSE) from ACEEE’s *Review of the Cost of Utility Energy Efficiency Programs*²⁵ annually from 2020-2050. CSE includes direct program costs like incentives, as well as measure installation, program design and administration, marketing, education, evaluation, and shareholder incentives/performance fees.
- Commercial

²⁴ American Council for an Energy Efficient Economy. (ACEEE). 2017. State Energy Efficiency Resource Standards. Accessed July 13, 2018. Available at <http://aceee.org/policy-brief/state-energy-efficiency-resource-standard-activity>

²⁵ American Council for an Energy Efficient Economy. (ACEEE). 2014. The Best Value for America’s Energy Dollar: A National Review of the Cost of Utility Energy Efficiency Programs. Accessed July 13, 2018. Available at <http://aceee.org/research-report/u1402>

- Energy Savings: The analysis team uses the same approach as residential, with savings percentages mirroring electricity.
- Cost Savings: Again, the team uses the same approach as residential.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Natural Gas Consumption (BBtu)	-15,883	-29,458	-25,153
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	845,010	1,567,198	1,338,143
SO ₂ Emission Reductions (MT)	4	8	7
NO _x Emission Reductions (MT)	653	1,211	1,034
Hg Emission Reductions (MT)	0.002	0.003	0.003
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$25.04	\$46.45	\$39.66
Fuel Savings (\$ Million)	\$180.56	\$402.41	\$313.96
Program Costs (\$ Million) ^a	\$30.27	\$52.70	\$46.40
Net Present Value (\$)			\$4,943,581,792
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			-\$119.17 ^b

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Public sector expenditures are in addition to the capital expenditures shown. This represents the administrative and incentive costs for energy efficient actions.

^b Negative cost-per-ton represents net cost savings.

Action: Expand energy assessments and provide more trainings on energy efficiency for industry

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Electricity
 - Energy Savings: Using the Pennsylvania Statewide Evaluator’s (SWE) *Energy Efficiency Potential Study for Pennsylvania*,²⁶ the analysis team applies the calculated maximum

²⁶ 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/pdocs/1345079.pdf>

achievable potential from 2020-2025 (1.2 percent) followed by the average incremental annual maximum achievable potential (1.2 percent) from 2016-2025 for years 2026-2050 for electricity.

- Cost Savings: The analysis team applies total incentive, administrative, and direct capital costs from PA SWE²⁷ annually from 2021-2050
- **Natural Gas**
 - Energy Savings: Using a 2009 Georgia Tech meta-review of efficiency potential studies²⁸, the team applies the natural gas average annual energy efficiency potential for the industrial sector of 0.6 percent from 2020-2050. The team assumes a measure lifetime of 10 years.
 - Cost Savings: The analysis team applies a \$0.35/therm levelized CSE from ACEEE's *Review of the Cost of Utility Energy Efficiency Programs*²⁹ annually from 2020-2050. CSE includes direct program costs like incentives, as well as measure installation, program design and administration, marketing, education, evaluation, and shareholder incentives/performance fees.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	-2,981	-6,211	-5,002
Change in Natural Gas Consumption (BBtu)	-15,781	-35,325	-26,790
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	1,901,335	3,110,031	2,786,470
SO ₂ Emission Reductions (MT)	2,190	2,236	2,754
NO _x Emission Reductions (MT)	1,607	2,296	2,276
Hg Emission Reductions (MT)	0.041	0.037	0.051
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$518.32	\$587.44	\$534.31
Fuel Savings (\$ Million)	\$382.07	\$930.66	\$694.36
Program Costs (\$ Million) ^a	\$156.24	\$183.94	\$165.20
Net Present Value (\$)			-\$718,032,002 ^b

²⁷ Ibid

²⁸ 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>

²⁹ American Council for an Energy Efficient Economy. (ACEEE). 2014. The Best Value for America's Energy Dollar: A National Review of the Cost of Utility Energy Efficiency Programs. Accessed July 13, 2018. Available at <http://aceee.org/research-report/u1402>

Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)	\$8.31
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Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Public sector expenditures are in addition to the capital expenditures shown. This represents the administrative and incentive costs for energy efficient actions.

^b NPV is only one metric used to assess the economic effects of an action. It does not include externality costs, such as those of GHGs or other emissions. A positive NPV indicates that cash inflows are greater than costs, whereas a negative NPV indicates the opposite. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action (e.g., cost per ton of CO₂ reduced, or macroeconomic benefits). A discount rate of 1.75% was used in this analysis, as representative of a societal policy perspective.

Strategy: Implement sustainable transportation planning and practices

Actions include:

- Reduce vehicle miles traveled for single-occupancy vehicles
- Implement a strategic plan and incentives for increasing electric vehicle use
- Increase the use of clean public transportation through electric municipal bus fleets

Action: Reduce vehicle miles traveled for single-occupancy vehicles

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- **VMT Reduction:** The analysis team uses an overall vehicle miles traveled (VMT) reduction target of 3.4 percent by 2030 and 7.5 percent of total VMT from BAU by 2050. This estimate is based on the draft Pennsylvania Energy Assessment Report prepared in 2018,³⁰ as well as Pennsylvania-specific runs of the EPA’s MOtor Vehicle Emission Simulator (MOVES),³¹ U.S. Energy Information Administration’s (EIA) *Annual Energy Outlook 2018*,³² and Federal Highway Administration VMT projections.³³

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
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³⁰ Pennsylvania Department of Environmental Protection (DEP). 2018. Draft Report: Energy Assessment Report for the Commonwealth of Pennsylvania.

³¹ <https://www.epa.gov/moves> Accessed July 3, 2018.

³² U.S. Energy Information Administration (EIA). 2018. Annual Energy Outlook. Accessed July 3, 2018. Available at: <https://www.eia.gov/outlooks/aeo/>

³³ 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

Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	-19	-195	-86
Change in Distillate Fuel Oil Consumption (BBtu)	-100	-546	-275
Change in Motor Gasoline Consumption (BBtu)	-7,790	-38,195	-19,582
Change in Biodiesel Consumption (BBtu)	-2.	-11	-6
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	573,260	2,820,936	1,448,026
SO ₂ Emission Reductions (MT)	21	91	55
NO _x Emission Reductions (MT)	731	996	790
Hg Emission Reductions (MT)	0.001	0.003	0.002
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$53.04	\$267.28	\$136.06
Maintenance and Repair Costs (\$ Million) ^a	-\$251.45	-\$1,263.82	-\$643.85
Fuel Savings (\$ Million)	\$175.35	\$875.06	\$446.60
Net Present Value (\$)			\$20,114,241,585
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			-\$447.32 ^b

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Negative maintenance and repair costs represent net cost savings. As fewer miles are traveled, reduced wear on vehicles results in savings on maintenance and repairs.^{ba} Negative cost-per-ton represents net cost savings.

