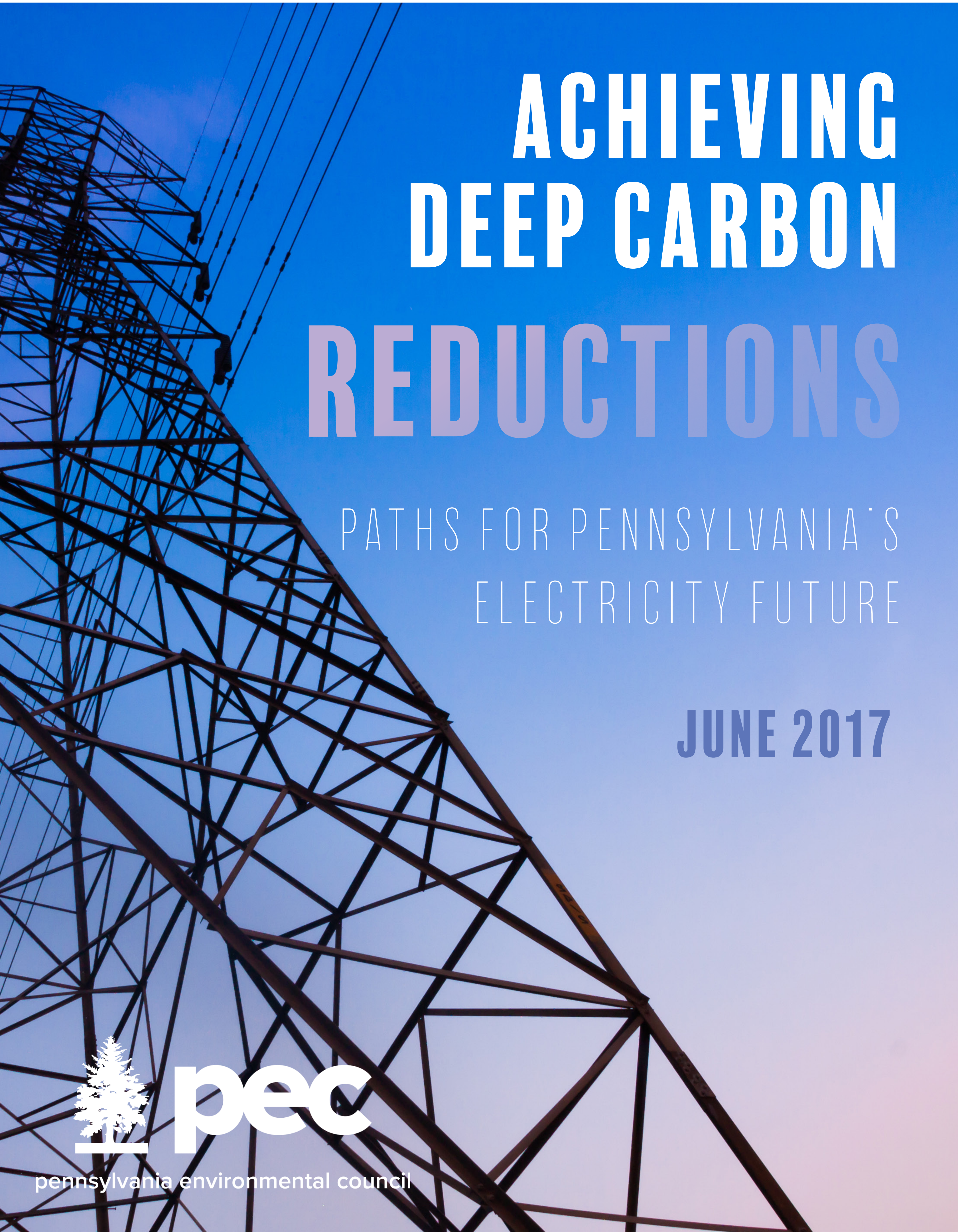

ACHIEVING DEEP CARBON REDUCTIONS

PATHS FOR PENNSYLVANIA'S ELECTRICITY FUTURE

JUNE 2017

pec

pennsylvania environmental council

Achieving Deep Carbon Reductions: Paths for Pennsylvania's Electricity Future
June 2017

Acknowledgments

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PEC believes in the value of partnerships with the private sector, government, communities and individuals to improve the quality of life for all Pennsylvanians.

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INTRODUCTION

Climate change is a global issue, and efforts must be taken globally both to avoid unmanageable impacts (climate mitigation) and to manage unavoidable impacts (climate adaptation). Pennsylvania, already in the midst of an energy transformation, has an important role to play. Climate change affects every facet of environmental protection and exacerbates challenges Pennsylvania currently faces, ranging from air quality to stormwater management to invasive species.

Achieving deep, as opposed to moderate, decarbonization will require greater systemic changes and consideration of alternative pathways for Pennsylvania's energy future.

Pennsylvania's contribution to global climate change is significant. Among U.S. states, Pennsylvania is the third-largest emitter of carbon dioxide (CO_2) and ranks fourth in electricity generation, fifth in coal production, and second in both nuclear power and natural gas production. Pennsylvania is also an important electricity exporter, which means the actions taken in the Commonwealth have impacts on neighboring states and beyond.

The Pennsylvania Environmental Council (PEC) believes the present level of dialogue and activity in the Commonwealth regarding decarbonization is insufficiently robust. Replacing coal-fired generation with gas-fired generation and moderately scaling up renewables will reduce greenhouse gas emissions — but achieve nowhere near the 80% reductions by 2050 (and 100% or greater thereafter) that both climate scientists and the international community in the Paris Agreement recognize will be necessary to avoid the worst impacts of climate change. A path of half-measures would also fail to realize the full economic potential of technologies and mechanisms that can reduce emissions in Pennsylvania — potential that has begun to be realized in recent years.

Achieving deep, as opposed to moderate, decarbonization will require greater systemic changes and consideration of alternative pathways for Pennsylvania's energy future. The Commonwealth must be careful to avoid pursuing near-term steps that lock in energy choices for decades or that lead to "dead ends" that make deep decarbonization impossible or unaffordable. PEC is exploring how Pennsylvania can achieve deep decarbonization while ensuring affordable and reliable energy supplies and a healthy economy.

On March 15–16, 2017, PEC convened a conference in Pittsburgh on Achieving Deep Carbon Reductions: Paths for Pennsylvania's Electricty Future. The conference brought together prominent thought-leaders on energy and climate issues for an open and honest discussion around the challenges of deep decarbonization and the potential pathways for Pennsylvania. Topics discussed included the science behind deep decarbonization pathways, the potential roles for a range of energy technologies, political and economic realities, and Pennsylvania-specific strategies. While efforts will have to be made to decarbonize all sectors of the economy, including transportation, manufacturing, and agriculture, the conference focused primarily (but not exclusively) on deep decarbonization of the electricity sector, which accounts for about 40% of Pennsylvania's energy-related CO_2 emissions.

This strategy paper draws in large part on (and has a similar scope as) the discussions that occurred at that conference. It lays out the rationale for deep decarbonization, the approaches and technologies that may be needed, and the role Pennsylvania can play. It also begins to lay out a strategy for advancing deep decarbonization efforts in the Commonwealth. As with deep decarbonization itself, this strategy will necessarily have to evolve and adapt over time — but the work must start now.

SUMMARY OF KEY RECOMMENDATIONS FOR PENNSYLVANIA

Pennsylvania needs a comprehensive, bold effort to commit to actions that will make the state a national decarbonization and zero-carbon energy leader. That effort should consider a portfolio of approaches.

Toward that end, the key recommendations for deep decarbonization action in Pennsylvania that emerged from the March 2017 conference include the following:

Electricity

- Implement carbon pricing at the state or regional level
- Promote modernization of the grid and utility business models
- Promote energy efficiency
- Enhance clean energy funding
- Lead by example with public buildings
- Advance renewables
- Preserve generation from existing nuclear plants
- Explore the potential for advanced nuclear
- Promote carbon capture, utilization, and storage
- Reduce methane emissions

Other Identified Areas[1]

- Achieve emission reductions from transportation by:
  + Advancing low-carbon fuels, including electricity
  + Supporting vehicle performance standards
  + Optimizing transport efficiency
- Encourage technologies to achieve negative emissions
- Support communities and workers in transition

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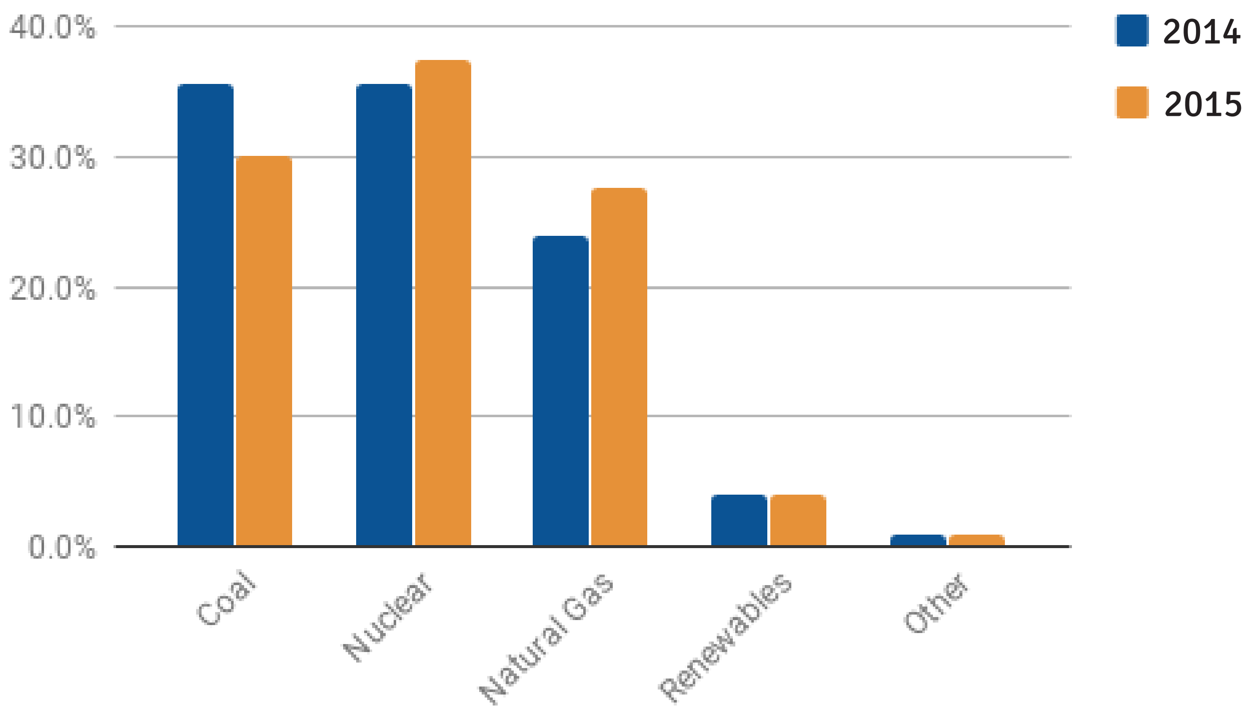
[1] While the conference focused primarily on deep decarbonization of the electricity sector, many attendees raised other key areas for action as well.

