COMPARATIVE PATHWAYS FOR REGIONAL ENERGY TRANSITION

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INTRODUCTION

Over the past year, the Kleinman Center developed the Pathways project to better support energy policy-making at the local and regional levels. We have argued for a new approach in a series of essays in diverse venues, including newspapers and scientific journals.[1] We have socialized the approach in a series of presentations, including at conferences of subnational governments and in meetings with federal agencies.[2] We have also supported teams of researchers to build a long-term project around the approach.[3] This report documents our progress through the project's first phase, which generated our regional "pathways" and refined our approach to decision support.

Several guiding questions motivated this project:

- First, what are the local net benefits of various energy-related policy strategies? This question differs from what is asked in most assessments of subnational policy options, which typically inquires "how much emissions reduction can be achieved in our city or region?" or "is an 80 percent reduction in local emissions by year 2050 feasible?" Maximizing local net benefits and treating emissions reductions as an output derived from local policy concerns provides a far more relevant and reliable basis for local decision-making and for predicting the sustained efforts of subnational governments over the longer term.
- Second, what are the local co-benefits of mitigation and adaptation policies? Local efforts at emissions reductions are likely to generate far more local net benefits from improved air quality than from climate change mitigation. This creates a potential—but not self-implementing—alignment between local and global policy efforts. Also, any local policy that generates both mitigation and adaptation benefits creates another opportunity to leverage local efforts to achieve global impacts.
- Third, what policy options and debates about energy characterize actual decision-making at the local and regional scale? Rather than backward-mapping from a global policy problem (such as deep decarbonization), we propose to tie our analysis to interests, issues, and opportunities already mobilized in a specific region. This approach better reflects the realities of local decision-making.

Decision support research begins with the engagement of decision makers. We built on our longstanding relationships with key partners and convened teams of researchers, advisers, and stakeholders. They developed different policy strategies based on policy discussions taking place within the Philadelphia region. We then translated these strategies into model inputs that can be used to estimate local net benefits associated with each strategy over time.

The Kleinman Center worked with ICF, a global consulting firm, to recruit stakeholders who were then tasked with combining several strategies into three ambitious and distinct pathways to mid-century in the region. The "Grid" pathway, which focuses on

1 https://thebulletin.org/cities-cant-lead-climate-change-mitigation10547

2 https://kleinmanenergy.upenn.edu/sites/default/files/Pathways%20PPT%202_0.pdf

3 https://kleinmanenergy.upenn.edu/pathways

modernizing the region's electricity grid and electrifying key sectors, was led by PECO (Pennsylvania's largest electric and natural gas utility); the "Gas Works" pathway, which seeks to take advantage of the region's location and infrastructure to capitalize on Pennsylvania's shale boom, was developed in consultation with Philadelphia Gas Works (PGW); and finally, the "Edge" pathway, which seeks to leverage distributed resources and storage to enhance the region's energy system was led by the Philadelphia Energy Authority (PEA).

These pathway leaders and participants were asked to define energy strategies out to mid-century that would maximize the local net benefits to the Philadelphia region. The only constraint we gave each group was that they could assume no significant change in state or federal policy. After preliminary stakeholder discussions, which spanned four months, it became clear that uncertainty was hindering the kind of thinking that we thought would emerge from this pathway design process. Uncertainty about the future in many ways limited stakeholders to proposing incremental changes in their strategies, rather than developing the far-reaching visions that we expected. Any strategy that was too ambitious became difficult to defend without relying on assumptions about highly uncertain policy and technology changes. As a result, three very realistic and actionable pathways were developed that deviated only modestly from a business-as-usual scenario.

We concluded that our characterization of the region as deadlocked over competing and significantly divergent visions of the region's energy future was wrong. *Uncertainty* rather than deadlock is what limits decision-making on Philadelphia's energy future. Uncertainty about technology, policy, and climate impacts makes it difficult to elaborate strategies for more than incremental departures from the status quo.

In the remainder of this report, we present the characterization of the stakeholder pathways and strategies constructed by ICF in partnership with the Kleinman Center. Each pathway consists of policy and program strategies that would generate estimated impacts in capital and operating costs, electricity and fuel consumption, and greenhouse gas and local air quality emissions. In future phases of the Comparative Pathways project, we will compare the local net benefits of stakeholder strategies for regional energy transition as well as compare the robustness of many different strategies under different futures that regional decision makers may face.

STAKEHOLDER PROCESS

The three pathways used in this analysis were designed over many months of collaboration with a diverse group of regional stakeholders. The process began in the summer of 2016 when an initial group of key parties came together to discuss the energy proposals and debates underway in the region over the preceding several years. That group built a theoretical framework that would support a bottom-up planning exercise for comparing and contrasting unique plans for maximizing local net benefits within the Greater Philadelphia region.

The project's first stage revolved around isolating what the major energy planning conversations were among regional stakeholders. PECO, PGW, and PEA, and GPEAT (Greater Philadelphia Energy Action Team) agreed to participate in, and in some cases lead, the design process for four unique pathways that would each emphasize different aspects of the regional energy conversations. We called these pathways: "Grid," "Gas Works," "Edge," and "Hub." Prior to submitting a narrative vision for the "Hub" pathway, Phil Rinaldi, then head of GPEAT, decided to withdraw GPEAT from the Pathways project and the "Hub" pathway was never developed. The remaining three pathway participants drafted narrative visions for the "Grid," "Gas Works," and "Edge" pathways and agreed to work with ICF to expand these visions into quantifiable strategies.

In 2017, Kleinman Center staff and ICF consultants met in-person with each of the pathway development groups—twice with the Gas Works group at PGW's headquarters, three times with the Grid team at PECO's headquarters, and three times with the Edge team at the Kleinman Center. In addition, Kleinman Center staff and

ICF corresponded regularly with pathway designers and data experts for each of the three pathways.

At each of these meetings, executive representatives from PGW, Tom Bonner, Energy Policy Manager for PECO, and Emily Schapira, Executive Director of the PEA led discussions with a small team of experts on designing the component elements of their respective pathways. We label these elements, "strategies." Once the narrative and model inputs for each of these strategies were completed, we then shared the pathways with PGW, PECO, and PEA. Each organization was given the opportunity to provide comments or raise concerns about the two pathways that they did not discuss with Kleinman Center staff and ICF consultants during the initial design process.

After the first phase of modeling was completed, the Kleinman Center then circulated an internal preliminary report containing the raw intermediate model outputs to the three pathway lead groups for a second round of review. PEA and PECO provided comments on this report, but we did not receive comments from PGW.

Finally, once all of PECO and PEA's concerns had been acknowledged in the preliminary report, a team of regional experts who had not participated in the pathway design process reviewed the three pathways. This review board included Rob Graff of the Delaware Valley Regional Planning Commission (DVRPC), Adam Agalloco from the Philadelphia Office of Sustainability (OOS), and Erik Johanson of the Southeastern Pennsylvania Transportation Authority (SEPTA). The following three sections of this report review each pathway and the strategies developed to maximize local net benefits.

Prior to its publishing, this interim report received comments and endorsements from PECO, PEA, DVRPC, SEPTA, and the City of Philadelphia. PGW did not endorse the data and methods presented in the interim report and withdrew their participation as Gas pathway lead.

This report presents a characterization of three energy pathways for the region and a proposed methodology for future detailed modeling of the local net benefits associated with each pathway to mid-century, including GHG and air pollutant emissions, health benefits, and macroeconomic benefits. The interim Grid pathway is endorsed for the purposes of this study by PECO. The interim Edge pathway is endorsed for the purposes of this study by PEA. The interim Gas pathway is not endorsed by any stakeholder in the region and is offered by the Kleinman Center and ICF as a third pathway generated by the same methodology applied to Grid and Edge.