Action: Implement a strategic plan and incentives for increasing electric vehicle use

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- EV Market Penetration:** The analysis team assumes EVs will represent 31 percent of the light-duty market share by 2030, rising to 88 percent by 2050. The target is based on a review of the U.S. EIA’s *Annual Energy Outlook 2018* national-level projections,³⁴ as well as the Pennsylvania

³⁴ U.S. Energy Information Administration (EIA). 2018. Annual Energy Outlook. Accessed July 3, 2018. Available at: <https://www.eia.gov/outlooks/aeo/>

DEP report *Pennsylvania Electric Vehicle Roadmap*,³⁵ with consideration for the current market share.³⁶

- **Costs and Fuel Economy:** Fuel cost, maintenance costs, and fuel economy values are based on Department of Energy (DOE) assumptions (via Argonne National Laboratory)³⁷ and Energy Information Administration (EIA) averages.^{38,39,40} EV charging infrastructure costs are based on a review of recent literature and industry information. Projected EV passenger vehicle costs are based on EIA's *Annual Energy Outlook 2018*⁴¹ projections as well as the National Renewable Energy Laboratory's (NREL) *Electrification Futures Study: A Technical Evaluation of the Impacts of an Electrified U.S. Energy System*.⁴² Bloomberg New Energy Finance cost forecasts⁴³ were also evaluated and considered for reference.
- **State Funding:** The analysis team estimates that state funding for infrastructure will be \$1.6 million per year from 2019 to 2028 based on the VW settlement funds of \$16 million. These annual levels are estimated with consideration of historical state funding for EV charging infrastructure, including Pennsylvania's Alternative Fuels Incentive Grant Program (AFIG)⁴⁴ and other state deployment projects (e.g., Pennsylvania Turnpike). This estimate is used as an input for the REMI model.
 - Pennsylvania's Alternative Fuels Incentive Grant program has been the primary source of state funding for EV charging stations as well as vehicles. \$5M is available for 2018, but only a portion of that has been routed to EVs and charging infrastructure. The team understands that \$1M is set aside for alternative fuel infrastructure of all types, including EV charging and can generally estimate that approximately \$1.5-2M per year (for the last few years) has been allocated to EVs and infrastructure.
 - This analysis does not include any federal funding, which, if available, would improve the economic case for purchasing EVs.

³⁵ Pennsylvania Department of Environmental Protection. (DEP). 2018. Pennsylvania Electric Vehicle Roadmap. *In Draft Final Stages as of November 21, 2018.*

³⁶ Level 1 equipment it's less expensive, but it is likely not going to receive much public funding as it is focused on residential and some businesses. Additionally, as batteries get bigger/ranges get longer, Level 1 likely will not be able to meet the technical requirements. Much of the market share and focus is on Level 2 equipment.

³⁷ ANL. 2017. AFLEET Tool. Accessed July 3, 2018. Available at: https://greet.es.anl.gov/afleet_tool

³⁸ U.S. EIA. 2018. Annual Energy Outlook 2018. Accessed July 3, 2018. Available at: <https://www.eia.gov/outlooks/aeo/>

³⁹ U.S. EIA. 2018. Weekly Retail Gasoline and Diesel Prices. Accessed July 3, 2018. Available at: https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r1y_a.htm

⁴⁰ U.S. EIA. 2018. Pennsylvania State Profile and Energy Estimates. Accessed July 3, 2018. Available at: <https://www.eia.gov/state/rankings/?sid=PA#series/31>

⁴¹ U.S. EIA. 2018. Annual Energy Outlook. Accessed July 3, 2018. Available at: <https://www.eia.gov/outlooks/aeo/>

⁴² NREL. 2018. Electrification Futures Study: A Technical Evaluation of the Impacts of an Electrified U.S. Energy System. Accessed July 3, 2018. Available at: <https://www.nrel.gov/analysis/electrification-futures.html>

⁴³ Bloomberg New Energy Finance. 2017. The Electric Car Revolution Is Accelerating. Available at: <https://www.bloomberg.com/news/articles/2017-07-06/the-electric-car-revolution-is-accelerating>

⁴⁴ <http://www.envirothonpa.org/documents/22fAFIG.pdf> Accessed on July 4, 2018.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	1,310	41,736	16,434
Change in Distillate Fuel Oil Consumption (BBtu)	-160	-5,788	-2,256
Change in Motor Gasoline Consumption (BBtu)	-12,951	-411,724	-162,144
Change in Biodiesel Consumption (BBtu)	-3	-118	-46
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	474,100	21,689,937	7,694,504
SO ₂ Emission Reductions (MT)	-949	-14,735	-8,012
NO _x Emission Reductions (MT)	782	4,761	1,926
Hg Emission Reductions (MT)	0.02	0.20	-0.13
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$1,927.83	\$5,664.45	\$3,556.81
Maintenance and Repair Costs (\$ Million)	-\$49.90	-1,597.41	-\$628.72
Fuel Savings (\$ Million)	\$108.40	\$3,450.53	\$1,358.73
Net Present Value (\$)			-\$35,983,465,661 ^a
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			\$150.85

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a NPV is only one metric used to assess the economic effects of an action. It does not include externality costs, such as those of GHGs or other emissions. A positive NPV indicates that cash inflows are greater than costs, whereas a negative NPV indicates the opposite. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action (e.g., cost per ton of CO₂ reduced, or macroeconomic benefits). A discount rate of 1.75% was used in this analysis, as representative of a societal policy perspective.

Action: Increase the use of clean public transportation through electric municipal bus fleets

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- **New EV Bus Purchases:** The analysis team assumes that 25 percent of new municipal transit bus purchases will be zero emission buses, specifically battery electric, by 2030, increasing to 60 percent by 2050. This projection is based on zero emission transit bus market penetration

projections from CALSTART⁴⁵ as well as various state targets. While hydrogen buses may also prove feasible in the long-term, battery electric buses are likely to dominate the zero emission bus market in Pennsylvania due to technology maturity, relatively lower low life cycle costs and environmental benefits⁴⁶.