FAST FACTS ABOUT PENNSYLVANIA

Pennsylvania's role nationally[2]

- 3rd largest energy producer
- 3rd largest CO_2 emitter
- 5th largest coal producer
- 4th largest electricity producer
- 2nd largest natural gas producer
- 2nd largest nuclear power producer

Figure 1: Pennsylvania's electricity generation by type[3]



[2] U.S. Energy Information Administration (EIA), Pennsylvania State Profile and Energy Estimates, Jan. 2017. https://www.eia.gov/state/?sid=PA

[3] EIA, Electric Power Industry Generation by Primary Energy Source, Pennsylvania, Jan. 2017. https://www.eia.gov/electricity/state/pennsylvania/xls/pa.xlsx

Figure 2: percent electricity use by end-use sector[4]

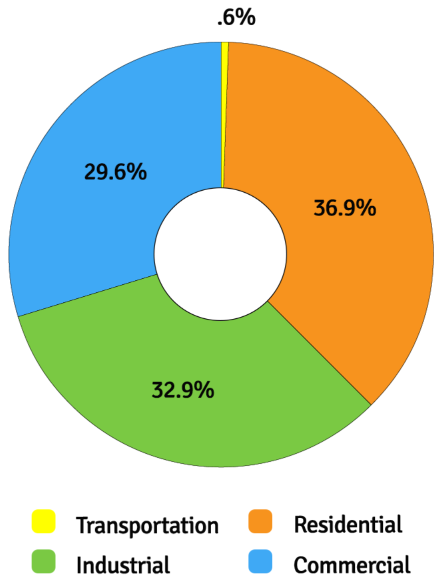
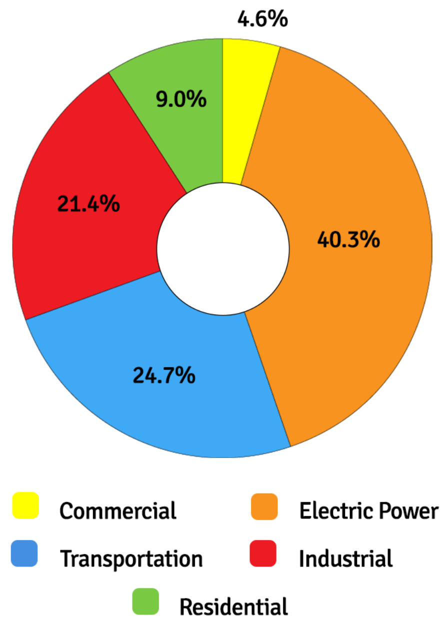


Figure 3: percent of energy-related CO_2 by sector[5]



[4] EIA, Retail Sales, Revenue, and Average Retail Price by Sector Back to 1990, Pennsylvania, Jan. 2017 (2014 data). https://www.eia.gov/electricity/state/pennsylvania/xls/sept08PA.xls

[5] EIA, 2014 state energy-related carbon dioxide emissions by sector, Jan. 2017. https://www.eia.gov/environment/emissions/state/analysis/pdf/table3.pdf

DEEP DECARBONIZATION SCIENCE & PATHWAYS

The Basic Science

The science-based targets in the Paris Agreement — keeping the increase in global average temperature this century to well below 2°C above pre-industrial levels, with the aim of limiting the increase to 1.5°C — are generally recognized as reflecting what is necessary to significantly reduce the risks and impacts of climate change. The world is already experiencing impacts from the current warming of about 1°C, so the 1.5°C and 2°C targets do not necessarily represent what is "safe" — just what will give humanity a meaningful chance of avoiding the worst impacts of climate change. Those targets are going to be extremely difficult to meet.

Addressing climate change is not like addressing conventional air pollution. Conventional air pollutants cycle out of the atmosphere relatively quickly, whereas CO_2 stays for centuries. (While CO_2 is the primary long-term driver of climate change, there are other greenhouse gases generated by fossil fuel development and use, such as methane, that have even stronger heat-trapping properties but remain in the atmosphere for shorter periods of time.[6] Attention has to be paid both to CO_2 and to these short-term climate forcers in order to achieve global climate targets.) Given the longevity of CO_2, climate change is more about the total amount in the atmosphere than about the amount emitted in any given year.

Accordingly, there is a very finite carbon budget remaining — in other words, a limited amount of greenhouse gases that can be emitted without exceeding the 1.5°C and 2°C thresholds. For example, one study has estimated that, to have more than a 66% chance of achieving the 2°C target, the total amount of CO_2 emitted into the atmosphere from 1870 into the future needs to stay below 3,670 billion tons ($GtCO_2$), which leaves only about another 765 $GtCO_2$ that could be added to the atmosphere from fossil-fuel combustion and industrial processes.[7] This will require a precipitous drop in emissions that needs to start now. Many policymakers and members of the public do not fully appreciate the challenge presented by the fact that CO_2 lasts for so long in the atmosphere — and the resulting, inescapable conclusion that serious decarbonization efforts have to start immediately.

There are many ways of understanding and visualizing such a steep reduction trajectory:

- According to a 2011 Duke University analysis, a 2% per year reduction in CO_2 emissions — every year, for decades — would level off atmospheric concentrations of carbon dioxide at below 450 parts per million, which generally correlates with a 2°C target.[8]

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[6] U.S. EPA, Greenhouse Gas Emissions: Understanding Global Warming Potentials website, visited Apr. 21, 2017, https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

[7] Glen P Peters et al., Measuring a fair and ambitious climate agreement using cumulative emissions, Environmental Research Letters, Vol. 10, No. 10, Oct. 15, 2015, http://iopscience.iop.org/article/10.1088/1748-9326/10/10/105004

[8] Eben Polk et al., Nicholas Institute for Environmental Policy Solutions, Duke University, G8 Leadership is Critical to Curbing Energy-Related CO2 Emissions, Sept. 2007, https://nicholasinstitute.duke.edu/sites/default/files/publications/g8-leadership-is-critical-to-curbing-energy-related-co2-emissions-paper.pdf

- The International Energy Agency (IEA) found in a March 2017 analysis that limiting warming to well less than 2°C will require global energy-related CO_2 emissions to peak before 2020 and fall by more than 70% by midcentury.[9]

- A March 2017 analysis in *Science* conducted by European and Australian researchers suggested that to limit warming to well below 2°C, anthropogenic CO_2 emissions have to be cut in half every decade — a global "carbon law" that requires the world to cut emissions in half in the 2020s, then in half again in the 2030s, etc. In addition, by 2050, net emissions from land use have to be zeroed out, while technologies to capture CO_2 directly from the air have to be massively scaled up to pull five $GtCO_2$ out of the atmosphere per year (almost twice what trees and soils accomplish now).[10] (See Figure 4)

- To have a greater than 66% chance of limiting warming to 2°C at the end of the century means having zero emissions — or lower — in this century, according to a recent study that looked at more than 100 scenarios in the Intergovernmental Panel on Climate Change's Fifth Assessment Report database, as well as other recent modeling exercises. Some modeled trajectories have emissions reaching zero around the middle of the century — some a bit later — and then achieving a significant amount of negative emissions thereafter.[11] (See Figure 5)

- There is no decarbonization trajectory that keeps warming below 1.5°C throughout the century; achieving that target by the end of the century would have to involve surpassing that level of warming and then coming back down. While it is theoretically possible to keep warming below 2°C, it is very likely that a similar pattern of surpassing and then coming back down would be needed to achieve that target before the end of the century.