PATHWAY DESIGN

GRID PATHWAY

The vast majority of U.S. grid electricity is still produced by burning fossil fuels. Nonetheless, the power system is decarbonizing faster than other sectors, such as transportation. By electrifying and integrating energy processes into the electricity grid, we can ensure that grid-level renewable energy generation will have the greatest effect on our overall energy-based carbon emissions. Some examples of fuel-dependent, distributed processes are transportation, heating, and industrial machinery.

In addition to potential environmental and climate benefits of grid integrated electrification, there are also significant public health benefits that accrue from removing fossil fuel emissions from the heart of densely populated urban areas. Instead, production would be relegated to the less densely populated sites of grid-scale electricity production. Under current conditions, grid electricity is also cheaper than buying distributed fuel and can, in theory, achieve a greater level of reliability than distributed fuel systems.

The Grid pathway is designed around the principles of increasing regional electrification and using the increased demand for grid electricity to maximize the environmental benefits of introducing grid-level, renewable generation. Development of this pathway was spearheaded by Tom Bonner, Energy Policy Manager for PECO, along with a team of PECO utility experts and modelers. PECO, as the region's largest electricity distributor, chose to limit their strategy development to the five-county region within the Delaware Valley (Philadelphia, Bucks, Chester, Delaware, and Montgomery) for whom it provides energy services.

GRID STRATEGIES

The Grid pathway team developed four policy strategies that cumulatively represent the goals and priorities of this pathway.

Incentivize Electric Vehicles (EV) over Petroleum Passenger Vehicles

This strategy involves fuel shifting of the passenger vehicle fleet toward increased electrification. It, however, does not increase the overall number of passenger vehicles compared to the business-as-usual case. This scenario gradually phases in electric vehicles from 1% of the five-county PECO region market in 2020 to 25% of all passenger vehicles in the region by 2045. Incentivizing the replacement of gasoline, diesel, and hybrid vehicles will reduce distributed emissions of air pollutants, many of which are known to have negative public health effects.

Switch Public Bus Fleet to Electric

Fuel shifting of the public transit bus fleet to electric vehicles involves replacing about 1,400 buses in the five-county PECO region beginning in 2020. The model imposes a 3% annual phase in rate and reaches 80% electrification of the fleet by 2045. It also assumes that, because of existing SEPTA plans to move to an all-hybrid fleet, the replaced buses will all be hybrid vehicles, affecting the potential emissions reductions and reducing capital costs as compared with a strategy that assumes diesel bus replacement.

Switch Fuel Oil to Electric

This strategy converts 100% of the 2010 fuel oil load in the five-county region (179 million gallons in the residential sector and 52 million gallons in the commercial sector)[4] to electric heating and hot water technologies over a 27- and 13-year time horizon, respectively. Capital costs are calculated as the marginal cost of electric systems over the cost of fuel oil system replacements, assuming systems are replaced only at the end of their natural life.

Increase Utility-Scale Renewables

This strategy proposes that utility-scale solar supplies 10% of the region's energy demand by 2030. This results in an additional 2,634 MW of PV capacity installed within the region. The goal emerges from Pennsylvania's SunShot program goal, which is to achieve 10% of Pennsylvania's retail electricity sales generated from in-state solar production by 2030.[5] Capital costs for this strategy are calculated annually between 2018 and 2030 when the full 10% capacity is reached. This strategy does not assume any continued development of utility-scale solar beyond 2030.

EDGE PATHWAY

The Grid pathway (discussed above) seeks to maximize grid-connected electrification as a way to minimize regional emissions and increase energy reliability. The Edge pathway uses a different approach to achieve similar goals. Instead of working to connect as much regional energy demand to the grid as possible, the Edge pathway looks to reduce overall energy demand through investments in building efficiency and distributed generation at the "edge" of the existing distribution grid. It achieves this while still prioritizing vehicle electrification. This pathway is designed to increase efficiency, lower energy costs, reduce environmental impacts, and increase local control over the region's energy sector.

The Edge Pathway also prioritizes resiliency in the region, by creating more local energy generation, thus reducing vulnerability to risks, such as infrastructure failures or energy shortages.

More than either of the two alternative pathways, Edge relies heavily on Pennsylvania state policies, including utility commission regulations or legislative actions for

4 DVRPC, personal communication with Shawn Legendre, 2017.

5 Pennsylvania DEP. "Finding Pennsylvania's Solar Future". 2017. http://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Pollution%20prevention%20and%20Energy%20assiatance/PA%20Solar%20Future%20March2nd%20Intro.%20(2).pdf

energy efficiency programs, net metering, community solar, and microgrids. For modeling purposes, the pathway includes community solar within Pennsylvania counties and compliance with more stringent state building codes. Both of these strategy aspects would require actions at the state level.

Development of this pathway was led by PEA's Emily Shapira, in partnership with a number of regional stakeholders, including Bill Kunze and Evan Endres from The Nature Conservancy, Alex Dews from the Delaware Valley Green Building Council, Roger Clark from the Reinvestment Fund, Rob Celentano from Celentano Energy Services, and Liz Robinson from the Energy Coordinating Agency. Because this pathway was not bound by the service region of a utility, the pathway design group decided that there was no reason not to consider strategies that spanned the whole nine-county DVRPC region, including Philadelphia, Bucks, Chester, Delaware, Montgomery counties in Pennsylvania, as well as Burlington, Camden, Gloucester, and Mercer counties in New Jersey.

EDGE STRATEGIES

The Edge pathway team developed six policy strategies that cumulatively represent the goals and priorities of this pathway.

Increase Solar Installations in the Region
This strategy covers the expansion of residential and commercial rooftop solar photovoltaics (PV), as well as community solar initiatives that aggregate electricity demand and arrange for contractual purchase of renewable generation. Recent actions in the Pennsylvania legislature indicate that the kinds of solar projects described in this section will likely be accelerated, making these estimates more achievable. For residential solar, the strategy assumes 5 kW systems for Philadelphia and 7.5 kW systems for all other counties. For commercial solar, the model assumes an average system size of 100 kW. For both sectors, a 0.5% annual degradation rate, 1% annual technological efficiency gains, and a 25-year lifetime were assumed. Community solar projects were each set to 1 MW in the model.

Support SEPTA Expansion and Electrification
This strategy expands regional access of SEPTA and phases in the electrification of the public bus fleet. Expansion of regional bus transit routes—18 additional routes—results in a mode shift from passenger vehicle to bus transit. Also, bus fleet electrification of 100% is achieved by 2050. It also assumes that, because of existing SEPTA plans to move to an all-hybrid fleet, the replaced hybrid buses affect the potential emissions reductions and capital costs as compared with a strategy that assumes diesel bus replacement. Although similar in scope to the electric bus strategy in the Grid pathway, this iteration of fleet electrification was modelled independently to reflect the unique design choices of the Edge pathway team.

Support Increase in Electric Passenger Vehicles
This strategy involves fuel shifting of the passenger vehicle fleet (i.e. electrification); it does not, however, increase the overall number of passenger vehicles in circulation compared to the business-as-usual case. Under this strategy, 26% of the vehicles in the nine-county region are electric by 2045. Public, electric-charging infrastructure in homes, workplaces, parking lots, hospitals, schools, etc. is installed to accommodate a total of 970,000 electric vehicles in the region. Although similar in scope to the electric passenger vehicle strategy in the Grid pathway, this iteration of fleet electrification was modelled independently to reflect the unique design choices of the Edge pathway team.