- **Costs and Fuel Economy:** Fuel costs, maintenance costs, and fuel economy values are based on U.S. Department of Energy (DOE) assumptions (via Argonne National Laboratory)⁴⁷ and U.S. EIA averages.^{48,49,50} Electric transit bus and charging infrastructure costs are based on a review of recent literature and industry information.^{51,52,53,54,55,56,57} This analysis does not include any state or federal incentive funding, which, if available, would significantly improve the economic case for purchasing zero emission buses.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	38	872	301
Change in Distillate Fuel Oil Consumption (BBtu)	-330	-7,543	-2,604

⁴⁵ CALSTART. 2015. Electric Truck & Bus Grid Integration: Opportunities, Challenges & Recommendations. Accessed July 3, 2018. Available at:

http://www.calstart.org/Libraries/Publications/Electric_Truck_Bus_Grid_Integration_Opportunities_Challenges_Recommendations.sflb.ashx

⁴⁶ Carnegie Mellon University (CMU) Scott Institute for Energy Innovation. 2016. Policymaker Guide: Which Alternative Fuel Technology is Best for Transit Buses?. Accessed July 15, 2018. Available at:

https://www.cmu.edu/energy/education-outreach/public-outreach/17-104%20Policy%20Brief%20Buses_WEB.pdf

⁴⁷ Argonne National Laboratory (ANL). 2017. Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool. Accessed July 3, 2018. Available at: https://greet.es.anl.gov/afleet_tool

⁴⁸ U.S. EIA. 2018. Annual Energy Outlook 2018. Accessed July 3, 2018. Available at:

<https://www.eia.gov/outlooks/aeo/>

⁴⁹ U.S. EIA. 2018. Weekly Retail Gasoline and Diesel Prices. Accessed July 3, 2018. Available at:

https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_r1y_a.htm

⁵⁰ U.S. EIA. 2018. Pennsylvania State Profile and Energy Estimates. Accessed July 3, 2018. Available at:

<https://www.eia.gov/state/rankings/?sid=PA#series/31>

⁵¹ Tyggestad, C., N. Sharma, J. van de Staaij, and A. McKinsey Energy Institute. 2017. Keizer, New Reality: Electric Trucks and their Implications on Energy Demand

⁵² California Air Resources Board (CARB). 2015. Draft Technology Assessment: Medium- and Heavy-Duty Fuel Cell Electric Vehicles. Available at: https://www.arb.ca.gov/msprog/tech/techreport/fc_tech_report.pdf

⁵³ Eudy, L. and M. Jeffers. National Renewable Energy Laboratory (NREL). 2017. Foothill Transit Battery Electric Bus Demonstration Results: Second Report. Available at: <https://www.nrel.gov/docs/fy17osti/67698.pdf>

⁵⁴ Swanton, A. BYD. 2017. The Pathway to Battery Electric. Presentation.

⁵⁵ Chandler, S., J. Espino, and J. O'Dea. Union of Concerned Scientists and The Greenlining Institute. 2017. Delivering Opportunity: How Electric Buses and Trucks Can Create Jobs and Improve Public Health in California. Available at: <https://www.ucsusa.org/sites/default/files/attach/2016/10/UCS-Electric-Buses-Report.pdf>

⁵⁶ CARB. 2015. Draft Technology Assessment: Medium- and Heavy-Duty Battery Electric Trucks and Buses. Available at: https://www.arb.ca.gov/msprog/tech/techreport/bev_tech_report.pdf

⁵⁷ CARB. 2017. Innovative Clean Transit. Available at: <https://arb.ca.gov/msprog/ict/ict.htm>

Change in Natural Gas Consumption (BBtu)	-57	-1,356	-465
Change in Biodiesel Consumption (BBtu)	-7	-154	-53
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	13,948	458,048	142,951
SO ₂ Emission Reductions (MT)	-27	-306	-145
NO _x Emission Reductions (MT)	93	1,453	496
Hg Emission Reductions (MT)	-0.00004	0.00576	0.00106
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$97.32	\$442.34	\$238.37
Maintenance and Repair Costs (\$ Million)	-\$0.70	-\$15.02	-\$5.30
Fuel Savings	\$2.71	\$57.76	\$20.38
Net Present Value (\$)			-\$4,527,294,366 ^a
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			\$1,021.53

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a NPV is only one metric used to assess the economic effects of an action. It does not include externality costs, such as those of GHGs or other emissions. A positive NPV indicates that cash inflows are greater than costs, whereas a negative NPV indicates the opposite. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action (e.g., cost per ton of CO₂ reduced, or macroeconomic benefits). A discount rate of 1.75% was used in this analysis, as representative of a societal policy perspective.

Sector: Energy Production

Strategies include:

- Increase use of clean, distributed electricity generation resources
- Create a diverse portfolio of clean, utility-scale electricity generation
- Reduce upstream impacts of fossil fuel energy production
- Increase production and use of alternative fuels

Strategy: Increase use of clean, distributed electricity generation resources

Actions include:

- Invest in and promote building-scale solar
- Incentivize and increase use of combined heat and power

Action: Invest in and promote building-scale solar

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Energy:** The analysis team uses information from the *Finding Pennsylvania's Solar Future Plan (PA Solar Future)*.⁵⁸ In this Plan, the building-scale solar is 10 percent of total solar development, as outlined in the Plan's Scenario B, and building-scale solar capacity is split evenly between residential and commercial. System costs are taken from the *PA Solar Future* study which come from the 2017 National Renewable Energy Laboratory (NREL) Annual Technology Baseline Data; residential system costs are assumed to fall from \$2.40/watt in 2020 to \$1.15/watt in 2050, while commercial system costs are assumed to fall from \$1.78/watt in 2020 to \$0.97/watt in 2050.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	0	-243	-208
Change in Renewable Energy Capacity (MW)	0	69	4
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	-	48,210	55,279
SO ₂ Emission Reductions (MT)	-	87	111
NO _x Emission Reductions (MT)	-	33	47
Hg Emission Reductions (MT)	-	0.001	0.002
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$0.00	-\$2.34	\$28.56
Maintenance and Repair Costs (\$ Million)	\$0.00	\$0.60	\$0.00
Fuel Savings (\$ Million)	\$0.00	\$34.94	\$0.71
Net Present Value (\$)			\$489,952,564
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			-\$285.11 ^a

Notes: Positive "changes" indicate increases from BAU values, whereas negative "changes" indicate reductions from BAU values. Positive "reductions" indicate reductions from BAU, whereas negative "reductions" indicate increases from BAU.

^a Negative cost-per-ton represents net cost savings.