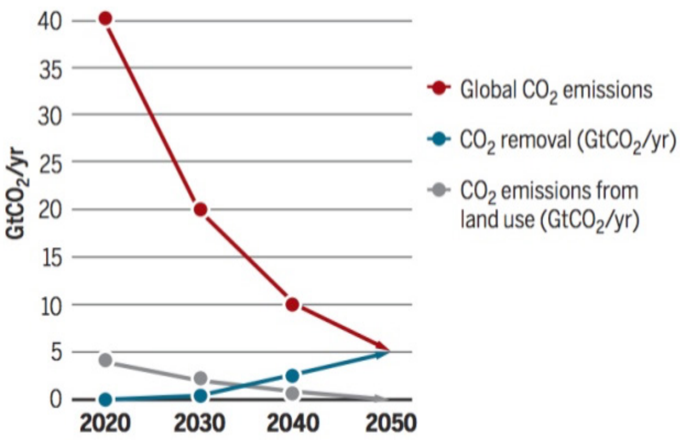

Figure 4:
Global carbon law guiding decadal pathways
Source: Rockström et al., 2017

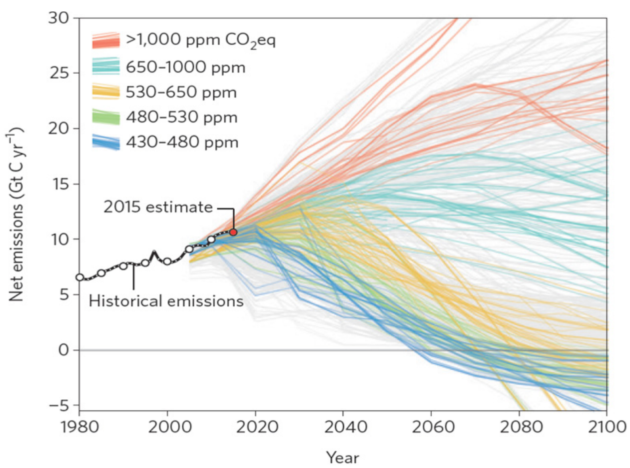

Figure 5:
Scenarios including negative emission technologies
Source: Smith et al., 2015

[9] IEA, Deep energy transformation needed by 2050 to limit rise in global temperature, Press release, Mar. 20, 2017, http://www.iea.org/newsroom/news/2017/march/deep-energy-transformation-needed-by-2050-to-limit-rise-in-global-temperature.html

[10] Johan Rockström et al., A roadmap for rapid decarbonization, Science, Vol. 355, Issue 6331, pp. 1269-1271, Mar. 24, 2017, http://science.sciencemag.org/content/355/6331/1269 (text also at: https://www.scribd.com/document/343117244/A-roadmap-for-rapid-decarbonization)

[11] Pete Smith et al., Biophysical and economic limits to negative CO2 emissions, Nature Climate Change, Vol. 6, Dec. 2015, http://www.nature.com/nclimate/journal/v6/n1/full/nclimate2870.html (text also at: https://www.researchgate.net/publication/285742474_Biophysical_and_economic_limits_to_negative_CO2_emissions)

Overview of Deep Decarbonization Pathways

The global energy system has evolved over more than 100 years, but to avoid the worst impacts of climate change, it now needs to fully transform over a matter of decades. This is an extremely challenging undertaking. There are many possible parts of the solution, and many possible paths to success — and to failure. Decarbonization must also go beyond just the energy sector to encompass every facet of the economy. As one of the researchers involved in the March 2017 *Science* analysis explained it, "It's way more than adding solar or wind. It's rapid decarbonization, plus a revolution in food production, plus a sustainability revolution, plus a massive engineering scale-up [for carbon removal]."[12]

There are many possible parts of the solution, and many possible paths to success — and to failure. Decarbonization must also go beyond just the energy sector to encompass every facet of the economy.

Deep decarbonization scenarios generally involve a range of technologies, policies, and actions. For instance, the March 2017 *Science* analysis described one possible pathway, broken down by decade:

By 2020: Annual emissions from fossil fuels must start falling; deep decarbonization strategies would need to be in place in industrialized cities, countries, and major corporations. Global fossil fuel subsidies would be eliminated, as would investments in new coal plants without carbon capture and storage (CCS). Policies such as carbon pricing and feed-in tariffs would be widely adopted, and incentives and strategies for sustainable food systems would be developed.

By 2030: Carbon pricing (starting at least around $50/ton) would have to cover most of the global economy. Aggressive energy efficiency programs would have to be in place. Coal power would be exiting the global energy mix. Leading cities would be free of fossil fuels. Leading countries would no longer sell new cars with internal combustion engines. Long-distance transport would be largely decarbonized. Investment in research and development of climate solutions would be far higher (with a focus on industrial efficiency, energy storage, cheaper CCS, improved smart grids, cleaner airplane propulsion systems, and sustainable urbanization). Reforestation of degraded land would increase, and technologies such as bioenergy with CCS (BECCS) and direct air capture would be removing 100-500 megatons of CO_2 each year.

By 2040: Oil would be exiting the global energy mix. Leading countries would have electrified all sectors of their economies and be virtually zero-carbon. Internal combustion engine cars would be rare on the world's roads. Airplanes would almost totally use carbon-neutral fuels (e.g., biofuels, hydrogen). Building construction would be carbon-neutral or carbon-negative. "Radical new energy generation solutions will enter the market," and carbon removal through BECCS would reach about one to two $GtCO_2$ annually.

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[12] Brad Plumer, Scientists made a detailed "roadmap" for meeting the Paris climate goals. It's eye-opening., Vox, Mar. 24, 2017, http://www.vox.com/energy-and-environment/2017/3/23/15028480/roadmap-paris-climate-goals

By 2050: The world would have reached net-zero CO_2 emissions and be fed by carbon-sequestering sustainable agriculture; most countries would be almost carbon-neutral. Natural gas with CCS would provide backup to electricity grids. Nuclear could be part of the energy mix in places, and more than 5 $GtCO_2$ would be removed from the air annually.[13]

The IEA suggests that achieving 70% reduction in global energy-related CO_2 emissions by midcentury will require:

95% of electricity to be low carbon

70% of new cars to be electric

80% reduction in CO_2 intensity in the industrial sector

$3.5 trillion annual energy-sector investments

retrofitting of entire existing building stock

and

fossil fuels accounting for about half of the energy demand they're responsible for today

This is just one pathway, but it highlights the enormity of the transformation required to meet global climate targets. Others have suggested the need for drastic measures and aggressive pathways as well. For example, the IEA suggested that achieving a 70% reduction in global energy-related CO_2 emissions by midcentury would require: almost 95% of electricity to be low-carbon (compared to less than 33% today); 70% of new cars to be electric (compared to 1% today); retrofitting of the entire existing building stock; an 80% reduction in CO_2 intensity in the industrial sector; fossil fuels accounting for about half of the energy demand they are responsible for today; and annual energy-sector investments of $3.5 trillion (twice today's levels), including increased investments in renewables, nuclear power, CCS, and transmission and distribution grids. The IEA analysis also suggested that such a deep transformation of the energy sector requires serious policy support, including rapidly phasing out fossil fuel subsidies, increasing carbon prices, extensive electricity market reforms to integrate renewables, and strong low-carbon and energy efficiency mandates.[14]

Similarly, in late 2016, the United States released the *United States Mid-Century Strategy for Deep Decarbonization*, which laid out pathways for reducing emissions 80% below 2005 levels by 2050. The report envisioned a pathway that would involve transforming the energy system through energy efficiency (in transportation, buildings, and industry), decarbonization of electricity (using nuclear, CCS, and lots of renewables), and fuel-switching to low-carbon fuels and electrification. It envisioned sequestering carbon through afforestation (and other land sink enhancements, including low/no-till agriculture) and CO_2 removal technologies (e.g., BECCS). It also envisioned some reductions in non-CO_2 gases.[15]

These sorts of scenarios tend to rely on the same sets of technologies. Deep decarbonization will generally involve at least the following pieces: (1) energy efficiency, (2) decarbonization of power (e.g., renewables, CCS, nuclear), (3) conversion of buildings and industry to electricity and other low-carbon fuels (e.g., for space heating, hot water heating, furnaces), (4)

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[13] Rockström et al., 2017, supra note 10

[14] IEA, Deep energy transformation needed by 2050, supra note 9

[15] United States Mid-Century Strategy for Deep Decarbonization, Nov. 2016, https://obamawhitehouse.archives.gov/sites/default/files/docs/mid_century_strategy_report-final.pdf

decarbonization of transportation (e.g., electricity, biofuels, hydrogen), and (5) achievement of negative emissions (e.g., cessation of deforestation, promotion of afforestation, improvement of agricultural practices, BECCS, direct air capture). The more delay there is in making significant reductions, the faster, more difficult, and more expensive the transition will have to be.

Many deep decarbonization scenarios include important roles for nuclear power and CCS, though some have shown pathways that rely primarily on energy efficiency, renewable energy, vehicle electrification, and a new transmission grid. In general, though, each time a technological option is removed from the toolbox, the task of deep decarbonization gets harder, and technologies may be deployed in ways for which they are not as well-suited. For instance, if CCS is available, achieving 2°C means utilities could take on the role of the negative emitter, going deeply negative by around mid-century (by using BECCS); removing CCS from the toolbox, however, means that negative emissions to achieve 2°C have to come from massive afforestation and perhaps direct air capture, and all other sectors — transport, buildings, industry, and non-CO_2 gases — have to reduce emissions even more. A recent review of deep decarbonization literature found "strong agreement that a diversified mix of low-CO_2 generation resources offers the best chance of affordably achieving deep decarbonization."[16] Deep decarbonization will be an enormous lift. It may be imprudent at this point to discard any zero-carbon options from the potential solution set.

The mix of and roles for resources needed for moderate reductions are likely quite different from what is needed for deep reductions. It is important to plan carefully for a pathway to achieve deep decarbonization targets, not just interim targets.

Without a clear focus on achieving deep decarbonization, though, some pathways could lock in technologies that will hit reduction dead-ends well short of the goal, resulting in stranded assets. The mix of and roles for resources needed for moderate reductions are likely quite different from what is needed for deep reductions. It is important to plan carefully for a pathway to achieve deep decarbonization targets, not just interim targets. A comprehensive strategy with clear goals is needed.

[16] Jesse D. Jenkins and Samuel Thernstrom, Deep Decarbonization of the Electric Power Sector: Insights from Recent Literature, Energy Innovation Reform Project, Mar. 2017, http://innovationreform.org/wp-content/uploads/2017/03/EIRP-Deep-Decarb-Lit-Review-Jenkins-Thernstrom-March-2017.pdf

Context and perspective

Projected pathways are not destiny. It is important to keep a sense of humility when evaluating studies and projections. They are necessarily based on assumptions and are fraught with uncertainty. There is a great deal that is always unknown — and often unknowable — in such projections (e.g., future technologies). What people value can also change, as was seen with smoking, and it is conceivable there could be societal shifts towards valuing non-emitting electricity sources and/or reduced energy demand. Uncertainty, however, is not an excuse for inaction.