Strengthen Building Codes for New Buildings
This strategy covers new energy code adoption for all new and substantially-renovated buildings in both the residential and commercial sectors. Future International Energy Conservation Code ("IECC") code versions were applied to the model every three years through 2030 on a kWh per house and MMBtu per house basis. Following 2030, the assumption was made that buildings would continue to be built up to the 2030 standard. The same assumption was made for the commercial sector using code version 90.1 developed by ASHRAE, the American Society of Heating, Refrigerating and Air-Conditioning Engineers. For both sectors, a compliance rate of 75% was assumed, with a measure lifetime of 30 years.

Increase Combined Heat and Power (CHP) Installations in the Region

Under this strategy, PGW directly installs or incentivizes the installation of about 30,000 mid-size CHP systems and 27 large CHP systems through 2045. These instillations would further reduce grid demand for electricity and would improve the efficiency of distributed heating.

Increase Existing Building Retrofits

This strategy covers incremental, energy-efficient upgrades to renovation and addition projects in the DVRPC building stock, thereby bringing existing homes and commercial buildings up to higher efficiency levels. For the residential sector, prescribed upgrades include 8.5 HSPF/15 SEER (seasonal energy efficiency ratio) air source heat pumps, R-60 attic insulation, and air sealing.[6] This strategy assumes 2.5% of owner-occupied units, or 36,068 homes per year, will undergo renovations,[7] at an incremental cost of approximately $6,000 per house.[8] Out of the 36,068 owner-occupied homes that are renovated each year, 75% were set to meet IECC codes from the New Building strategy. This strategy assumes that the building retrofits have a 15-year lifetime and that commercial space has a 1.5% efficiency improvement per square foot per year.

GAS WORKS PATHWAY

PGW is the largest municipally-owned gas utility in the country, maintaining thousands of miles of gas mains and half-a-million service lines to residential, commercial, and industrial customers in the city of Philadelphia. The Pennsylvania Public Utility Commission (PUC) regulates PGW as if it were a public utility, but municipal ownership continues to afford opportunities for local policy strategies to leverage PGW's system as a positive force for the region's energy future. PGW offers the opportunity to adopt a "systems thinking" approach to energy production and use, especially in the form of district energy systems, which often apply combined heat and power (or "CHP"), among other technologies. Additionally, Pennsylvania enjoys affordable and plentiful access to natural gas thanks to shale development north and west of Philadelphia. This energy development is likely to continue for several decades and offers the city the opportunity to displace fuel oil and petroleum burning with cheap and relatively clean burning natural gas for the health and economic benefit of local residents.

The Gas Works pathway, as the name would suggest, was principally developed and designed through discussions with executive representatives from PGW. Because PGW operates only within the city's boundaries, this became the chosen geographic scope of the pathway strategies.

GAS WORKS STRATEGIES

The Gas Works pathway team developed three policy strategies that cumulatively represent the goals and priorities of this pathway.

Switch from Fuel Oil to Natural Gas

This strategy covers fuel switching of space heating and water heating equipment from fuel oil to natural gas for both the residential and commercial sectors. Fuel oil sales in Philadelphia in 2010 totaled 25 million gallons in the residential sector and 6.5 million gallons in the commercial sector.[9] The Gas Works pathway displaces this load over a 27-year time horizon with efficient natural gas boilers, furnaces, and water heaters, using the PGW distribution network and regional access to affordable natural gas. This strategy uses a linear phase-in rate of ~4% a year.

Increase Installation of Combined Heat and Power (CHP)

This strategy covers CHP applications in three markets, including micro CHP for single-family residential (1–5 kW), mid-size CHP for multifamily (50–500 kW), and large CHP (>500 kW) in Philadelphia. Midsize

6 PECO Incremental Cost Database.

7 Harvard Joint Center for Housing Studies, 2013.

8 PECO Incremental Cost Database.

9 DVRPC, personal communication with Shawn Legendre, 2017.

CHP systems are installed in multifamily housing or commercial buildings, while larger CHP systems are installed in large campus-sized facilities such as universities, hospitals, and brownfield projects such as the Navy Yard. PGW directly installs or incentivizes the installation of about 12,000 mid-size CHP systems and 6 large CHP systems through 2045, as well as 3,010 micro-CHP units every year after 2030. Although similar in design to the CHP strategy in the Edge pathway, this iteration of CHP instillation was modelled independently to reflect the unique design choices of the Gas Works pathway team.

Convert Buses from Petroleum to Compressed Natural Gas (CNG)

The Gas Works pathway supports fuel shifting of the public transit bus fleet to natural gas, by replacing about 1,200 buses in Philadelphia County at the end of their natural life, phased in from 3% of the fleet in 2020 to 80% of the fleet in 2045, increasing incrementally in the intermediate years. This strategy increases the percentage of the bus fleet that is natural gas-fueled. However, it does not increase the overall number of buses in circulation compared to the business-as-usual case. It also assumes that, because of existing SEPTA plans to move to an all-hybrid fleet, the replaced buses are all hybrid vehicles, affecting potential emissions reductions and leading to capital cost savings as compared to the business-as-usual case.

STAGE 1 MODEL ASSUMPTIONS

BUSINESS-AS-USUAL (BAU) CASE

All three pathways were designed so that their impacts are based on the deviation from a predicted BAU case. This BAU case—consistent across all three pathways—was designed around DVRPC's historical 2010 regional inventory and demographics data, and projected based on publicly sourced data as well as data provided by the pathway owners and stakeholders. One of the most notable assumptions incorporated into the BAU case was that SEPTA is soon going to operate a 100% hybrid bus fleet. This assumption was included based on input from Erik Johanson, Innovation Director for SEPTA, who said that SEPTA already has plans to move toward an 100% hybrid fleet even in the absence of any future policy incentives. Furthermore, the BAU case assumes that hybrid buses will continue to be priced higher than diesel and natural gas alternatives. By including these assumptions in the BAU case, the financial and emissions impacts for the three bus strategies were altered significantly. Because hybrid buses are more expensive and produce fewer emissions than diesel buses, strategies that involved replacing buses with electric or CNG buses were much more affordable and much less impactful on overall emissions than they would have otherwise been had the BAU case assumed diesel bus replacement.

FUEL PRICES AND CARBON ACCOUNTING

Another assumption made during the analysis of the Stage 1 model results concerns the approximation of fuel costs, grid level emissions, and carbon pricing. Fuel costs in the ICF spreadsheet model were calculated for some of the strategies using U.S. Energy Information Administration (EIA) predictions of future fuel costs to the region. Any strategy, however, that involves a change in transportation fuel use was not subject to an analysis of fuel costs because of the complexity of this analysis. Predicting fuel costs out to mid-century is highly uncertain and could have significant implications for the operational costs of strategies. For this reason, and to ensure consistency across pathways, these fuel cost savings are not reported in this interim report and are not included in the operations and management (O&M) cost calculations. In later phases of this research, fuel cost can be more accurately estimated using the MOVES (a motor vehicle emissions simulator) model provided by ICF.

Grid-level (i.e. powerplant) emissions were also excluded from the emissions accounting in this phase of the modeling. For the purposes of this report, grid-level emissions have been retroactively added to the emissions output of the model by applying a static conversion equation to the electricity reduction outputs and then adding these emissions to the existing CO_2e

emissions outputs for each strategy. This was done to ensure that strategies that involved electrification were not unfairly favored in the emissions accounting of the pathways. This method of emissions accounting, however, is highly imprecise and assumes an unchanging grid generation profile out to mid-century. Future steps taken outside of the nine counties to reduce grid-level emissions could completely alter the balance of this accounting effort. The emissions of criteria air pollutants from the grid were not retroactively included in this way, since those emissions will fall outside of the region and have little impact on local net benefits.