⁵⁸ Pennsylvania Department of Environmental Protection (PA DEP). 2018. Finding Pennsylvania's Solar Future Plan. Accessed July 3, 2018. Available at:

<http://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/SolarFuture/Pages/Finding-Pennsylvania%E2%80%99s-Solar-Future.aspx>

Action: Incentivize and increase use of combined heat and power

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- **Preferential Rate Incentive:** Efficient combined heat and power (CHP) systems are assumed to receive a preferential retail natural gas rate of \$5 per MMBtu, escalating according to BAU natural gas growth rates through 2050. The preferential natural gas rate is similar to natural gas rates offered to CHP customers through New York and California investor-owned utilities (IOUs). While current natural gas rates are lower, given the timeframe of this analysis a \$5 price is assumed as the ceiling price for which CHP would remain competitive. This action will improve project economics and encourage greater deployment of utility-scale industrial CHP installations as well as CHP systems under 20 MW in size. The analysis team uses 20 MW as the threshold in line other related work conducted, such as for the DOE report *Combined Heat and Power (CHP) Technical Potential in the United States*.⁵⁹ Potential host sites for utility-scale CHP in Pennsylvania are identified in ICF's CHP Database.⁶⁰ The analysis team estimates payback periods for each potential project using cost and performance assumptions, based on system sizes, from the previous analysis for the draft Pennsylvania Energy Assessment Report prepared in 2018.⁶¹
- **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.
 - **>20 MW:** With utility-scale CHP defined as CHP applications 20 MW or larger in size, the business-as-usual case relies on the assumption that all high load factor sites have economic potential, with about one-third of the full potential annualized through 2030, and a phase-out of annual installations from 2031 to 2035 as the electricity grid gets cleaner and CHP becomes a less effective mitigation option. The incentive appears to have a marginal effect on economics for sites supporting >20 MW CHP, as \$5/MMBtu is not significantly lower than the BAU natural gas rate. However, the lower natural gas rate did push one large low load factor site – the City of Philadelphia government building complex – into economic territory. Overall, an additional 636 MW of utility-scale CHP is expected through 2050, compared to the BAU case, and the economic incentive would only have a marginal effect on the annualized numbers.
 - **<20MW:** For CHP at large campuses, hospitals, and industrial buildings, the team expects an increase in end-use natural gas consumption coupled with a decrease in end-use electricity consumption as a result of sites producing their own power and heat with CHP. Savings from utility transmission and distribution losses are estimated based on

⁵⁹ Department of Energy. (DOE). 2016. Combined Heat and Power (CHP) Technical Potential in the United States. DOE/EE-1328. Accessed July 15, 2018. Available at: <https://www.energy.gov/sites/prod/files/2016/04/f30/CHP%20Technical%20Potential%20Study%203-31-2016%20Final.pdf>

⁶⁰ ICF. Combined Heat and Power Database. Proprietary. Accessed July 3, 2018.

⁶¹ Pennsylvania Department of Environmental Protection (DEP). 2018. Draft Report: Energy Assessment Report for the Commonwealth of Pennsylvania.

eGrid factors from EPA’s State Inventory Tool (SIT). With natural gas costs starting at \$5/MMBtu, economics for CHP are greatly improved for smaller applications. All potential CHP sites for high load factor applications under 20 MW in size—identified from ICF’s CHP Technical Potential Database—would have economic potential for CHP. Additionally, some low load factor applications in the 500-999 kW size range become economical with the lower natural gas rate. Overall, this represents an increase of 1.8 GW of economic potential compared to the BAU case, which would be primarily installed from 2020 to 2030, with installations slowing from 2031 to 2035 as the electricity grid gets cleaner and CHP becomes a less effective mitigation option. The increase would likely start in 2020, as CHP projects generally take two years to go from planning to commissioning and operation.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	-7,855	-17,618	-14,075
Change in Natural Gas Consumption (BBtu)	42,448	95,191	127,243
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO _{2e})	544,502	-1,561,128	-209,176
SO ₂ Emission Reductions (MT)	5,695	6,169	7,605
NO _x Emission Reductions (MT)	619	-1,881	-106
Hg Emission Reductions (MT)	0.10	0.08	0.12
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$327.12	\$0.00 ^a	\$135.68
Maintenance and Repair Costs (\$ Million)	\$103.50	\$232.69	\$185.81
Fuel Savings (\$ Million)	\$577.72	\$1,181.75	\$1,012.83
Net Present Value (\$)			\$7,295,090,181
Cost-per-ton of GHG Emission Reductions (\$/mt CO _{2e})			NA ^b

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a There are no new installations after 2035.

^b Because this action (CHP) is projected to result in a net increase in GHG emissions by 2050, a reduction cost per ton is not an applicable metric. GHG emissions reduced through electricity savings are counter balanced by GHG emissions resulting from increased natural gas use: as grid carbon intensity declines, it reaches a point where reducing electricity use by increasing natural gas use begins to increase net CO₂ emissions. In this modeling analysis, that point occurs during the 2040s.

Strategy: Create a diverse portfolio of clean, utility-scale electricity generation

Actions include:

- Increase Alternative Energy Portfolio Standard(AEPS) Tier 1 targets, and further increase in-state generation and use of renewables
- Implement policy to maintain nuclear generation at current levels
- Limit carbon emissions through an electricity sector cap and trade program

Action: Increase AEPS Tier 1 targets, and further increase in-state generation and use of renewables

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Energy: The analysis team increases AEPS requirements from eight percent Tier I renewables by 2020 (2020-2021 year) to 30 percent Tier 1 by 2030 and 50 percent by 2050 with a six percent solar carve out phased in linearly to 2030.⁶² These increases are in line with what the analysis team found for other states, and represent an aggressive target.⁶³ More specifically:
 - The solar carve out is in line with *Finding Pennsylvania's Solar Future Plan*.⁶⁴
 - Generation for wood/wood waste solids, low impact hydro, black liquor, coal mine methane and other biogas from 2017 through 2050 was developed based on the Lawrence Berkeley National Lab's (LBNL) report *Renewables Portfolio Standards: 2017 Annual Status Report*.⁶⁵ If these resources are developed through other strategy actions (e.g., Promote the production and use of alternative fuels), the related impacts are built into this AEPS action.

⁶² The solar carve out means that solar must account for 6% of utility sales by 2030. This percentage is phased in from 2020 to 2030 in equal annual increments. The AEPS solar carve out in the Pennsylvania Solar Futures Study (PASF) remained between 4 and 8 percent; a 6 percent AEPS solar carve out was deemed a feasible and appropriate option by the PASF stakeholder group.