It is also important to recognize that deep decarbonization cannot be pursued without consideration of people, society, culture, institutions, and communities, as well as technologies, economics, and politics. These are all important constraints within which decarbonization has to occur. For example, a deep decarbonization strategy that entails rapid escalation in the cost of energy will fail. Relatedly, businesses in the energy space have to be able to earn money; if investors cannot get returns on their investments, financing the transition to deep decarbonization will prove unworkable. Deep decarbonization efforts also have to maintain the reliability of the provision of energy and accommodate rising energy use in the industrializing world.

In addition, public support will be needed for the necessary infrastructure buildout — whether transmission systems, renewable energy systems, pipelines, or other energy infrastructure — which should spur efforts to work with communities and social equity movements to address concerns. Public support and buy-in will also be needed to really move the needle on technology adoption — whether electric vehicles, energy efficiency, or something else. At the moment, however, the sense of public urgency around climate change is low; while a strong majority of Americans believe climate change is real and needs to be addressed, few understand how it will impact them or their livelihoods.[17]

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[17] Nadia Popovich et al., How Americans Think About Climate Change, in Six Maps, The New York Times, Mar. 21, 2017, https://www.nytimes.com/interactive/2017/03/21/climate/how-americans-think-about-climate-change-in-six-maps.html

A DEEPER LOOK: POTENTIAL TECHNOLOGIES FOR DEEP DECARBONIZATION

There is no silver bullet for achieving deep decarbonization. A portfolio approach is needed, and time is of the essence.

The Electricity System

The framework of having an electricity system that consists of baseload, intermediate, and peaker generation resources may no longer be appropriate given the technologies now and soon to be on the grid and the need for deep decarbonization. One framing that accounts for the evolving nature of electric power sources might be:

While there is no question renewable energy has to be boosted for deep decarbonization, exactly how — and how much — are matters of debate.

- "Flexible base" (or dispatchable base), which could include nuclear, fossil fuels with CCS, biomass, geothermal, or reservoir hydro;
- "Fuel savers" (or variable renewables), which could include wind, solar, and run-of-river hydro; and
- "Fast flexers" (or fast rampers), which could include resources such as storage and demand response.[18]

While this is by no means the only possible vision of how a deeply decarbonized electricity system could be structured, a decarbonized system will surely be different from the current one. The following technologies could be some of (but not the only) important parts of such a system.

Renewables

Renewables are viewed by many as the "ideal" future of energy from an environmental perspective — and perhaps in terms of the economy and employment as well. This may prove to be the case in the long term. At present, however, renewable energy represents a fairly modest 15% of current U.S. electricity production, with hydro accounting for 6.5%, wind 5.6%, biomass 1.5%, and solar and geothermal both under 1%.[19]

While there is no question renewable energy has to be boosted for deep decarbonization, exactly how — and how much — are matters of debate. Several renewable energy technologies, particularly wind and solar, have been experiencing big price declines and increased deployment,

[18] See, e.g., Jesse Jenkins, Renewable Energy Potential and Limitations, Presentation at PEC conference on Achieving Deep Carbon Reductions, Pittsburgh, PA, Mar. 15, 2017, https://youtu.be/f2svsJsDmE4?list=PLM8MlLkuIIB07r1cwNtV2NJm9-YorAJ6B&t=696

[19] EIA, What is U.S. electricity generation by energy source?, last updated Apr. 18, 2017, https://www.eia.gov/tools/faqs/faq.php?id=427&t=3

[20] See, e.g., The Solutions Project, http://thesolutionsproject.org/

leading some to call for going with 100% renewables.[20] Others are unwilling to take the bet that renewable energy can be the whole solution for zero-carbon electricity generation, given the need for near total elimination of carbon emissions and achievement of substantial negative emissions by 2050 and beyond.

The weather-dependency of wind and solar technologies and solar's confinement to daytime hours (which shorten during the winter) present serious issues once those technologies begin to represent a larger portion of installed capacity. The recent review of the deep decarbonization literature[21] (and other studies) concluded that relying too much on variable renewables to achieve deep decarbonization raises several challenges, including:

- The marginal system value of variable renewables falls as more variable renewables join the grid, even with energy storage. The more there are, the less the overall electricity system gains from adding a bit more. For instance, the value of solar photovoltaics (PV) drops by about half at a 15% energy share and by nearly 70% at a 30% energy share.[22]

- High renewables scenarios require smoothing out renewable energy variability by capturing energy across wider regions. This, in turn, requires significant expansion of long-distance transmission grids (e.g., a continent-spanning high-voltage direct current [HVDC] supergrid), raising issues of siting and land use.

- Because production of wind and solar power is variable, relying on them for large amounts of electricity load requires significant over-building of capacity to ensure adequate supply. This means there are times when available wind and solar generation will exceed demand, requiring the excess generation to be curtailed (wasted) or stored. This extra cost and waste can only be somewhat addressed with current storage capabilities, flexible demand, and expansion of long-distance transmission interconnection.

- The problem of excess capacity will not be limited to renewables. Because wind and solar are variable, a fleet of reliable, dispatchable resources — or weeks' worth of storage, which is way beyond current technology — would still be needed in a high renewables scenario. This means that there will be excess capacity and low utilization rates for all resources on the system.

- Because of these factors, the cost of a 100% renewables pathway to deep decarbonization rises steeply and non-linearly.

Some dispute the seriousness or existence of some of these challenges.[23] They point to the precipitous declines in the cost of renewables such as solar PV and battery storage, which give

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[21] Jenkins and Thernstrom, supra note 16

[22] See Varun Sivaram and Shayle Kann, Solar power needs a more ambitious cost target, Nature, Apr. 7, 2016, https://www.nature.com/articles/nenergy201636.epdf

[23] See Herman K. Trabish, Is 100% renewable energy the best goal to cut power sector emissions?, Utility Dive, Mar. 20, 2017, http://www.utilitydive.com/news/is-100-renewable-energy-the-best-goal-to-cut-power-sector-emissions/438401/

the technologies significant room to grow and maneuver.

Even if over-building of renewable generation is needed at high levels of penetration, that may not be much of a problem if the cost is sufficiently cheap (though getting solar to be that cheap will not be easy). Renewables such as wind and solar also can scale fast. As with many disruptive technologies, they will likely follow an S-curve of deployment, with slow growth followed by rapid scaling and then something of a plateau.[24] The size of the scaling — the shape of the S-curve — for technologies such as solar PV will likely be known within five or 10 years.

Buildings are responsible for a significant portion of U.S. greenhouse gas emissions and electricity use (about 45% and 75%, respectively, in 2010), but sizable energy savings with relatively short payback periods are available now.

Either way, boosting the role of renewables requires major changes in the grid and how electricity is regulated, valued, and priced. For instance, when variable renewables become major players in competitive markets, regulators will have to figure out how to adjust dispatch rules to deal with these zero-marginal-cost resources. In addition, since deep decarbonization may require both centralized and distributed energy resources, there will be a need for improved integration of distributed renewables.

Even with market forces now pushing increased renewables deployment, policy support will continue to be needed to ramp up the scale, scope, and pace of such deployment. While the political winds blowing from Washington, D.C. may not be quite as friendly to renewables as they used to be, there still tends to be bipartisan support at the federal and state levels for policies to advance renewables.

Energy Efficiency

There is enormous potential to reduce CO_2 emissions through more efficient use of electricity — while reducing costs for consumers — though the climate impact of reducing a kilowatt-hour (kWh) depends on the fuel mix in the geography where the efficiency occurs. Efficiency is also often cheaper and more readily implementable than adding new generation, and electricity grid operation is increasingly focusing on demand reduction and flexible demand.

Buildings are responsible for a significant portion of U.S. greenhouse gas emissions and electricity use (about 45% and 75%, respectively, in 2010),[25] but sizable energy savings with relatively short payback periods are available now. For instance, LED lighting, which is far more efficient than incandescent and compact fluorescent lighting, has plummeted in price while improving in

[24] See, e.g., Fraunhofer ISE, Current and Future Cost of Photovoltaics. Long-term Scenarios for Market Development, System Prices and LCOE of Utility-Scale PV Systems, on behalf of Agora Energiewende, Feb. 2015, https://www.ise.fraunhofer.de/content/dam/ise/de/documents/publications/studies/AgoraEnergiewende_Current_and_Future_Cost_of_PV_Feb2015_web.pdf

[25] See Architecture 2030, Why the building sector? Webpage (citing EIA 2012 data), http://architecture2030.org/buildings_problem_why/

performance. Consumer-led efficiency efforts in buildings — coupled with innovative financing mechanisms, business models, and technologies — are transforming buildings into grid assets rather than just one-way consumers of energy. Addressing building energy use is widely acknowledged as one of the key aspects of decarbonization, with momentum at national, state, and local levels, as well as within the private sector.

Creating a better business case for efficiency — recognizing a broader range of value streams — can help unlock deeper energy retrofits for buildings. Traditional retrofits look only at the retrofit cost compared to energy savings, but there are additional values such as reduced maintenance and operating costs, rental premiums, and higher employee productivity.[26] A zero-net-energy community being designed in Pittsburgh is seeking to combine those kinds of different value streams.[27]

There are energy efficiency opportunities to consider beyond buildings as well. For instance, while traditional industries can shift load in time (e.g., demand response), data center networks can shift load in space.[28] Continued improvements in industrial energy efficiency and in the efficiency of energy generation technologies are also possible.