Finally, for the purposes of this Stage 1, limited-scope modeling, no carbon price was incorporated at any point between now and mid-century. Given the policies implemented internationally and in other regions of the U.S., this assumption may not hold, and could have a significant impact on the overall costs of the strategies.[10] In future phases of this research, proprietary models can be used to yield vastly more accurate approximations of total strategy emissions, public health effects, total costs including local fuel costs and carbon costs associated with the strategies, and long-term economic impacts of the pathways. No model, however, that attempts to predict future conditions out to mid-century is invulnerable to future uncertainty. These next phase assessment models have yet to be applied to any of the pathway strategies.

GEOGRAPHIC SCOPE

One of the design choices made by each pathway team was to set a geographic scope for their strategies. Both PGW and PECO determined that rather than set the geographic scope of their strategies to the whole nine-county DVRPC region, they would instead design strategies that were only applied within their service area. In PECO's case this meant the five Pennsylvania counties contained within the DVRPC region, and for PGW this translated to a geographic scope of just the City of Philadelphia.

When drawing conclusions from the Stage 1 model outputs, it is important to consider that the costs, emissions, and infrastructure associated with a strategy only encompass actions that take place within the geographic scope of that strategy's pathway. Similarly, the BAU case used across the strategies, though consistent, was adjusted to the geographic scope of each pathway. In the Gas Works strategies, model outputs are only representative of the deviation from the BAU case for Philadelphia County. By contrast, in Edge strategies, the impacts are representative of the deviation from the nine-county BAU case.

Owing to this variation in the geographic scope of the three pathways, one would expect that the scale of the pathway impacts are similarly variable. Because the Gas Works pathway strategies were designed for use within only one of the nine counties, one would expect the impacts of those strategies to be more limited than Edge strategies, which were designed for the whole DVRPC region. Looking at the pathway impact tables, this is generally the trend that we see. Following the more comprehensive Stage 2 modeling of the pathway impacts, this variation in scope can be managed by comparing impacts of the pathway per capita or per county.

EMISSIONS ASSUMPTIONS

When designing these pathways, our goal was to build a suite of energy policy strategies that would maximize local net benefits to the Philadelphia region. Therefore, to compare the three pathways and determine success, local net benefits was used as the primary measure. These benefits include:

1. Cost savings for the region
2. Investment in the region
3. Public health improvements from emissions reductions
4. Improved energy security

Nationally and internationally, however, there are numerous efforts to reduce global greenhouse gas (GHG) emissions. Philadelphia has committed to an ambitious emissions target that has made GHG emissions reduction a local priority, so the impact of each pathway on regional emissions is a second important point of comparison.

10 In January of this year, New Jersey governor Phil Murphy signed an executive order for his state to rejoin the RGGI cap and trade agreement. Pennsylvania Governor Tom Wolf has also expressed interest in his state joining the initiative. https://www.utilitydive.com/news/new-jersey-to-rejoin-rggi-in-new-executive-order/515802/

That being said, GHG emissions reduction was not the stated goal of this Stage 1 modeling and pathway design effort. Even an extremely impactful emissions reduction strategy will not be successful if it does not provide the target region with localized benefits.

Local air pollution is a strong indicator of local net benefits generated by these policy strategies, so when comparing the three pathways, SO_2, NO_x, and $PM_{2.5}$ emissions reductions and their impact on regional air quality and health should be considered carefully. The Stage 2 modeling effort is designed to quantify emissions, air quality concentrations, and resulting health effects with a high degree of precision. Public health and regional air pollution are vitally important in trying to piece together a measurement of local net benefits. Not only can reductions in these pollutants improve quality of life, but improved air quality has been shown to reduce the number of sick days taken by workers in the region, reduce the number of missed school days by children, and significantly reduce overall medical costs and emergency room visits.

- **SO_2** can cause respiratory distress in vulnerable populations such as children, the elderly, and individuals with asthma.
- **NO_x** is also a respiratory irritant and has a detrimental effect on the formation of Volatile Organic Compounds (VOC's) and ground level ozone, both of which have negative health effects.
- **$PM_{2.5}$**, the smallest classification of particulate matter classified as a criteria air pollutant, are solid or liquid particles small enough to pass from the respiratory system into the bloodstream, leading to many associated health risks.

ECONOMIC IMPACT

The intermediate Stage 1 model outputs contained within this report include estimated capital and O&M costs for each strategy. This report, however, does not include a comprehensive analysis of how these costs would translate to regional economic benefits; such impacts would be quantified using rigorous econometric modeling in Stage 2. It is safe to assume that investment within the region would increase overall employment to some extent and that efficiency improvements and reduced fuel costs will save local consumers money. Precise estimates of these impacts, however, will require further modeling. We are currently working to develop a method for effectively estimating these pathway effects and measure their impacts on local net benefits.

INTERMEDIATE STAGE 1 PATHWAY OUTPUTS

The following data tables summarize the fuel and electricity demands and resulting emissions from each of the thirteen unique strategies used in the three energy pathways (four strategies for Grid, six for Edge, and three for Gas Works). Several of the strategies used between pathways are similar in terms of infrastructure investment, but because input data, scope, geographic extent, and exact methods of calculation were developed independently by the pathway leads, they have been included here as distinct, unrelated strategies with their own output results. For example, both Grid and Edge have a strategy for incentivizing electric passenger vehicles in the region. In further analysis, these similar strategies will likely be combined into a single strategy that builds on the strengths of each independently developed variation. Strategy impacts are measured across six five-year intervals, but the values listed are *only representative of the annual impact in that year*. In other words, except where indicated, *the columns are not cumulative, nor do they represent the total impact for the five-year term*.

The GHG reductions in this report include estimated emissions from a change in grid electricity. These emissions, however, were not included in ICF's Stage 1 spreadsheet model and have been added retroactively. These additions were based on an average of 0.39 tons of CO_2e per MWh of grid demand and should be considered temporary stand-in values that will be significantly improved with future analysis using robust power sector modeling in Stage 2.

Output values that are in parentheses "()" are negative. For example, an electricity reduction output of (1,200) represents an increased demand for grid electricity.

GRID STRATEGIES

Each of the four strategies used in the Grid Pathway were scaled to encompass the five-county PECO region, including Philadelphia, Bucks, Chester, Delaware, and Montgomery.

Grid Strategy #1: Electric Vehicles:
This strategy achieves a 26% electric vehicle fleet by 2045. Costs reflect the marginal capital cost and O&M costs of purchasing an electric vehicle over a conventional gasoline, diesel, or hybrid vehicle. The plan to increase the number of electric passenger vehicles and replace conventional gasoline and diesel vehicles has high capital cost implications. However, this also reduces maintenance costs as well as regional fossil fuel use and related emissions. GHG emissions are reduced somewhat, though some of the emission effects are externalized to the electricity grid. NO_x, and particulate matter emissions from the grid are not considered, as they occur outside of the geographic region.