⁶³ ICF reviewed renewable energy policies from New Jersey, Delaware, Maryland, District of Columbia, North Carolina, Michigan, Ohio, Illinois, New York, California, Oregon, and Rhode Island. This list captures the PJM Region states as well as states that are likely the most aggressive in their renewable policies. Lawrence Berkeley National Lab (LBNL). 2017. U.S. Renewables Portfolio Standards: 2017 Annual Status Report. Accessed July 3, 2018. Available at: <https://emp.lbl.gov/publications/us-renewables-portfolio-standards-0>

⁶⁴ Pennsylvania Department of Environmental Protection (PA DEP). 2018. Finding Pennsylvania's Solar Future Plan. Accessed July 3, 2018. Available at: <http://www.dep.pa.gov/Business/Energy/OfficeofPollutionPrevention/SolarFuture/Pages/Finding-Pennsylvania%E2%80%99s-Solar-Future.aspx>

⁶⁵ Lawrence Berkeley National Lab (LBNL). 2017. U.S. Renewables Portfolio Standards: 2017 Annual Status Report. Accessed July 3, 2018. Available at: <https://emp.lbl.gov/publications/us-renewables-portfolio-standards-0>

- Wind is scaled up to make up the difference between total Tier 1 generation and the sum of the solar and other non-solar Tier 1 resources.⁶⁶
- All future solar Alternative Energy Credits (AECs) are closed to Pennsylvania borders through 2050. This assumption is based on the Pennsylvania House Bill 118, 2017 Act 40 published on October 30, 2017).⁶⁷
- **Costs:** The analysis team relies on cost data from the National Renewable Energy Laboratory's (NREL) 2017 Annual Technology Baseline Data,⁶⁸ using the mid-cost scenario for utility-scale solar, building-scale solar, and wind. These data are also used in *Finding Pennsylvania's Solar Future Plan*. The wind cost scenario was chosen based on the 30 percent statewide capacity factor indicated in the LBNL *Renewables Portfolio Standards: 2017 Annual Status Report*.⁶⁹

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Renewable Energy Generation (GWh)	13,867	58,725	34,149
Change in Renewable Energy Capacity (MW)	6,496	24,486	14,849
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	10,532,686	51,422,405	28,007,231
Target-Related GHG Emission Reductions (MTCO ₂ e) ^a	6,703,719	27,639,941	16,108,474
SO ₂ Emission Reductions (MT)	12,770	76,275	17,475
NO _x Emission Reductions (MT)	6,100	34,217	17,475
Hg Emission Reductions (MT)	0.3	1.4	0.7
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$1,949.16	\$1,126.74	\$1,202.80
Maintenance and Repair Costs (\$ Million)	\$89.47	\$156.55	\$160.66
Fuel Savings (\$ Million)	\$337.12	\$1,557.02	\$879.20
Net Present Value (\$)			-\$13,550,651,044 ^b
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			\$27.13

Notes: Positive "changes" indicate increases from BAU values, whereas negative "changes" indicate reductions from BAU values. Positive "reductions" indicate reductions from BAU, whereas negative "reductions" indicate increases from BAU.

⁶⁶ The team also assumes that wind (and other AEPS generating sources) are being produced in-state.

⁶⁷ Pennsylvania House Bill 118, 2017 Act 40. Accessed on July 3, 2018. Available at:

<http://www.legis.state.pa.us/cfdocs/legis/li/uconsCheck.cfm?yr=2017&sessInd=0&act=40>

⁶⁸ National Renewable Energy Laboratory (NREL). 2017. Annual Technology Baseline. Accessed July 3, 2018.

Available at: <https://atb.nrel.gov/>

⁶⁹ Lawrence Berkeley National Lab (LBNL). 2017. U.S. Renewables Portfolio Standards: 2017 Annual Status Report. Accessed July 3, 2018. Available at: <https://emp.lbl.gov/publications/us-renewables-portfolio-standards-0>

^a Target-related GHG emission reductions represent the portion of emission reductions associated with in-state electricity consumption. This metric is shown only for actions that affect Pennsylvania's electricity generation fuel mix since these result in additional GHG emission reductions that are not accounted for within the commonwealth (i.e., emissions associated with generated electricity that is exported and consumed outside of Pennsylvania). For actions that do not affect the grid, 100 percent of total GHG emission reductions are counted toward the target.

^b NPV is only one metric used to assess the economic effects of an action. It does not include externality costs, such as those of GHGs or other emissions. A positive NPV indicates that cash inflows are greater than costs, whereas a negative NPV indicates the opposite. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action (e.g., cost per ton of CO₂ reduced, or macroeconomic benefits). A discount rate of 1.75% was used in this analysis, as representative of a societal policy perspective.

Action: Implement policy to maintain nuclear generation at current levels

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Energy:** For the BAU, the analysis team assumes that as announced Three Mile Island closes in 2019 and Beaver Valley closes in 2021.⁷⁰ BAU nuclear generation levels are held constant after these plants are closed.⁷¹ 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.
- Costs:** Operating and maintenance costs are based on EPA's Base Case for the Integrated Planning Model and include fixed and variable operation and maintenance (O&M) costs associated with increased nuclear generation and capacity as well as O&M savings from reduced natural gas and coal electricity generation.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	28,928,575	39,353,499	29,677,777
Target-Related GHG Reductions (MTCO ₂ e) ^a	18,412,115	21,152,811	17,526,325
SO ₂ Emission Reductions (MT)	35,974	36,267	33,548

⁷⁰ <http://www.businessinsider.com/three-mile-island-nuclear-plant-closing-2017-5> and <https://www.bizjournals.com/pittsburgh/news/2018/03/28/firstenergy-announces-plans-to-close-beaver-valley.html>. Accessed July 3, 2018.

⁷¹ This BAU is different than what is represented in the recent draft report *Commonwealth of Pennsylvania Energy Assessment Report*. In the BAU in Energy Assessment report, only the Three Mile Island closure was accounted for; the Beaver Valley closure was announced after the analysis for the Energy Assessment was completed.

NOx Emission Reductions (MT)	16,755	24,605	17,303
Hg Emission Reductions (MT)	0.7	1.0	0.7
Economic Benefits and Costs			
Maintenance and Repair Costs (\$ Million)	\$843.72	\$1,136.27	\$879.46
Fuel Savings (\$ Million)	\$248.14	\$267.79	\$242.69
Net Present Value (\$)	-\$14,463,164,164 ^b		
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)	\$26.31		

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Target-related GHG emission reductions represent the portion of emission reductions associated with in-state electricity consumption. This metric is shown only for actions that affect Pennsylvania’s electricity generation fuel mix since these result in additional GHG emission reductions that are not accounted for within the commonwealth (i.e., emissions associated with generated electricity that is exported and consumed outside of Pennsylvania). For actions that do not affect the grid, 100 percent of total GHG emission reductions are counted toward the target.

^b NPV is only one metric used to assess the economic effects of an action. It does not include externality costs, such as those of GHGs or other emissions. A positive NPV indicates that cash inflows are greater than costs, whereas a negative NPV indicates the opposite. A negative NPV does not necessarily indicate that a strategy or action is not cost-effective, as there are other metrics that should be used to evaluate cost-effectiveness of an action (e.g., cost per ton of CO₂ reduced, or macroeconomic benefits). A discount rate of 1.75% was used in this analysis, as representative of a societal policy perspective.