It is important, however, to design, implement, and measure energy efficiency in ways that allow it to be relied upon for deep decarbonization. True energy and dollar savings from energy efficiency programs have been hard to measure, though there has been good progress in getting credible estimates. Good, credible, data-driven evaluation and measurement strategies have to be considered in designing energy efficiency programs in order to be able to figure out what is being saved and what works (or does not). Data from smart-meters, big-data analytics, and proper experimental design may help provide insights regarding the actual savings.

The strategic behaviors of consumers in the market also have to be considered in policy design. Policy design can have unintended consequences (e.g., appliance rebates leading people to get a new, efficient appliance but keep their old appliance as well, or to replace their old appliance with a new, more efficient, but much bigger appliance, leading to increased electricity usage), so design has to try to ensure improved outcomes. There may also be a need to make sure that efficiency policies do not penalize people who take steps to reduce emissions that end up increasing their electricity use (e.g., purchasing an electric vehicle, transitioning from fossil fuel heat to an electric heat pump). Most efficiency policies are focused, understandably, on bills going down, not on emissions or fuel streams, but efficiency policies should not be designed in ways that discourage steps that lead to decarbonization.

Nuclear

There is uncertainty and dispute about the extent of nuclear power's role in deep decarbonization.

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[26] See Rocky Mountain Institute, How to Calculate and Present Deep Retrofit Value: A Guide for Owner-Occupants, 2014, http://www.rmi.org/retrofit_depot_deepretrofitvalue

[27] See Matt Jungclaus, An Integrative Technical and Business Approach to District Energy, presentation to Getting to Zero National Forum, Oct. 14, 2016, http://gettingtozeroforum.org/wp-content/uploads/sites/2/2016/10/AlmonoZeroEnergyCommunity_Jungclaus_PresentationHandout.pdf

[28] See Horner, Azevedo, et al., Dynamic data center load response to variability in private and public electricity costs, Smart Grid Communications, 2016, http://ieeexplore.ieee.org/

Nuclear power has many benefits. It produces no greenhouse gas or conventional air pollution and has a high capacity factor (about 90%), high economic impact in the regions where it operates, and a small land footprint. Uranium also has massive fuel energy density. Nuclear power brings value to the electricity system, as it provides high-quality, reliable power. Nuclear plants might also be able to provide some of the flexible base generation needed as more intermittent renewables come onto the system; existing nuclear plants can be somewhat flexible and load-following, though the business case for it is tough. (In the future, advanced designs could provide enhanced flexibility and load-following.) Nuclear power can also help industry decarbonize, such as by providing zero-carbon process heat.

The loss of the existing nuclear fleet would make the deep decarbonization challenge even harder, especially if nuclear power is replaced by fossil generation.

Nuclear power, however, faces many long-standing challenges as well, including economics, waste management, and concerns about nuclear weapons proliferation, plant safety, and plant security. These challenges have led some to be skeptical of the centrality of nuclear's role in achieving deep decarbonization. For instance, while nuclear power has a good safety record — only three major incidents over 60 years and more than 16,000 reactor years of operation[29] — it is unclear what society's tolerance is for those kinds of low-probability, high-impact nuclear accidents.

As of late 2016, there were 61 commercially operating nuclear power plants (99 nuclear reactors) in the United States.[30] Many of these plants, particularly those located in competitive power markets, are struggling economically, largely due to competition from lower-priced (but carbon-emitting) natural gas. Several plants in the United States have closed or are at risk of closing.

The loss of the existing nuclear fleet would make the deep decarbonization challenge even harder, especially if nuclear power is replaced by fossil generation. The loss of just four nuclear plants in 2013-14 (Crystal River, Kewaunee, San Onofre, and Vermont Yankee) wiped out an amount of zero-carbon electricity nearly equivalent to all that was generated from U.S. solar in 2015.[31] Deep decarbonization will be much more challenging if humanity is spending money and effort trying to replace the loss of existing zero-carbon energy rather than adding new zero-carbon energy to the grid. (Of course, if nuclear plants are non-economic and are going to close anyway, it is clearly preferable to replace them with other zero-carbon sources.)

Maintaining existing nuclear reactors is typically more cost-effective than building new low-carbon generation sources, and some states (e.g., New York, Illinois) are pursuing controversial (and contested) market adjustments to protect the existing nuclear fleet. These conversations

[29] World Nuclear Association, Safety of Nuclear Power Reactors, updated May 2016, http://www.world-nuclear.org/information-library/safety-and-security/safety-of-plants/safety-of-nuclear-power-reactors.aspx

[30] EIA, How many nuclear power plants are in the United States, and where are they located?, last updated Nov. 8, 2016, https://www.eia.gov/tools/faqs/faq.php?id=207&t=3

[31] EIA, Electric Power Monthly: Net Generation from Renewable Sources, Apr. 25, 2017, https://www.eia.gov/electricity/monthly/epm_table_grapher.cfm?t=epmt_1_01_a; International Atomic Energy Agency, Power Reactor Information System, https://www.iaea.org/pris/CountryStatistics/CountryDetails.aspx?current=US

are also beginning to occur in Pennsylvania, most notably through the creation of a nuclear caucus in the state legislature in March 2017.

There are also technologies (e.g., new materials, fuels) that could extend the life of and enable generation capacity increases at existing nuclear plants. Between 1977 and 2016, the U.S. nuclear industry added, or at least had approval for, more than seven GW of additional nuclear capacity by deploying new technologies to increase electricity generation from existing reactors.[32]

As for new nuclear plants, the rest of the world is building them, but only four new reactors are under construction in the United States — the AP1000s in the Southeast in vertically integrated utilities with Public Utilities Commissions (PUCs) that allow the costs to be added to the rate base. These new U.S. reactors are over budget and behind schedule. The prospects for new nuclear plants are further challenged by turmoil in the industry. Westinghouse recently declared bankruptcy, while French companies Areva and EDF have both seen their share prices plummet over the past several years.[33]

Advanced nuclear reactors, meanwhile, are still over the horizon, with pilots, commercialization, and deployment at least a decade away. There are now dozens of startups in the advanced nuclear space exploring different designs that could offer significant enhancements in safety, economics, load-following potential, scalability (up and down), and alternative uses and deployment options (e.g., for industrial process heat, offshore reactors). For instance, advanced designs can be smaller (10-300 MW), more manufacturable, and reliant on alternative coolants (i.e., not water), all of which can improve the business case, reduce costs, simplify the construction process, and enhance nuclear's ability to deploy faster. Advanced designs also have passive safety features to radically reduce accident risk. Still, there has been far too little government and private expenditure on advanced reactor R&D, and such advanced reactors are unlikely to be available for many years. Most advanced designs are so far from being ready for the licensing stage that the Nuclear Regulatory Commission (NRC) reasonably has only recently begun efforts to get ready to consider applications. There has been a bit of progress on water-cooled small modular reactors (SMRs) in the United States, but even there, NuScale's SMR design was only just accepted for NRC review in March 2017. The reality for now is that advanced nuclear designs are not prototyped, licensed, or reliable yet, which makes it difficult to rely on them as a climate solution. The costs and risks of advanced nuclear also have to be compared to other zero-carbon alternatives, given the realities of constrained financial resources. Still, it seems prudent to support the innovation cycle to help some of these designs get to the finish line. States can do some things to keep nuclear moving forward, but ultimately federal involvement will be needed to make advanced nuclear a reality (as was the case for renewables).

The end goal is decarbonization of the energy system to address climate change, and many

[32] Nuclear Energy Institute, US Nuclear Power Uprates by Plant, updated May 2016, https://www.nei.org/Knowledge-Center/Nuclear-Statistics/US-Nuclear-Power-Plants/US-Nuclear-Power-Uprates-by-Plant

[33] Paul Whitfield, EDF Has Been Decimated as Investors Dump Ex-Rights Shares, TheStreet, Mar. 8, 2017, https://www.thestreet.com/story/14031524/1/edf-has-been-decimated-as-investors-dump-ex-rights-shares.html

deep decarbonization scenarios see nuclear power as playing a vital role. At the very least, it is hard to envision a workable path to deep decarbonization that does not preserve much of the existing nuclear fleet for the foreseeable future.

Carbon capture, utilization, and storage

As appealing as the vision of achieving deep decarbonization using only renewables and efficiency may be to some, most deep decarbonization scenarios also assume the need to develop and deploy technologies that enable use of fossil fuels without releasing CO_2 to the atmosphere, especially when looking at the challenge in the context of global energy consumption. This involves a suite of technologies known as carbon capture and storage, sometimes also called carbon capture and sequestration. If the captured CO_2 is being utilized as a feedstock instead of stored, then the term is carbon capture, utilization, and storage, or CCUS. The International Energy Agency has repeatedly identified CCS as a vital part of long-term emission reduction strategies (including for achieving negative emissions through BECCS).[34]

Technology exists that can capture more than 90% of emissions.

CCS can be used for coal plants, natural gas plants, industrial sources, biomass plants, or fossil fuel plants co-fired with biomass. Use in conjunction with natural gas plants sometimes gets overlooked, as the switch from coal to natural gas spurred by the shale revolution has already led to some power sector decarbonization (as well as reductions in air pollution); for the same amount of generation, a gas plant produces half as much CO_2 as a coal plant. Emissions from natural gas plants are not zero, though, and these emissions will have to be addressed if natural gas is to be part of the deep decarbonization solution set.

Technology exists that can capture more than 90% of emissions.[35] Once the CO_2 emissions have been captured, they are then compressed and either stored on-site, used on-site, or transported for storage/utilization elsewhere. The sequestration occurs in geologic formations, including shale formations that are plentiful in Pennsylvania. The United States and Canada have thousands of years' worth of sequestration capacity, and Pennsylvania alone has at least several hundred years' worth.[36] CO_2 can also be utilized as a feedstock for other industrial processes. Currently, this is most often enhanced oil recovery (EOR), but there are many other uses to explore, such as using CO_2 for chemicals or as a substitute for water in fracking.