GRID STRATEGY #1: ELECTRIC VEHICLES

	2020	2025	2030	2035	2040	2045
Change in # of Electric Passenger Vehicles (additive)	2,178	66,774	121,328	192,163	281,486	358,560
Direct Capital Expenditures ($)	48,125,040	226,099,010	171,513,211	383,069,177	385,398,894	388,607,467
Direct O&M Costs ($)	-470,863	-14,692,711	-27,196,766	-43,650,413	-64,532,516	-83,226,614
Electricity Reductions (MWh)	-8,557	-262,335	-476,657	-754,943	-1,105,863	-1,408,664
Gasoline Reductions (Gallons)	1,004,377	30,467,349	54,517,570	85,204,050	123,627,032	155,469,832
Diesel Fuel Reductions (MMBtu)	1,891	85,644	217,642	422,894	700,190	1,030,085
GHG Reductions (KT CO_2e)	6	171	295	457	660	944
SO_2 Emission Reductions (lbs)	-	-	-	-	-	-
NOx Emission Reductions (lbs)	2,992	91,263	164,440	258,459	376,541	476,166
Mercury Reductions (lbs)	-	-	-	-	-	-
$PM_{2.5}$ Reductions (lbs)	177	5,409	9,776	15,404	22,482	28,499

Grid Strategy #2: SEPTA Electrification

This strategy proposes replacing 80% of the SEPTA bus fleet with electric buses. Because of existing SEPTA plans to replace all conventional diesel buses with hybrid buses, costs in this strategy reflect the marginal capital cost and O&M costs of purchasing an electric bus over a hybrid bus. Replacing SEPTA buses with electric buses reduces maintenance and saves fuel, but has little effect on emissions because of the decision to model the replacement of only hybrid buses. NO_x and particulate matter emissions from the grid are not considered, as they are generated outside of the geographic region.

GRID STRATEGY #2: SEPTA ELECTRIFICATION

	2020	2025	2030	2035	2040	2045
Change in # of Diesel Public Transport Buses	0	0	0	0	0	0
Change in # of Electric Public Transport Buses (additive)	42	257	481	710	942	1,207
Change in # of Hybrid Public Transport Buses (additive)	-42	-257	-481	-710	-942	-1,207
Direct Capital Expenditures ($)	8,017,561	8,278,324	8,602,818	16,996,431	17,387,315	23,435,412
Direct O&M Costs ($)	-30,831	-187,993	-351,068	-518,687	-688,457	-882,054
Diesel Fuel Reductions (MMBtu)	44,892	273,731	511,179	755,242	1,002,438	1,284,328
Electricity Reductions (MWh)	-6,038	-36,815	-68,750	-101,574	-134,820	-172,732
GHG Reductions (KT CO_2e)	-2	-12	-22	-32	-42	-54
SO_2 Emission Reductions (lbs)	-	-	-	-	-	-
NO_x Emission Reductions (lbs)	-2,379	-14,505	-27,087	-40,020	-53,119	-68,056
Mercury Reductions (lbs)	-	-	-	-	-	-
$PM_{2.5}$ Reductions (lbs)	-41	-250	-466	-689	-914	-1,171

Grid Strategy #3: Fuel Oil Heating to Electric Heating

This strategy replaces 100% of residential and commercial space and water heating systems that use fuel oil. By 2045, all of these systems are replaced with high-efficiency, grid-connected, electric heating systems. Replacing low efficiency residential and commercial oil heating with high efficiency electric systems requires high additional replacement spending, but significantly reduces fossil fuel usage and emissions.

GRID STRATEGY #3: FUEL OIL HEATING TO ELECTRIC HEATING

	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	-293,768	-1,028,190	-1,762,611	-2,234,922	-2,641,706	-3,048,489
Fuel Oil & Kerosene Reductions (MMBtu)	3,139,369	10,987,791	18,836,214	24,034,799	28,570,925	33,107,052
Direct Capital Expenditures ($)	40,630,159	40,630,159	40,630,159	39,338,965	39,338,965	39,338,965
GHG Reductions (KT CO_2e)	119	415	999	914	1,092	1,270
SO_2 Emission Reductions (lbs)	4,821	16,875	28,929	36,913	43,879	50,846
NO_x Emission Reductions (lbs)	407,444	1,426,055	2,444,666	3,119,366	3,708,089	4,296,812
Mercury Reductions (lbs)	9	33	57	72	86	99
$PM_{2.5}$ Reductions (lbs)	38,481	134,683	230,885	294,607	350,208	405,810

Grid Strategy #4: Utility-Scale Solar

This strategy considers the MWh of fossil fuel generated grid electricity that could be displaced by building utility-scale solar instillations to meet 10% of regional electricity demand. Even though this strategy requires an increase in regional generating capacity, it leads to electricity reductions in the model because existing generation would be displaced, assuming stable demand. This quantification method is a simplification of the complex ramifications this strategy would have on the regional electricity market, but is reasonable if we assume a competitive market for solar.

GRID STRATEGY#4: UTILITY-SCALE SOLAR

Summary Metric	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	-809,122	-2,157,659	-3,775,903	-3,775,903	-3,775,903	-3,775,903
Direct Capital Expenditures ($)	335,386,188	335,386,188	670,772,376	-	-	-
Direct O&M Costs ($)	10,535,072	28,093,525	49,163,669	49,163,669	49,163,669	49,163,669
GHG Reductions (KT CO_2e)	317	844	1,477	1,477	1,477	1,477
NO_x Emission Reductions (lbs)	-	-	-	-	-	-
Mercury Reductions (lbs)	-	-	-	-	-	-
$PM_{2.5}$ Reductions (lbs)	-	-	-	-	-	-

*GHG reductions are calculated by assuming that the added solar capacity will displace existing carbon emissions using the exiting average grid emissions ratio (0.39 tons/MWh)

EDGE STRATEGIES

Each of the six strategies used in the Edge pathway were scaled to encompass the DVRPC nine-county region, including southeastern Pennsylvania and southwestern New Jersey.

Edge Strategy #1: Distributed Solar
As opposed to the Grid #4 strategy, which introduces 10% utility scale solar into the grid generating mix, this strategy proposes a 10% distributed solar penetration rate of available and appropriate residential and commercial roof space as well as a single 350 kWh large solar instillation every year. Very high capital costs of rooftop solar significantly reduce regional demand for grid electricity and only add moderate O&M costs. GHG emissions are calculated based on the grid generation capacity that this solar capacity will displace.

EDGE STRATEGY #1: DISTRIBUTED SOLAR

	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	1,001,750	2,380,841	3,861,169	5,371,995	6,911,564	8,478,126
Direct Capital Expenditures ($)	592,570,336	560,405,071	503,239,806	455,415,826	407,591,845	790,183,690
Direct O&M Costs ($)	19,537,146	45,458,578	72,380,010	99,301,443	126,222,875	153,144,307
GHG Reductions (KT CO_2e)	392	932	1,511	2,102	2,704	3,317
SO_2 Emission Reductions (lbs)	-	-	-	-	-	-
NO_x Emission Reductions (lbs)	-	-	-	-	-	-
Mercury Reductions (lbs)	-	-	-	-	-	-
$PM_{2.5}$ Reductions (lbs)	-	-	-	-	-	-

Edge Strategy #2: Electrify and Expand SEPTA

This strategy not only electrifies the existing SEPTA fleet but also adds additional electric buses in order to further reduce passenger vehicle miles traveled in the region. Maintenance costs are reduced, and fossil fuel usage is replaced with higher grid electricity demand. The added SEPTA fleet leads to a net reduction in capital costs, but the additional cost of replacing hybrid buses with electric buses means that the overall capital cost of the strategy is positive. Emissions reductions are negative in this strategy, which is surprising for an electrification strategy, and suggests that the emissions from added demand on a business-as-usual grid is higher than the emissions from the existing hybrid bus fleet.