Action: Limit carbon emissions through an electricity sector cap and trade program

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- **Carbon Limit:** The analysis team establishes a carbon emission limit for each year, modeling a 30 percent reduction from 2020 carbon dioxide (CO₂) levels by 2030. The team assumes that the post-2030 emissions cap is stringent enough to phase out most remaining coal generation other than waste coal by 2050. Both the AEPS expansion and maintaining current levels of nuclear generation contribute to meeting the emission reductions target set by the power sector carbon cap and trade action. Remaining reductions needed are met through the abatement actions described here.
- **Abatement Actions:** Carbon abatement is modeled as two steps, which when combined are sufficient to meet the modeled carbon limit. These steps include:
 - **Step 1:** Natural gas dispatch is increased up to 75 percent utilization, while coal generation drops an equivalent amount. This decrease in coal generation is met through coal retirements.
 - **Step 2** (if the emissions decreases in step 1 are insufficient to meet the emission limit in a given year): Coal generation decreases until the CO₂ limit is met, and this decrease in

coal generation is taken out of Pennsylvania exports. Like in step 1, decreases in coal generation are modeled through coal retirements.

- **Carbon Price:** Each abatement action has an associated marker carbon price derived based on relative levelized cost of electricity (LCOE) calculations.⁷² In other words, the carbon prices are designed to achieve the cap selected for modeling purposes (see above); the carbon price is high enough to reduce the cost-competitiveness of coal relative to natural gas, which is the incremental step beyond the AEPS that is needed to meet carbon limits and overall GHG reduction targets used for this modeling exercise.⁷³ The carbon price is estimated to be \$1.00 per metric ton of CO₂ equivalent from 2021 through 2050.
- **Carbon Revenue Recycling:** Revenues from the cap and trade program are modeled in REMI as a simple payment to electricity consumers to offset the cost of the program.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	7,697,521	0	4,972,721
Target-related GHG Emission Reductions (MTCO ₂ e) ^a	4,899,227	0	3,035,130
SO ₂ Emission Reductions (MT)	9,572	0	5,955
NO _x Emission Reductions (MT)	9,131	0	5,773
Hg Emission Reductions (MT)	0.4	0	0.2
Economic Benefits and Costs			
Maintenance and Repair Costs (\$ Million)	-\$616.34	\$0.00	-\$404.31
Fuel Savings (\$ Million)	-\$242.46	\$0.00	-\$197.97
Net Present Value (\$)			\$5,174,461,283
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			\$55.00 ^b

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Target-related GHG emission reductions represent the portion of emission reductions associated with in-state electricity consumption. This metric is shown only for actions that affect Pennsylvania’s electricity generation fuel mix since these result in additional GHG emission reductions that are not accounted for within the commonwealth (i.e., emissions associated with generated electricity that is exported and consumed outside of Pennsylvania). For actions that do not affect the grid, 100 percent of total GHG emission reductions are counted toward the target.

⁷² The marker carbon price is derived by comparing the LCOE of lower-emitting vs. higher-emitting generation technologies; e.g. a carbon price of X would be enough to make lower-emitting generator A economically competitive with higher-emitting generator B.

⁷³ The carbon price used for the cap and trade program is not equivalent to a social cost of carbon, which is aimed at valuing the climate impact of GHG emissions (i.e., the cost of levelized damages over the lifetime of the emissions).

^b Negative cost-per-ton represents net cost savings.

Strategy: Reduce upstream impacts of fossil fuel energy production

Actions include:

- Implement policies and practices to reduce methane emissions across natural gas systems

Action: Implement policies and practices to reduce methane emissions across oil and natural gas systems

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Emissions and BAU Reduction Baseline:
 - To establish an initial source level baseline, the analysis team utilized a study performed by Environmental Defense Fund (EDF)⁷⁴ which characterized upstream oil and natural gas emissions by determining cumulative source level emission and reduction estimates in future years under various regulation scenarios. The “DEP provided” cumulative emissions baseline from the study (“No Control” scenario, Short Term (2018-2020)) is considered in this analysis for both new and existing sources. Specific to this analysis, DEP-provided cumulative reduction percentages are used to generate BAU reductions for each source to provide revised 2020 cumulative emission and reduction estimates. These percentages represent the impact of complying with both federal and state level regulation of methane emitting upstream oil and natural gas sources.
 - Cumulative source level estimates are annualized using an iterative process which considers the 2020 cumulative existing and new emission “target” results, Energy Information Administration (EIA) Annual Energy Outlook (AEO) projections of oil and natural gas production (see discussion below)⁷⁵, and a decreasing trend in applicable reduction. Reduction effectiveness is assumed to decrease over time as regulation requirements are met. Existing sources have an annual assumed turnover rate (i.e., retirement and replacement with new activity to account for missing capacity). All retired existing sources are considered replaced regardless of whether overall production has decreased in a future year. Retirements are included as new sources with appropriate compliance to BAU regulations per DEP input. EDF new source 2020 cumulative result “targets” are also adjusted with respect to existing source turnover rates from 2015 to 2020.
 - Because DEP estimates are provided for unconventional sources only, conventional estimates are assumed to match that of unconventional sources per DEP input. Downstream emissions estimates are provided by EPA State Inventory Tool (SIT)⁷⁶ results and are projected from 2015 to 2050 using EIA AEO 2017 reference case natural

⁷⁴ Environmental Defense Fund. (EDF). “Explore Pennsylvania’s oil and gas pollution”, <https://www.edf.org/energy/explore-pennsylvanias-oil-and-gas-pollution>

⁷⁵ U.S. Energy Information Administration. (EIA). Annual Energy Outlook (AEO) 2017. <https://www.eia.gov/outlooks/archive/aeo17/>

⁷⁶ U.S. Environmental Protection Agency. (EPA). State Inventory and Projection Tool. <https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool>

gas consumption⁷⁵. All upstream results generated in this analysis are scaled to match upstream SIT estimates to give appropriate segment proportions and to match Task 1 BAU case estimates.