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[34] See, e.g., IEA, 20 Years of Carbon Capture and Storage: Accelerating Future Deployment, 2016, https://www.iea.org/publications/freepublications/publication/20YearsofCarbonCaptureandStorage_WEB.pdf

[35] NETL, Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3, July 6, 2015, https://www.netl.doe.gov/File%20Library/Research/Energy%20Analysis/Publications/Rev3Vol1aPC_NGCC_final.pdf; Matthias Finkenrath, Cost and Performance of Carbon Dioxide Capture from Power Generation, IEA Working Paper, 2011, http://www.iea.org/publications/freepublications/publication/costperf_ccs_powergen.pdf

[36] PA DCNR, Geologic Carbon Sequestration Opportunities in Pennsylvania, 2009, https://www.scribd.com/document/336476356/Geologic-Carbon-Sequestration-Opportunities-in-PA-2009

CCS technologies are not new; they are well-known and have been operating in the industrial sector for decades. In the United States, more than 850 million metric tonnes of CO_2 have been injected below ground for EOR since 1972, using a 4,000-mile CO_2 pipeline network.[37] However, most CCS technologies have been operated at relatively small scale, especially in the power sector. Around the world, there are only 22 large CCS projects in operation or under construction across a range of industries, with another 18 in stages of development planning.[38] Such projects in the power sector include the CCS retrofit of Unit 3 of the Boundary Dam coal plant, which came online in 2014 in the Canadian province of Saskatchewan and captures about one million tons of CO_2 per year.[39]

In late 2016, the Petra Nova CCS coal retrofit, which was constructed on-time and on-budget in Texas, became the world's largest post-combustion carbon capture unit, capable of capturing 1.6 million tons of CO_2 per year.[40] Also promising is the technology from NET Power, which claims to be able to capture all CO_2 produced from its natural gas generation for the same cost as other modern gas-fired turbines; if proven by the demonstration plant it is building in Texas, NET Power could be a CCS game-changer.[41] There are also 18 utilization projects around the world beyond EOR.[42]

While these operating and planned projects are a decent start, international emissions reduction scenarios to achieve 2°C suggest a need for CCS deployment that is orders-of-magnitude greater — from the 28 $MtCO_2$ captured annually in 2016 to around 6.1 $GtCO_2$ annually in 2050, which requires average growth of more than 15% per year.[43] The pace of CCS deployment has to be seriously accelerated to meet global targets. The United States is going much too slowly in making CCS a viable reality, though others around the world (e.g., China, Japan) are making real investments in CCUS projects, which they see as competitive business opportunities. The industrial sector can continue to provide near-term opportunities to further test CCS technologies and business models, particularly since some industrial sources have a purer stream of carbon and thus a lower cost of capture.

CCS is potentially cost-competitive with some other energy resources. Financial advisory firm Lazard found that the levelized cost of energy (LCOE) for CCS with coal or integrated gas combined cycle was comparable to the LCOE for rooftop solar, offshore wind, and battery storage.[44] Policy support, however, is needed to allow for investments in CCS plants to be recouped. Renewable energy incentives (e.g., tax credits) in recent years have dwarfed support for CCS, and greater parity

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37 Bruce Hill et al., Geologic carbon storage through enhanced oil recovery, Energy Procedia, 2013, http://www.sciencedirect.

38 Global CCS Institute, Large Scale CCS Projects, visited Apr. 25, 2017, https://www.globalccsinstitute.com/projects/large-scale-ccs-projects

39 Pete Danko, World's First Full-Scale 'Clean' Coal Plant Opens in Canada, National Geographic, Oct. 2, 2014, http://energyblog.nationalgeographic.com/2014/10/02/worlds-first-full-scale-clean-coal-plant-opens-in-canada/

40 NRG, Petra Nova website, http://www.nrg.com/generation/projects/petra-nova/

41 NET Power, NET Power Breaks Ground on Demonstration Plant for World's First Emissions-Free, Low-Cost Fossil Fuel Power Technology, Press Release, Mar. 9, 2016, https://netpower.com/news-posts/net-power-breaks-ground-on-demonstration-plant- for-worlds- first-emissions-free-low- cost-fossil-fuel-power- technology/; Robert F.Service, Fossil Power, Guilt Free, Science, May 26, 2017, http://science.sciencemag.org/content/356/6340/796

42 Global CCS Institute, CO 2 utilisation projects, visited Apr. 25, 2017, https://www.globalccsinstitute.com/projects/co2-

43 IEA, 20 Years of Carbon Capture and Storage: Accelerating Future Deployment, supra note 34

44 Lazard, Levelized Cost of Energy Analysis – Version 8.0, 2014, https://www.lazard.com/

may be needed. Congress has been very committed to this kind of technology, and it can likely continue to be funded and advanced even in the current U.S. political environment.

Beyond policy, CCUS faces some other serious challenges in achieving scale. For instance, it is still relatively costly. CCS also requires a great deal of energy — essentially a sizable energy penalty for a plant.[45] In addition, outside of a couple of regions, there is a general lack of CO_2 pipeline and storage infrastructure, which slows the development of new and retrofit CCS plants.[46] Furthermore, CCS faces public acceptance challenges and will likely encounter continued local opposition to specific projects, as well as general resistance from opponents who fear that CCS perpetuates fossil fuel extraction and use (with their associated societal and environmental costs), creates the potential for CO_2 leakage from pipelines or storage sites, and takes dollars away from renewables development and deployment.

Decarbonizing transport will likely have to involve converting cars and light trucks to electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs) running on zero-carbon electricity, which in turn will require a significant build-out of vehicle charging infrastructure.

BRIEF REVIEW OF OTHER KEY AREAS

Transportation

Transportation accounts for about 14% of global greenhouse gas emissions, but in 2016, it surpassed electric power generation to become the largest source of U.S. CO_2 emissions.[47] (Each now represents about a third of U.S. CO_2 emissions.)

Most of the energy used in transportation is used for road transport. Decarbonizing transport will likely have to involve converting cars and light trucks to electric vehicles (EVs) or plug-in hybrid electric vehicles (PHEVs) running on zero-carbon electricity, which in turn will require a significant build-out of vehicle charging infrastructure. While there is great dispute about whether using corn ethanol to power light-duty vehicles is better on a lifecycle CO_2 basis than using gasoline, there are other potential net-zero-carbon liquid fuels, such as fuels created by using genetically modified organisms, captured CO_2, or possibly crop residues (i.e., cellulosic

[45] Kurt Zenz House et al., The Energy Penalty of Post-Combustion CO2 Capture & Storage and Its Implications for Retrofitting the U.S. Installed Base, Energy & Environmental Science (2), 2009, https://dash.harvard.edu/bitstream/handle/1/12374812/1239214136-mja188.pdf

[46] NETL and Great Plains Institute, Siting and Regulating Carbon Capture, Utilization and Storage Infrastructure, U.S. Department of Energy workshop report, Jan. 2017, https://energy.gov/sites/prod/files/2017/01/f34/20-46%20Workshop%20Report%20-%20Siting%20and%20Regulating%20Carbon%20Capture%2C%20Utilization%20and%20Storage%20%28CCUS%29%20Infrastructure.pdf

[47] U.S. EPA, Global Greenhouse Gas Emissions Data, https://www.epa.gov/ghgemissions/global-greenhouse-gas-emissions-data; Brad Plumer, Power plants are no longer America's biggest climate problem, Vox, June 13, 2016, http://www.vox.com/2016/6/13/11911798/emissions-electricity-versus-transportation

ethanol). More efficient long-haul trucks have to be part of decarbonizing transportation as well, as do solutions to reduce CO_2 from the "last mile" of delivery.

Shipping by rail is more energy efficient than by truck, so moving more freight to rail can also contribute to decarbonization — as can reducing emissions from rail, such as through electrification or use of low-carbon fuels (e.g., hydrogen, if not made from methane).

Non-CO_2 gases

As noted earlier, reductions in non-CO_2 gases such as methane and nitrous oxide are also needed to achieve deep decarbonization. In the context of the energy system, the main contributor to methane emissions is leakage from natural gas systems. For natural gas to truly play a meaningful role as a climate solution, methane leakage from natural gas production and distribution has to be addressed, and there are cost-effective technologies available that can do so. Other gas-producing states have already enacted leak detection and repair requirements for methane.

Negative emissions

As noted earlier, projections and models for achieving deep decarbonization mostly envision surpassing the targets and then coming back to them via negative emissions technologies. While carbon removal from the atmosphere appears to be vital to achieving deep decarbonization, most strategies do not scale particularly well. For instance, afforestation, reforestation, and no-till agriculture have multiple benefits and are well worth pursuing, but they cannot offset all the CO_2 humans are releasing. Fertilizing the oceans with iron could enhance biotic uptake of CO_2 (if it works), but the ecological consequences are unknown and could be catastrophic. Bioenergy with CCS could meet some energy needs while achieving negative emissions — the biomass absorbs carbon while growing, and then the combusted carbon is captured and sequestered. BECCS could in theory achieve large-scale negative emissions, while co-firing biomass with fossil fuels could have a small negative emissions impact. BECCS, though, also faces challenges in achieving scale. In particular, BECCS at scale could have land use and ecosystem implications, including potentially competing with food and other natural resource production.

Direct capture of CO_2 from the air — using a sorbent and then removing and sequestering the CO_2 — may be the best solution and may be on the horizon of cost-effectiveness, but it is currently still small-scale and expensive. It remains untested and unproven at anything approaching the necessary scale.

In general, the contrast between the urgent need for negative emissions technologies and the current deployment and cost status of those technologies is a significant area of concern.