EDGE STRATEGY #2: ELECTRIFY AND EXPAND SEPTA

	2020	2025	2030	2035	2040	2045
Change in Passenger Vehicle VMT	-3,815,766	-22,894,595	-41,973,424	-61,052,252	-80,131,081	-99,209,910
Change in # of Registered Vehicles—Diesel Public Transport Buses	-	-	-	-	-	-
Change in # of Electric Public Transport Buses (additive)	75	455	848	1,252	1,661	2,002
Change in # of Hybrid Public Transport Buses (additive)	-67	-412	-769	-1,137	-1,510	-1,815
Direct Capital Expenditures ($)	10,370,867	10,455,648	10,856,864	21,173,533	21,698,388	15,114,708
Direct O&M Costs ($)	-333,510	-1,997,069	-3,649,107	-5,293,305	-6,934,744	-8,503,305
Change in # of Total Passenger Vehicles (additive)	-307	-1,841	-3,375	-4,910	-6,444	-7,978
Gasoline Reductions (Gallons)	141,148	826,408	1,465,640	2,072,497	2,665,188	3,208,670
Diesel Fuel Reductions (MMBtu)	71,931	439,122	820,547	1,212,968	1,611,069	1,936,583
Electricity Reductions (MWh)	-22,088	-133,375	-246,229	-360,330	-475,093	-579,729
GHG Reductions (KT CO_2e)	-7	-40	-75	-110	-146	-179
SO_2 Emission Reductions (lbs)	-	-	-	-	-	-
NO_x Emission Reductions (lbs)	4,220	25,657	47,714	70,257	93,060	111,871
Mercury Reductions (lbs)	-	-	-	-	-	-
$PM_{2.5}$ Reductions (lbs)	90	544	1,003	1,467	1,933	2,325

Edge Strategy #3: Electric Vehicles

This strategy is similar to the Grid EV strategy but scaled to the nine counties. This is an extremely costly strategy with large reductions in regional gasoline usage and regional emissions. Capital costs of the strategy are significant, but O&M costs are reduced because of the added reliability of electric vehicles over conventional passenger vehicles.

EDGE STRATEGY #3: ELECTRIC VEHICLES

	2020	2025	2030	2035	2040	2045
Change in # of Electric Passenger Vehicles (additive)	3,181	97,455	176,859	279,830	409,618	521,520
Direct Capital Expenditures ($)	70,295,776	329,590,487	249,144,613	557,507,263	560,093,370	564,360,185
Direct O&M Costs ($)	-687,785	-21,443,567	-39,644,578	-63,564,422	-93,907,696	-121,051,624
Electricity Reductions (MWh)	-12,499	-382,869	-694,820	-1,099,360	-1,609,252	-2,048,876
Gasoline Reductions (Gallons)	1,467,083	44,466,175	79,469,966	124,075,486	179,902,018	226,128,096
Diesel Fuel Reductions (MMBtu)	2,762	124,995	317,255	615,824	1,018,917	1,498,240
GHG Reductions (KT CO_2e)	8	250	450	706	1,026	1,296
SO_2 Emission Reductions (lbs)	-	-	-	-	-	-
NO_x Emission Reductions (lbs)	4,371	133,195	239,703	376,373	547,942	692,575
Mercury Reductions (lbs)	-	-	-	-	-	-
$PM_{2.5}$ Reductions (lbs)	258	7,894	14,251	22,432	32,715	41,451

Edge Strategy #4: New Building Efficiency

This strategy estimates the cost of achieving 75% compliance with increasingly stringent state building efficiency codes for new buildings constructed each year. The capital costs are high, and both natural gas usage and electricity usage are reduced. This is the only strategy that reduces energy demand and emissions without relying on a transition from one energy source to another.

EDGE STRATEGY #4: NEW BUILDING EFFICIENCY

Summary Metric	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	69,983	266,772	521,203	750,296	936,733	1,091,807
Natural Gas Reductions (MMBtu)	369,789	1,859,091	3,583,931	5,111,396	6,360,780	7,396,022
Direct Capital Expenditures ($)	44,757,625	39,732,679	43,106,935	37,362,804	30,498,882	25,310,008
GHG Reductions (KT CO_2e)	47	203	395	565	705	820
SO_2 Emission Reductions (lbs)	216	1,085	2,092	2,983	3,713	4,317
NO_x Emission Reductions (lbs)	33,813	169,995	327,714	467,384	581,628	676,290
Mercury Reductions (lbs)	0	0	1	1	2	2
$PM_{2.5}$ Reductions (lbs)	2,734	13,744	26,496	37,789	47,025	54,679

Edge Strategy #5: Combined Heat and Power Systems

Installing large, utility-scale units and multifamily building units generates distributed electricity and uses the generated heat to replace standard natural gas heating systems. These CHP systems increase overall natural gas demand but reduce overall emissions and electricity demand.

EDGE STRATEGY #5: COMBINED HEAT AND POWER SYSTEMS

	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	301,739	902,074	1,794,722	2,395,057	2,703,080	2,718,791
Direct Capital Expenditures ($)	61,693,856	471,956	61,693,856	471,956	471,956	471,956
Direct O&M Costs ($)	3,733,980	11,126,530	22,026,830	29,419,380	33,304,180	33,681,232
Natural Gas Reductions (MMBtu)	-1,267,658	-3,788,201	-7,532,077	-10,052,619	-11,349,827	-11,423,701
GHG Reductions (KT CO_2e)	51	152	302	403	454	456
SO_2 Emission Reductions (lbs)	-740	-2,211	-4,396	-5,867	-6,624	-6,668
NO_x Emission Reductions (lbs)	-115,914	-346,392	-688,731	-919,208	-1,037,825	-1,044,580
Mercury Reductions (lbs)	0	-1	-2	-3	-3	-3
$PM_{2.5}$ Reductions (lbs)	-9,372	-28,006	-55,685	-74,319	-83,909	-84,455

Edge Strategy #6: Existing Building Retrofits

This strategy improves building efficiency through insulation and also replaces natural gas heating with electric air source heat pumps. Because of this fuel use change, despite being an efficiency strategy, electricity demand increases significantly. Because natural gas demand is displaced and efficiency is improved, this strategy leads to a significant decrease in regional emissions.

EDGE STRATEGY #6: EXISTING BUILDING RETROFITS

Summary Metric	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	-132,080	-461,671	-784,810	-972,772	-959,395	-948,243
Natural Gas Reductions (MMBtu)	9,293,146	32,548,876	55,905,089	70,067,294	70,342,600	70,576,681
Direct Capital Expenditures ($)	334,006,971	334,006,971	334,006,971	334,006,971	334,006,971	334,006,971
GHG Reductions (KT CO_2e)	442	1,550	2,666	3,345	3,365	3,382
SO_2 Emission Reductions (lbs)	5,424	18,997	32,629	40,895	41,056	41,193
NO_x Emission Reductions (lbs)	849,762	2,976,259	5,111,944	6,406,932	6,432,105	6,453,510
Mercury Reductions (lbs)	2	8	14	18	18	18
$PM_{2.5}$ Reductions (lbs)	68,704	240,634	413,306	518,007	520,043	521,773

GAS WORKS STRATEGIES

Each of the three strategies used in the Gas Works pathway were scaled to just include Philadelphia County.

Gas Works Strategy #1: Fuel Oil to Natural Gas

Replacing fuel oil heating with natural gas heating does not have any impact on electricity demand and still relies heavily on fossil fuels for heating. Natural gas, however, burns much cleaner than fuel oil, leading to substantial emissions reductions, especially NO_x emissions, which can lead to respiratory distress in vulnerable populations.