- **Annualization and Projection of Emission and Reduction Results:**
 - Energy Information Administration (EIA) Annual Energy Outlook (AEO) 2017 reference case oil and natural gas production values⁷⁵ are used to both annualize source level results for 2015-2020 and project 2020 estimates to 2050. Certain sources are driven using forecasted natural gas production, while others are driven using a combination of oil/natural gas production (combined BTU). AEO estimates utilized in this analysis are representative of the Middle Atlantic and East supply regions respectively. Natural gas prices used when determining recovered revenue as discussed below are also representative of the East supply region. BAU reductions in future years are determined by applying a reduction percentage to projected source level emission estimates.
- **Voluntary Reductions and Associated Costs:**
 - Voluntary reductions are determined by source using assumed applicability (e.g., technical limitations may exist at certain sites), reduction effectiveness, and incentive for an operator replace an existing source. Each of the above assumptions by source are based on ICF input. The analysis team assumed operator incentive to reach full applicability by 2050. Voluntary reduction volumes are determined by applying these assumptions to both existing emissions source and new sources which are not controlled through compliance with BAU regulations.
 - Capital and operating costs are determined using the voluntary reduction volume as determined above with an associate reduction per activity. This determines a number of required actions (and associated capital and operating cost) to account for the appropriate volume of voluntary reductions for each source. Recovered revenue is also calculated using voluntary reduction volumes as determined above for activities where capture is possible. An upstream natural gas composition of 78.8% methane is considered when determining recovered revenue.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	104,879	29,598	70,913
SO ₂ Emission Reductions (MT)	0	0	0
NO _x Emission Reductions (MT)	0	0	0
Hg Emission Reductions (MT)	0	0	0
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$2.51	\$5.49	\$3.71
Maintenance and Repair Costs (\$ Million)	\$0.52	\$1.23	\$0.81
Net Present Value (\$)			-\$58,851,222
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			\$18.70

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

Strategy: Increase production and use of alternative fuels

Actions include:

- Increase recovery and use of gas from coal mines, agriculture, wastewater, and landfills for energy

Action: Increase recovery and use of gas from coal mines, agriculture, wastewater, and landfills for energy

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- Coal Mine Methane
 - Energy Production and Consumption: The analysis team assumes that the full economic potential, estimated in the draft Pennsylvania Energy Assessment Report prepared in 2018,⁷⁷ is realized each year through 2050. The team assumes that all production is provided to natural gas pipelines and that production does not result in any additional natural gas consumption in PA.
 - Emission Reductions: Expected greenhouse gas emission reductions are calculated using the Coal Module from EPA’s State Inventory Tool (SIT).⁷⁸ The team assumes that captured methane would otherwise be vented and can therefore subtract the project methane production from total coal mining emissions for the commonwealth, as projected by the SIT through 2050.
 - Costs: The team relies on estimates from the U.S. Environmental Protection Agency’s (EPA) *Global Mitigation of Non-CO₂ Greenhouse Gases, 2010-2030* report for project capital expenditures.⁷⁹ The analysis team assumes that additional capital costs are incurred based on the average production of methane per mine in the BAU scenario. Based on projected production, the team estimates an additional three projects would be developed between 2018 and 2050, costing approximately \$8.6 million per project. The team relies on operation and maintenance cost estimates from EPA’s Coal Mine Methane Project Cash Flow Model Version 3.⁸⁰
- Agriculture Waste, Landfill Gas, and Wastewater

⁷⁷ Pennsylvania Department of Environmental Protection (DEP). 2018. Draft Report: Energy Assessment Report for the Commonwealth of Pennsylvania.

⁷⁸ <https://www.epa.gov/statelocalenergy/download-state-inventory-and-projection-tool> Accessed on July 3, 2018.

⁷⁹ United States Environmental Protection Agency. (USEPA). 2013. Global Mitigation of Non-CO₂ Greenhouse Gases: 2010-2030. EPA-430-R-13-011. Accessed July 3, 2018. Available at:

https://www.epa.gov/sites/production/files/2016-06/documents/mac_report_2013.pdf

⁸⁰ <https://www.epa.gov/cmop/cmm-cash-flow-model> Accessed on July 3, 2018.

- **AEPS Support:** The analysis team estimates expected AEC prices based on the historic relationship between the stringency of the AEPS Tier 1 targets and average prices, as reported by the Pennsylvania Public Utility Commission (PUC). Assuming a ramp up schedule consistent with the action discussed above, the team estimates AEC prices through 2050, with the ACP price (\$45/MWh) under current law acting as a ceiling. The team assumes that this serves as an additional incentive when determining project payback periods, accelerating deployment rates.
- **Costs:** Capital expenditures plus operation and maintenance costs are based on estimates provided by the Oak Ridge National Laboratory's *Combined Heat and Power Market Potential for Opportunity Fuels* report.⁸¹ These are consistent with assumptions used in the Energy Assessment Report.
- **Energy Savings:** Renewable energy generation is expected to increase as a result of added capacity; this increase in renewable energy is modeled as a displacement of electricity consumption from the grid. We also estimate a decline in natural gas consumption resulting from displaced thermal output caused by the additional CHP deployment for wastewater and agricultural applications, while additional landfill applications are expected to only increase electricity generation from landfill gas. The amount of natural gas displacement is based on the expected thermal output and utilization rates of projects, which varies by project capacity.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Electricity Consumption (GWh)	-331	-876	-668
Change in Natural Gas Consumption (BBtu)	-1,413	-3,772	-2,871
Change in Biogas Consumption (BBtu)	3,598	9,522	7,261
Change in Renewable Energy Capacity (MW)	40	105	80
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	1,673,531	2,796,683	2,339,415
SO ₂ Emission Reductions (MT)	197	193	272
NO _x Emission Reductions (MT)	-778	-2,222	-1,629
Hg Emission Reductions (MT) ^a	NE	NE	NE
Economic Benefits and Costs			
Capital Expenditures (\$ Million) ^b	\$37.03	\$0.24	\$15.80
Maintenance and Repair Costs (\$ Million)	\$9.46	\$20.47	\$16.09

⁸¹ Jones, David and Paul Lemar. 2015. Combined Heat and Power Market Potential for Opportunity Fuels. Resource Dynamics Corporation. Prepared for Oak Ridge National Laboratory. ORNL/TM-2015/745. Accessed July 3, 2018. Available at: <https://info.ornl.gov/sites/publications/Files/Pub60457.pdf>

Fuel Savings (\$ Million)	\$44.78	\$131.53	\$96.61
Net Present Value (\$)			\$1,299,263,126
Cost-per-ton of GHG Emission Reductions (\$/MTCO ₂ e)			-\$17.54 ^c

“NE” indicates that the value was not estimated.

Notes: Positive “changes” indicate increases from BAU values, whereas negative “changes” indicate reductions from BAU values. Positive “reductions” indicate reductions from BAU, whereas negative “reductions” indicate increases from BAU.

^a Appropriate emission factors for Hg from biogas consumption were not readily available.

^b Capital expenditures of \$8.64 million for coal mine methane capture occur in 2020, 2024, and 2037. These years are not shown in this table, but are captured in the annual average capital expenditures.

^c Negative cost-per-ton represents net cost savings.