PATHWAYS FOR PENNSYLVANIA

While climate change is a global issue, mitigation and adaptation activities will occur in cities, counties, and states. Particularly in the current national political environment, bottom-up action will be needed to show what is achievable, rebuild the political center, and change the political conversation on clean energy and climate change to enable the national-level policies that will ultimately be needed. Beyond particular technological solutions, the next few years have to be used to engage constituencies and build support for serious action. Deep decarbonization will be a decades-long effort, so the key is to do what is achievable now that gets humanity at least on the right trajectory towards that end goal. There is no need to over-commit to any particular policy or technology now; politics and technologies will change, but the end goal and commitment must be clear.

For Pennsylvania and the United States as a whole, deep decarbonization is an environmental issue, a jobs issue, an economic issue, and an energy security issue.

For Pennsylvania and the United States as a whole, deep decarbonization is an environmental issue, a jobs issue, an economic issue, and an energy security issue. Framing of decarbonization should be sure to include an emphasis on economic development and job creation — and such efforts should seek to avoid achieving success on the backs of struggling electricity ratepayers.

Pennsylvania has redefined its role in the energy world over and over. At various times in its history, Pennsylvania's economy, and many of its communities, have centered around oil, coal, or natural gas. There is no reason Pennsylvania could not redefine itself again to be a leader in zero-carbon energy, if it can muster the political will and vision. Pennsylvania (and the United States) can help lead the new world economy or can fall further behind.

In 2015, the Pennsylvania Department of Environmental Protection released an updated Climate Change Action Plan laying out numerous suggested actions to address climate change, including 12 recommendations for legislative action.[48] Those are strong recommendations, and some of them are reflected here, but there is much more that needs to occur in order to put Pennsylvania on a path to deep decarbonization. The following are the key recommendations for Pennsylvania that emerged from the March 2017 conference.[49]

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[48] Pennsylvania DEP, 2015 Climate Change Action Plan Update, Aug. 2016, http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-114163/FINAL%202015%20Climate%20Change%20Action%20Plan%20Update.pdf

[49] These are offered here at a fairly high level of generality. Specific actions and policy levers will have to be identified through future dialogue (as described in the next section, Moving Forward).

Electricity

- **Implement carbon pricing** — The market tends to treat things that are priceless as valueless; markets generally only care about things that have a price. Many economists have called for a steadily rising carbon tax as the most efficient way to reduce CO_2 emissions — internalizing the externality by making carbon pollution no longer free. A price could also be placed on carbon via a cap-and-trade system, particularly if the emissions allowances are auctioned.

  There is no chance of a global carbon price any time soon, and the prospects for a national one in the United States — which were not bright to begin with — plummeted following the November 2016 elections. The next best option would be a regional price, particularly given that Pennsylvania's power plants benefit multiple adjoining states. Such a regional price could be realized by the Commonwealth joining the Regional Greenhouse Gas Initiative (RGGI), a course of action that might already be authorized by the Pennsylvania Air Pollution Control Act and the Pennsylvania Uniform Interstate Air Pollution Agreements Act and that therefore might be accomplished via rulemaking, without the need for any new legislative authority.[50] Money raised from RGGI allowance auctions would flow into the state treasury and could be used to further support efforts to put Pennsylvania on a path to deep decarbonization, to help coal communities transition, and for other climate-related purposes (such as adaption).

  Given that Pennsylvania is part of a regional grid, an alternative way to achieve a regional carbon price would be via PJM implementing one through dispatch. PJM generators receive capacity payments for being available when needed and energy payments for the power they actually provide. Even a low carbon price could impact dispatch. PJM has begun considering a sub-regional carbon pricing approach, including border adjustments to prevent price and emissions leakage between states with carbon prices and those without.[51]

  Should a regional price prove undesirable or unworkable for Pennsylvania, there is also the option of pursuing a state-specific approach. Several states are exploring new carbon pricing policies, including both carbon taxes (e.g., Massachusetts, Washington) and cap-and-trade systems (e.g., Virginia).[52]

- **Promote modernization of the grid and utility business models** — Several states are undertaking grid modernization proceedings to evaluate and plan for the changes expected and needed in the electricity grid as clean energy, distributed energy resources, battery storage, thermal storage, electric vehicles, and other technologies proliferate. Pennsylvania's Public Utilities Commission should initiate a similar inquiry and planning process.

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[50] See, e.g., Exelon, Comments of Exelon Corporation on Pennsylvania's Implementation of the Clean Power Plan, Nov. 12, 2015, pp.9-10, https://www.eenews.net/assets/2016/01/19/document_cw_02.pdf ; Pennsylvania Uniform Interstate Air Pollution Agreements Act, 35 P.S. §§ 4101-4106Document-114163/FINAL%202015%20Climate%20Change%20Action%20Plan%20Update.pdf

[51] PJM, Advancing Zero Emissions Objectives through PJM's Energy Markets, May 2017, http://www.pjm.com/~/media/library/reports-notices/special-reports/20170502-advancing-zero-emission-objectives-through-pjms-energy-markets.ashx

[52] Chelsea Harvey, Defying Trump, these state leaders are trying to impose their own carbon taxes, Washington Post, May 12, 2017, https://www.washingtonpost.com/news/energy-environment/wp/2017/05/12/defying-trump-these-state-leaders-are-trying-to-impose-their-own-carbon-taxes/; Patricia Sullivan, McAuliffe proposes statewide carbon cap, Washington Post, May 16, 2017, https://www.washingtonpost.com/local/virginia-politics/mcauliffe-proposes-statewide-carbon-cap/2017/05/16/7eda81f6-39bb-11e7-a058-ddbb23c75d82_story.html

In addition, the current electric utility pricing structure was designed for a one-way grid with large, centralized generating stations. That structure needs to be re-examined to accommodate the wide range of technologies and the bi-directional flow of energy that are likely to be more prevalent in the future. At a minimum, there is a need to ensure ratemaking structures provide the appropriate incentives for the development of cost-effective zero-carbon energy resources throughout the network on both sides of the customer meter, potentially including through decoupling and real-time pricing.

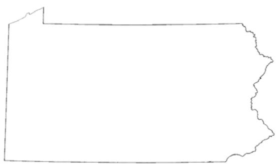
CALIFORNIA, 2015

$1.38 billion

Electricity energy efficiency programs

3.4%

of statewide utility revenues



PENNSYLVANIA, 2015

$217 million

Electricity energy efficiency programs

1.4%

of statewide utility revenues

- **Promote energy efficiency** — Energy efficiency is typically cheaper than any other resource and requires local labor; it should be the first strategy pursued in a deep decarbonization portfolio. Pennsylvania has opportunities to advance efficiency in the legislature, the PUC, and elsewhere.

Utility-funded energy efficiency and demand-side management programs have been increasing around the country. In 2015, California spent $1.38 billion on electricity energy efficiency programs (3.4% of statewide utility revenues) and $337 million on natural gas efficiency programs (more than $32 per customer). Pennsylvania, in contrast, spent $217 million on electricity efficiency programs (1.4% of statewide utility revenues) and $12.7 million on natural gas efficiency programs (more than $5 per customer).[53] Pennsylvania needs to ramp up its efficiency programs and spending and perhaps restructure utility business models to really drive energy efficiency. It should also be careful to structure its efficiency policies to drive who take steps to reduce emissions that end up decarbonization and to avoid penalizing people ncreasing their electricity use (e.g., purchasing an electric vehicle). In addition, Pennsylvania could explore whether to keep utilities in charge of energy efficiency or to hand off that responsibility to a third party, as is done in Vermont.Promoting energy efficiency ratings for buildings, especially residential buildings, could also help bring a market value to energy efficiency. Furthermore, the various manufacturing initiatives in the region should be encouraged to focus on improved energy efficiency.

[53] ACEEE, State Spending and Savings Table, data from 2016 State Energy Efficiency Scorecard, 2016, http://database.aceee.org/sites/default/files/docs/spending-savings-tables.pdf

While Pennsylvania is already implementing Act 129, which requires electric utilities and the PUC to promote energy efficiency and conservation, there is a strong need for data on how well Act 129 is working so it can be assessed and improved. Randomized controlled trials and natural experiments can also help policymakers understand if policies are delivering the intended savings and, if not, how to make them work better.

> **While project siting can be a challenge, community scale projects, with solar in particular, can engage and empower citizens to participate in decarbonization. Solar is also labor-intensive and can provide boosts to local employment.**

Understanding the landscape of efficiency opportunities in the Commonwealth would be valuable. Pennsylvania could conduct (or commission) a bottom-up engineering economic study (similar to the McKinsey abatement curve) of efficiency opportunities (and other greenhouse gas reduction opportunities) in the Commonwealth, including real-world data where possible, as well as a detailed assessment of the current building and equipment stock. Carnegie Mellon's Residential Regional Energy Efficiency Model (RREEM) could be of use in that regard.

Enhance clean energy funding — Deploying technology inherently depends on the availability of financing. While it is unlikely that additional public subsidies will be made available in Pennsylvania, the Commonwealth could affect market signals by harmonizing the currently disparate financing programs it offers to allow for better utilization of existing programs. The Pennsylvania State Treasury is also investigating the creation of a state green bank, which could be a valuable tool for impact investing that boosts energy efficiency and clean energy in the Commonwealth.

- **Lead by example with public buildings** — The Commonwealth can lead by example in improving the energy efficiency and use of clean energy in public buildings. All state buildings are fair game for private energy efficiency / ESCO projects. Encouragingly, Pennsylvania will be one of five states that will participate in a National Governors Association state retreat to explore innovative policies and programs to improve energy efficiency in public facilities, enhance the use of clean energy in public facilities, and improve resiliency in the public sector.[54]

- **Advance renewables** — Pennsylvania could increase its renewable energy generation from all sources, including wind and solar, and at all scales, from community- and utility-scale to distributed resources on individual homes and businesses. While project siting can be a challenge, community scale projects, with solar in particular, can engage and empower citizens to participate in decarbonization. Solar is also

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[54] National Governors Association, States Advance Energy Goals Through New NGA Opportunity, Press release, Mar. 23, 2017, https://www.nga.org/cms/home/news-room/news-releases/2017--news/col2-content/states-advance-energy-goals.html

labor-intensive and can provide boosts to local employment. Community solar and solar garden pilots could be encouraged in Pennsylvania.