GAS WORKS STRATEGY #1: FUEL OIL TO NATURAL GAS

	2020	2025	2030	2035	2040	2045
Natural Gas Reductions (MMBtu)	-362,886	-1,270,100	-2,177,315	-2,803,585	-3,359,619	-3,915,654
Fuel Oil & Kerosene Reductions (MMBtu)	433,672	1,517,852	2,602,032	3,311,619	3,927,559	4,543,498
Direct Capital Expenditures ($)	5,539,126	5,539,126	5,539,126	1,605,865	5,539,126	5,539,126
GHG Reductions (KT CO_2e)	13	45	78	97	114	130
SO_2 Emission Reductions (lbs)	454	1,590	2,725	3,450	4,071	4,692
NO_x Emission Reductions (lbs)	23,102	80,857	138,613	173,441	202,537	231,634
Mercury Reductions (lbs)	1	4	7	9	11	13
$PM_{2.5}$ Reductions (lbs)	2,633	9,215	15,798	19,865	23,304	26,744

Gas Works Strategy #2: Micro, Midsize, and Large CHP Systems

Replacing natural gas heating systems with micro, mid-sized and large CHP systems is expensive and has a very minimal impact on achieving regional CO_2e emission reductions and leads to an overall increase in many criteria air pollutants.

GAS WORKS STRATEGY #2: MICRO, MIDSIZE, AND LARGE CHP SYSTEMS

	2020	2025	2030	2035	2040	2045
Electricity Reductions (MWh)	3,808	107,592	248,952	638,053	1,027,154	1,221,380
Direct Capital Expenditures ($)	190,657	20,597,957	13,735,657	13,735,657	34,142,957	13,735,657
Direct O&M Costs ($)	76,159	1,372,341	3,419,999	9,642,813	15,865,877	19,750,442
Natural Gas Reductions (MMBtu)	-17,906	-455,527	-1,049,978	-2,679,525	-4,309,072	-5,123,064
GHG Reductions (KT CO_2e)	1	18	42	107	173	205
SO_2 Emission Reductions (lbs)	-10	-266	-5,697	-32,067	-58,437	-84,332
NO_x Emission Reductions (lbs)	-1,637	-41,653	-131,855	-460,085	-788,316	-1,041,972
Mercury Reductions (lbs)	0	0	0	-1	-1	-1
$PM_{2.5}$ Reductions (lbs)	-132	-3,368	-7,638	-19,064	-30,489	-35,885

Gas Works Strategy #3: Compressed Natural Gas (CNG) SEPTA Bus Replacement

Replacing SEPTA hybrid buses with CNG buses reduces SEPTA capital costs, assuming buses are replaced at the end of their lifetime. This is because the CNG buses used in the model are cheaper than new hybrid vehicles. Because hybrid vehicles are very efficient, however, replacement with CNG buses actually increases emissions.

GAS WORKS STRATEGY #3: COMPRESSED NATURAL GAS (CNG) SEPTA BUS REPLACEMENT

	2020	2025	2030	2035	2040	2045
Change in # of Diesel Public Transport Buses (additive)	-	-	-	-	-	-
Change in # of Natural Gas Public Transport Buses (additive)	24	146	273	402	533	682
Change in # of Hybrid Public Transport Buses (additive)	-24	-146	-273	-402	-533	-682
Direct Capital Expenditures ($)	-3,349,104	-3,441,627	-3,566,445	-7,052,893	-7,191,365	-9,679,332
Direct O&M Costs ($)	77,676	472,496	880,792	1,299,325	1,721,844	2,203,004
Natural Gas Reductions (MMBtu)	-53,434	-325,035	-605,905	-893,817	-1,184,472	-1,515,466
Diesel Fuel Reductions (MMBtu)	37,051	225,375	420,126	619,761	821,297	1,050,804
GHG Reductions (KT CO_2e)	-2	-15	-28	-41	-55	-70
SO2 Emission Reductions (lbs)	-	-	-	-	-	-
NOx Emission Reductions (lbs)	-1,854	-11,280	-21,027	-31,018	-41,105	-52,592
Mercury Reductions (lbs)	-	-	-	-	-	-
PM2.5 Reductions (lbs)	31	188	350	516	683	874

COMBINED PATHWAY OUTPUTS

When the cost, fuel demand, electricity demand, and emissions of individual strategies within each pathway are totaled, the resulting Stage 1 modeling outputs are as follows.

Combined Grid Pathway Outputs
(geographically scaled to the PECO five-county region)

COMBINED GRID PATHWAY OUTPUTS

	2020	2025	2030	2035	2040	2045
Direct Capital Expenditures ($)	432,158,948	610,393,682	891,518,564	439,404,573	442,125,175	451,381,845
Direct O&M Costs ($)	10,033,378	13,212,821	21,615,835	4,994,570	-16,057,303	-34,944,998
Electricity Reductions (MWh)	-1,117,485	-3,484,998	-6,083,920	-6,867,342	-7,658,292	-8,405,788
Gasoline Reductions (Gallons)	1,004,377	30,467,349	54,517,570	85,204,050	123,627,032	155,469,832
Diesel Fuel Reductions (MMBtu)	46,783	359,375	728,820	1,178,136	1,702,629	2,314,413
Fuel Oil & Kerosene Reductions (MMBtu)	3,139,369	10,987,791	18,836,214	24,034,799	28,570,925	33,107,052
Natural Gas Reductions (MMBtu)	-	-	-	-	-	-
GHG Reductions (KT CO_2e)	439	1,419	2,750	2,817	3,188	3,637
SO_2 Emission Reductions (lbs)	4,821	16,875	28,929	36,913	43,879	50,846
NO_x Emission Reductions (lbs)	412,815	1,531,823	2,636,193	3,417,845	4,137,748	4,841,034
Mercury Reductions (lbs)	9	33	57	72	86	99
$PM_{2.5}$ Reductions (lbs)	38,699	140,342	241,127	310,700	373,604	435,480

Combined Edge Pathway Outputs

(geographically scaled to the DVRPC nine-county region)

COMBINED EDGE PATHWAY OUTPUTS

	2020	2025	2030	2035	2040	2045
Direct Capital Expenditures ($)	779,688,460	940,655,841	868,042,075	1,071,931,382	1,020,354,442	1,395,440,548
Direct O&M Costs ($)	22,249,832	33,144,472	51,113,156	59,863,095	58,684,615	57,270,610
Electricity Reductions (MWh)	895,383	708,077	1,048,357	1,151,911	1,047,987	788,299
Gasoline Reductions (Gallons)	1,608,231	45,292,582	80,935,605	126,147,984	182,567,205	229,336,765
Diesel Fuel Reductions (MMBtu)	74,693	564,117	1,137,802	1,828,792	2,629,986	3,434,823
Fuel Oil & Kerosene Reductions (MMBtu)	-	-	-	-	-	-
Natural Gas Reductions (MMBtu)	8,395,277	30,619,767	51,956,944	65,126,071	65,353,553	66,549,001
GHG Reductions (KT CO_2e)	542	2,115	3,737	4,908	5,405	5,776
SO_2 Emission Reductions (lbs)	4,900	17,871	30,325	38,011	38,144	38,842
NO_x Emission Reductions (lbs)	776,252	2,958,715	5,038,344	6,401,737	6,616,910	6,889,666
Mercury Reductions (lbs)	2	8	13	16	17	17
$PM_{2.5}$ Reductions (lbs)	62,415	234,810	399,372	505,376	517,807	535,772

Combined Gas Works Pathway Outputs

(geographically scaled to Philadelphia County)