Sector: Agriculture

Strategies include:

- Use agricultural best practices

Strategy: Use agricultural best practices

Actions include:

- Implement and provide training for no-till farming practices

Action: Implement and provide training for no-till farming practices

To quantify the cost and effects of this action, the analysis team used the following assumptions, data, and methods:

- **Total Acres Planted:** The analysis team assumes total acres planted in Pennsylvania will increase by approximately 2 percent annually based on the U.S. Department of Agriculture (USDA) Pennsylvania Tillage Survey statistics for 2013 and 2014.⁸²
- **Acres Planted by Crop:** The team assumes that the percent of acres planted by crop will be 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.⁸³
- **Tillage Adoption:** The team assumes conventional tillage acres will transition to reduced tillage acres, and reduced tillage acres will transition to no-tillage acres.⁸⁴

⁸² https://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Publications/Annual_Statistical_Bulletin/2013_2014/ Accessed on July 4, 2018.

⁸³ <https://quickstats.nass.usda.gov/> Accessed July 4, 2018.

⁸⁴ In 2013, conventional till acres comprised 16.6 percent, reduced till acres comprised 21.5 percent, and no till acres comprised 61.9 percent. 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

- No-Till Adoption: According to USDA’s Pennsylvania Tillage Survey statistics, no-till acres increased by approximately 8.5 percent from 2013 to 2014.⁸⁵ The analysis team conservatively assumes no-till acres in Pennsylvania will increase by approximately six percent annually based on the slower, historical trend of no-till adoption. The team also assumes that no-till adoption will reach a maximum of 98 percent of acres planted by 2024.
- Reduced Till Adoption: According to USDA Pennsylvania Tillage Survey statistics, reduced till acres decreased by approximately 16 percent from 2013 to 2014. For this analysis, the team assumes 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 percent of total acres planted in 2024. After 2024, the share of reduced till acres will remain constant at approximately one percent of total acres planted.
- Conventional Till: Conventional till acres are assumed to equal the difference between total acres planted, no-till acres, and reduced till acres.
- Carbon Sequestration: The analysis team obtains emission reductions by crop/tillage practice for USDA’s Northeast region from the USDA’s report *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States*.⁸⁶ The team then weights emission reductions by crop/tillage practice according to Pennsylvania’s average share of acres planted by crop from 2011 to 2017.
- Changes in Yield: Similarly, the team obtains changes in yield by crop/tillage practice for USDA’s Northeast region from USDA’s report *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States*.⁸⁷ The team then weights changes in yield by crop/tillage practice according to Pennsylvania’s average share of acres planted by crop from 2011 to 2017.
- Changes in Production and Revenue: To determine decreases in revenue due to reduced yield, the analysis team multiplies estimates of reduced yield by the projected estimates of conventional, reduced, and no-till acres in Pennsylvania to obtain reduced production. The team then multiplies production by weighted revenue in dollars per short ton of production.
- Energy Savings: The analysis team estimates 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 team assumes diesel, natural gas, liquefied petroleum gas (LPG), motor gasoline, and kerosene represented 73, 23, 2, 3, and less than one percent of consumption on a BTU basis, respectively, based on consumption data for

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https://www.nass.usda.gov/Statistics_by_State/Pennsylvania/Publications/Annual_Statistical_Bulletin/2013_2014/ Accessed on July 4, 2018.

⁸⁶ U.S. Department of Agriculture. (USDA). 2013. *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States*. Accessed July 4, 2018. Available at: https://www.usda.gov/oce/climate_change/mitigation_technologies/GHG_Mitigation_Options.pdf

⁸⁷ U.S. Department of Agriculture. (USDA). 2013. *Greenhouse Gas Mitigation Options and Costs for Agricultural Land and Animal Production within the United States*. Accessed July 4, 2018. Available at: https://www.usda.gov/oce/climate_change/mitigation_technologies/GHG_Mitigation_Options.pdf

the Agriculture economic sector from U.S. EPA's 1990-2016 *Inventory of U.S. Greenhouse Gas Emissions and Sinks*.⁸⁸

- **Capital Expenditures:** The analysis team relies on estimates of capital costs per acre from University of Illinois' 2017 Machinery Cost Estimates.⁸⁹ The team then applies per acre capital costs to the projected estimates of conventional, reduced, and no-till acres in Pennsylvania.
- **Operation & Maintenance (O&M) Costs:** The analysis team weights USDA Pennsylvania O&M plowing, planting, drilling, and spraying costs by crop, fertilizer usage, and tillage practice. The team then applies the weighted O&M costs per acre to the projected estimates of conventional, reduced, and no-till acres in Pennsylvania.

Summary of Annual Energy, Environmental, and Economic Benefits and Costs

	2025	2050	Annual Average (2020 – 2050)
Energy Benefits and Costs			
Change in Distillate Fuel Oil Consumption (BBtu) ^a	-213	-336	-247
Change in Natural Gas Consumption (BBtu)	-68	-107	-79
Change in LPG Consumption (BBtu)	-5	-8	-6
Change in Kerosene Consumption (BBtu)	-0.1	-0.2	-0.1
Change in Motor Gasoline Consumption (BBtu)	-8	-12	-9
Environmental Benefits and Costs			
Total GHG Emission Reductions (MTCO ₂ e)	208,331	328,070	241,905
SO ₂ Emission Reductions (MT)	-0.2	-0.3	-0.2
NO _x Emission Reductions (MT)	-18	-27	-20
Hg Emission Reductions (MT) ^b	NE	NE	NE
Economic Benefits and Costs			
Capital Expenditures (\$ Million)	\$14.15	\$22.28	\$16.20
Maintenance and Repair Costs (\$ Million)	-\$12.01	-\$18.92	\$14.00
Fuel Savings (\$ Million)	\$6.13	\$11.74	\$7.92
Net Present Value (\$)			\$134,737,276
Cost-per-ton of GHG Emission Reductions (\$/mt CO ₂ e)			-\$17.90 ^c

"NE" indicates that the value was not estimated.

Notes: Positive "changes" indicate increases from BAU values, whereas negative "changes" indicate reductions from BAU values. Positive "reductions" indicate reductions from BAU, whereas negative "reductions" indicate increases from BAU.

⁸⁸ U.S. Environmental Protection Agency. (EPA). 2018. Inventory of U.S. Greenhouse Gas Emissions and Sinks (1990-2016). EPA 430-R-18-003. Accessed July 4, 2018. Available at:

<https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks-1990-2016>

⁸⁹ <https://farmdocdaily.illinois.edu/2017/06/machinery-cost-estimates-for-2017.html> Accessed July 4, 2018.

^a *The change in distillate fuel oil consumption likely contains a small amount of biodiesel.*

^b *Appropriate emission factors for Hg from LPG and kerosene consumption were not readily available.*

^c *Negative cost-per-ton represents net cost savings.*

Appendix B. Comments from the Climate Change Advisory Committee