Pennsylvania could also explore its offshore wind potential in Lake Erie. Erie County has joined the Lake Erie Energy Development Corporation (LEEDCo), the organization advancing efforts to develop Lake Erie wind. In advancing renewables, Pennsylvania should not ignore hydropower; improved access to financing through state sources could allow for lower costs of capital, and run-of-the-river projects provide very reliable, predictable green power.

Pennsylvania could also potentially re-open its Alternative Energy Portfolio Standard (AEPS) and increase the Tier 1 requirement. Further, creating a new tier for other non-emitting technologies, including nuclear power and CCUS, could gain political support, while pushing the AEPS toward being zero-carbon.

In addition, Pennsylvania needs to explore ways to improve renewables interconnection, particularly to enable distributed energy resources to interconnect with the grid.

- **Preserve generation from existing nuclear plants** — As noted earlier, Pennsylvania is second in the nation in nuclear power generation, with nuclear representing 37% of the Commonwealth's generation. Pennsylvania has nine nuclear reactors at five sites (Beaver Valley, Limerick, PPL Susquehanna, Peach Bottom, and Three Mile Island). The average reactor age in Pennsylvania is around 35 years old, and seven of the nine have 60-year licenses, which will reach their end between 2033 and 2047. Some nuclear uprate projects have been abandoned due to market conditions, and Exelon recently announced that the economically challenged Three Mile Island plant will shut down in 2019 unless additional state policy reforms are implemented. Pennsylvania needs to make some decisions very soon about the fate of its existing reactors.

  Climate gains from adding zero-carbon renewables to the grid can be wiped out quickly by the closure of existing zero-carbon nuclear plants. The Commonwealth must explore options for protecting the existing sources of zero-carbon generation that are being pushed out of the market, including evaluating whether the controversial zero-emission credits approach pursued in New York and Illinois are an appropriate model or whether other approaches would be preferable or more politically viable. Some of the options described earlier, such as changes to the AEPS or a regional or subregional carbon price, could help make the zero-carbon power that nuclear plants provide more competitive as well. In addition, gigawatts of uprates at existing plants may be possible and should be pursued where practical. The March 2017 creation of a bipartisan, bicameral Nuclear Energy Caucus in the state legislature is a positive development toward exploring these questions.

- **Explore the potential for advanced nuclear** — Pennsylvania was the birth place of civilian nuclear power. It has significant nuclear technical expertise in Pennsylvania State University, Carnegie Mellon University, the University of Pittsburgh, and elsewhere, as well as the headquarters of (the troubled) Westinghouse Electric Company. Pennsylvania should explore whether its existing nuclear supply chain, workforce, and expertise could position it to be a leader in demonstrating advanced reactor designs as they become available over the next decade.

- **Promote CCUS** — Even if deep decarbonization could be technologically achieved solely with renewables and efficiency, the reality of Pennsylvania's political dynamics and economy means it is impossible to ignore the role of the gas and coal industries in the Commonwealth. If Pennsylvania is to achieve a no-carbon future, it has to be careful not to lock in gas and coal (and the associated infrastructure) without CCS. If natural gas is a "bridge" to an even lower carbon future, then Pennsylvania should leverage its gas endowment to help build the other end of that bridge.

  Pennsylvania was a CCUS leader a decade ago, with the Department of Conservation and Natural Resources (and its Carbon Management Advisory Group) producing reports on geological sequestration capacity and liability risks and partnering with the Clinton Climate Initiative to explore an "early mover" CCS network to capture economies of scale. There is potential to dust off the work Pennsylvania has already done on CCUS, and the Commonwealth has many assets that lend themselves to further exploration. For instance, the shale boom in Pennsylvania has likely made assembling adequate large-scale pore space for CO2 sequestration even easier. Pennsylvania should also explore the use of captured CO2 as a replacement for water in the hydraulic fracturing process.

  In addition, Pennsylvania should press the Department of Energy to keep the National Energy Technology Lab's CCS programs healthy and well-supported, so CCS can be advanced for the Commonwealth's gas and coal plants. NET Power's technology could also be particularly promising in Pennsylvania, where natural gas is abundant and cheap.

  Ultimately, CCUS could enable Pennsylvania to use its natural gas and coal endowments to provide zero-carbon power to the region.

- **Reduce methane emissions** — As natural gas continues its exponential growth in Pennsylvania and continues to displace coal as a fuel for electric generation, it is essential to accurately measure and aggressively control methane emissions from natural gas production, transport, and distribution. Pennsylvania is currently working toward the finalization of proposed policies, through both permitting and regulatory measures, to accomplish this with regard to new and existing sources. These policies should be embraced and completed as soon as possible.

Other Areas: Transportation

- **Advance low-carbon fuels, including electricity** — Especially given the political clout of gas and coal in Pennsylvania — but the lesser clout of oil — transportation fuels could be a strong focus of deep decarbonization efforts in the Commonwealth, including promoting big deployment of alternative fueling stations, low-carbon fuel standards, and the like. Transportation is now the country's largest source of emissions — not the power sector — and in Pennsylvania is an easier political target.

  Pennsylvania and its leading cities should promote greater electrification of public transport (powered by clean electricity), add more public charging stations for electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs), and encourage regional universities to undertake more research and collaborative demonstrations with industry on net-zero liquid fuels. Millions of dollars from the Volkswagen settlement[55] can be used by Pennsylvania to help promote vehicle electrification.

  While one could argue that using natural gas directly for transportation (e.g., through compressed natural gas) may not be its best use compared to home heating, the political need to bring the gas industry in Pennsylvania to the side of decarbonization may make it worth additional consideration. Potentially more promising is the use of natural gas as a feedstock for zero-carbon liquid fuels such as ammonia.

- **Support vehicle performance standards** — While carbon prices could be very useful in driving emissions from point sources (e.g., power plants), they likely would not be high enough to change the makeup of the transportation fleet in a meaningful way (at least not within a reasonable timeframe). For mobile sources, there is a need for performance standards (such as the federal vehicle efficiency and emissions standards) to drive a faster transition to low-carbon vehicle fleets. Pennsylvania currently adopts California's stricter vehicle emission standards, and it should continue to do so, while at the same time pushing federal authorities to retain California's right under the Clean Air Act to set more stringent standards.

- **Optimize transport efficiency** — Pennsylvania cities should continue to work on optimizing traffic flow as part of regional smart city efforts and build on the region's expertise in robotics to grow research and collaborative demonstrations on

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[55] See http://www.dep.pa.gov/Business/Air/Volkswagen/Pages/default.aspx

decarbonizing the "last mile" of delivery (including through use of drones).

Other Areas: Negative Emissions

Encourage technologies to achieve negative emissions — Pennsylvania could encourage the Department of Energy, the National Energy Technology Lab, and others to make the Commonwealth the site of a major research and demonstration effort on direct air capture of CO_2. Pennsylvania also has a significant agricultural sector, creatingopportunities for smaller-scale, soil-preserving, carbon-capturing agricultural practices, and there is excellent work being done by the Rodale Institute exploring storing carbon in trees and soils.

Other areas: Transition

Support communities and workers in transition — Efforts to deeply decarbonize Pennsylvania's electricity sector will require shifts in the state's economy, including losses of some jobs and creation of others. Deep decarbonization efforts must be implemented in a way that positively impacts all Pennsylvanians, and ensures a workable economic transition for displaced workers, such as coal miners, and their communities.

To be truly successful, a deep decarbonization strategy must transcend adversarial attitudes that have taken hold of environmental and energy policy in general and climate change in particular.

This is not about "winners" and "losers"; this is about securing a workable strategy that will reduce greenhouse gas emissions as rapidly as possible while maintaining, or even improving, energy distribution, reliability, cost savings, and employment.

MOVING FORWARD: PEC'S APPROACH

Achieving deep decarbonization in the long term requires commitment to robust dialogue and action in the near term. To be truly successful, a deep decarbonization strategy must transcend adversarial attitudes that have taken hold of environmental and energy policy in general and climate change in particular. This is not about "winners" and "losers"; this is about securing a workable strategy that will reduce greenhouse gas emissions as rapidly as possible while maintaining, or even improving, energy distribution, reliability, cost savings, and employment. The recommendations identified in this document, while by no means exhaustive, represent a broad scope of opportunities for Pennsylvania, and they will require tremendous examination and commitment.

In 2007, PEC released its Climate Change Roadmap for Pennsylvania. That report, in turn, helped frame and advance passage of Pennsylvania's Climate Change Act of 2008, requiring the Commonwealth to perform periodic climate assessments, emissions reporting, and identification of greenhouse gas reduction options through an advisory committee. While these activities have produced a wealth of information, very little action has been taken by leadership in Pennsylvania to date. It is time for Pennsylvania to act.

The March 2017 conference, combined with this strategy document, set the table for dialogue and action. Now it is time to dig in. Over the next year, PEC intends to convene stakeholder workgroups, with inclusive representation, to formulate tangible recommendations for an effective deep decarbonization strategy that can be implemented through policy and practice in Pennsylvania. PEC will undertake this effort in partnership with industry, environmental, academic, and government leaders.

The deep decarbonization strategy must address what actions are currently possible under existing law, as well as where new policy and program initiatives must be enacted. It must consider multi-state approaches to maximize options and affordability. It must also try to devise a suite of actions that, as a package, can gain the necessary political support.

It is PEC's intention to have final workgroup recommendations by the start of 2018. ■