COMBINED GAS WORKS PATHWAY OUTPUTS

	2020	2025	2030	2035	2040	2045
Direct Capital Expenditures ($)	2,380,679	22,695,456	15,708,338	8,288,629	32,490,718	9,595,451
Direct O&M Costs ($)	153,836	1,844,837	4,300,791	10,942,138	17,587,721	21,953,446
Electricity Reductions (MWh)	3,808	107,592	248,952	638,053	1,027,154	1,221,380
Gasoline Reductions (Gallons)	-	-	-	-	-	-
Diesel Fuel Reductions (MMBtu)	37,051	225,375	420,126	619,761	821,297	1,050,804
Fuel Oil & Kerosene Reductions (MMBtu)	433,672	1,517,852	2,602,032	3,311,619	3,927,559	4,543,498
Natural Gas Reductions (MMBtu)	-434,226	-2,050,662	-3,833,198	-6,376,928	-8,853,164	-10,554,184
GHG Reductions (KT CO_2e)	11	48	92	163	232	266
SO_2 Emission Reductions (lbs)	444	1,324	-2,971	-28,617	-54,366	-79,639
NO_x Emission Reductions (lbs)	19,610	27,924	-14,269	-317,663	-626,883	-862,930
Mercury Reductions (lbs)	1	4	7	9	10	11
$PM_{2.5}$ Reductions (lbs)	2,531	6,035	8,509	1,317	-6,501	-8,267

OBSERVATIONS

The Stage 1-modeled impacts of the three pathways contained within this interim report should be viewed as intermediary outputs based on a limited analysis of the inputs provided by the pathway leaders and ICF experts. While these intermediate model outputs can be informative, they should not be relied on to draw conclusions about the actual costs or impacts associated with the strategies. Such conclusions would come from a more rigorous modeling effort, as envisioned in the Stage 2 effort for this project. Nonetheless, part of the purpose of this report is to highlight some of the most interesting trends that we see across the strategies that are unlikely to be attributable to the imprecise nature of these results.

One important observation is that the outputs of each pathway are driven largely by just one or two strategies within that pathway. For example, nearly 80% of the cost of the Grid pathway is attributable to the utility scale solar strategy, and 75% of the Edge pathway is attributable to the distributed solar strategy. In the Gas Works pathway, the CNG bus strategy significantly mitigates the costs of the fuel-oil-to-gas strategy. When combined, these two strategies account for over 90% of the pathways total costs.

The three pathway teams were given the flexibility to design any energy related strategies for the region, but all three teams decided to limit their pathways to dealing with road transportation, building efficiency/heating, and electricity generation. This demonstrates agreement over which areas of the existing regional energy system could and should be improved, even if the groups may differ on the best method for maximizing local net benefits. Local waste management is one area of potential energy savings that none of the groups tackled. The processing of solid and liquid waste requires a huge amount of energy, but both, in theory, could be harnessed as a source of new energy. Some of the discussions during the pathway design process began to consider waste management, but none of the pathway groups included these strategies in their final pathway.

Additionally, the pathway leads could have included strategies that would incentivize increased population and economic density in Philadelphia and the surrounding counties; however, none of them chose to do so. Philadelphia's population density and urban form are already an asset when it comes to maximizing local net benefits. Shorter distances lead to quicker commutes, easier access to services, and fewer emissions from vehicles in the city. Economic and population densification within the region would increase the number of households that would have access to public transportation as a viable method of commuting, further reducing vehicle miles traveled, and grid distribution infrastructure could serve more customers at a lower cost.

That being said, there are challenges to centralized development that the pathway leads may have wanted to avoid. For example, dense urban development limits the ability of residential rooftop solar to meet a significant share of residential energy demand because of reduced rooftop space and additional shading from other buildings. There are numerous other examples of energy policy strategies that one of the pathway groups could have chosen to develop but decided not to.

As mentioned earlier in the report, the accounting of emissions from grid-transmitted electricity was substantially simplified for the purposes of this report because a thorough analysis was beyond the budgetary scope of this phase of the research. Rather then modeling grid level emissions, 0.39 tons of CO_2e was added (or subtracted) from the modeled local emissions for every MWh of increased (or decreased) grid electricity demand. This analysis resulted in an annual reduction (from the BAU case) of 3,637 kilotons of CO_2e for the Grid pathway by 2045, a 5,776 kiloton reduction for the Edge pathway, and a 266 kiloton reduction by the Gas Works pathway.

If one assumes that grid level emissions will be significantly reduced in the future, it might be expected that these emissions outputs would also change significantly. However, if instead of 0.39 tons/MWh, we use 0.25 tons/MWh as a stand-in measure of grid emissions—representing approximately a 36% reduction in emissions—the overall CO_2e emissions reductions (from the BAU case) for each pathway would be as follows: 3,715 KT for the Grid pathway, 5,743 KT for the Edge pathway, and 93 KT for the Gas Works pathway. Comparing these outputs to the outputs using

0.39 tons/MWh, one can see that there is actually very little difference in the pathways' overall emissions reductions. This is because most of the emissions benefits are derived from local actions that would have a disproportionate effect on overall emissions. Also, in the Grid pathway, the accounting of emissions reductions for the utility-scale solar strategy means that this strategy actually contributes less to the overall pathways emissions reductions in a low-carbon grid scenario.

CONCLUSION

This interim report is just that: an update on work to date that should not be read for its conclusions but rather for the information it provides about the kinds of conclusions that will be available in the next phase of work.

After nearly two years of working with the stakeholder groups, we recognize that our initial characterization of the region as deadlocked over competing and divergent visions of the future energy policy was wrong. Uncertainty, rather than deadlock, is what limits decision-making on Philadelphia's energy future. Uncertainty about technology, policy, and climate impacts make it difficult to confidently elaborate strategies for more than incremental changes from the business-as-usual status quo. This is especially true when the strategy framers are bound by their responsibility to an institution, as was the case with the PGW and PECO stakeholder groups and, to a lesser extent, with PEA's Edge group.

To preserve credibility, institutions must limit their assumptions about the future, and instead rely on existing data and carefully measured short-term projections to define their official platform. Conversely, long-term visionary strategy planning demands stakeholders to make certain assumptions about the future, thus opening those strategies to criticism. During the pathway design process, it became clear that balancing these planning processes in the face of future uncertainty was challenging.

Accordingly, we are extending the Pathways project using decision-making frameworks designed to address deep uncertainty, such as "robust decision-making" (RDM) and "dynamic adaptive policy pathways" (DAPP). Robust decision-making stress-tests policy strategies against hundreds or even hundreds of thousands of possible futures, represented by combinations of multiple uncertainties over time. Rather than estimate the optimal strategy under a set of assumptions about the future, this approach identifies the strategies that are robust (i.e., perform well) across ranges of possible futures. Once we establish the robustness of strategies, we can then use DAPP to map strategies through a series of potential tipping points. As the future unfolds, DAPP guides decision makers to more robust strategies under emerging conditions. The power of the framework is it requires no agreement on which future is the most or more likely. Instead, it guides decision makers through robust responses to whatever future emerges over time, prepares for agile policy responses, monitors the most important indicators, and preserves as many options as possible—for as long as it is prudent.

This approach leverages the results of the Pathways effort in new ways. We take the strategies and pathways developed with our stakeholders. Each pathway consists of policy strategies that would generate estimated impacts in capital and operating costs, electricity and fuel consumption, and greenhouse gas and local air quality emissions. In future phases of the Comparative Pathways project, we can compare the local net benefits of stakeholder strategies for regional energy transition as well as compare the robustness of many different strategies under different futures that regional decision makers may face.

Our process has generated the Philadelphia region's first analysis of diverse visions of our energy future in a framework that will allow for comparisons of the costs and benefits of those visions. We are grateful for the generous effort and collegial trust that stakeholders have devoted to this effort. Combined with our planned application of decision-making under deep uncertainty methods, this work is intended both to facilitate productive discussion among advocates and stakeholders of competing visions and to support decision-makers facing investment and policy choices in the present and near future.

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