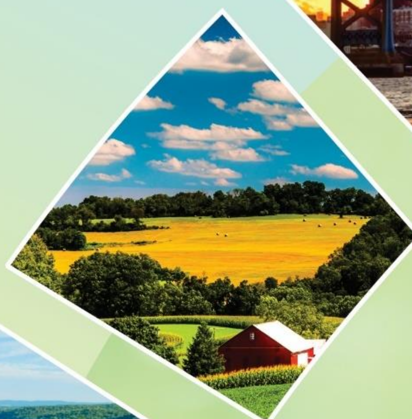
2015 Climate Change Action Plan Update

August 2016

Comment Response Document



Presented to:
Governor Tom Wolf

Presented by:

pennsylvania
DEPARTMENT OF ENVIRONMENTAL PROTECTION

The 2015 Pennsylvania Climate Change Action Plan Update was prepared by the department, in consultation with the Climate Change Advisory Committee, to meet the requirement in Act 70 of 2008 (Act 70). Act 70 specifically requires that the report identify the following information:

(1) Identifies GHG emission and sequestration trends and baselines in this Commonwealth.

(2) Evaluates cost-effective strategies for reducing or offsetting GHG emissions from various sectors in this Commonwealth.

(3) Identifies costs, benefits and co-benefits of GHG reduction strategies recommended by the climate change action plan, including the impact on the capability of meeting future energy demand within this Commonwealth.

(4) Identifies areas of agreement and disagreement among committee members about the climate change action plan.

(5) Recommends to the General Assembly legislative changes necessary to implement the climate change action plan.

The Draft 2015 Climate Change Action Plan Update was released on January 30, 2016 for a 60-day comment period. The department accepted comments through March 30, 2016. Commenters were able to submit comments to the Department's by using the on-line eComment tool, by email and by postal service mail.

Fourteen commenters submitted comments to the department. The 14 commenters submitted a total of 270 comments on the Draft Pennsylvania 2015 Climate Change Action Plan Update.

The comments were reviewed by the Department and a comment response document was prepared. In addition, the department revised the 2015 Pennsylvania Climate Change Action Plan Update where clarification and additional information was needed to reflect the concerns of both the commenters and the department.

For the purposes of this document, comments of similar subject material have been grouped. The following table lists the names and organizations, where indicated, of commenters. The Commentator ID number is found in parentheses following the comments in the comment response document. Multiple comments that contained similar themes are identified with multiple Commenter ID; i.e. 1, 2, 3 etc. and not listed individually.

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The following table lists the individual commenters and their associated organization. The table also provides the commenter number assigned to each commenter throughout the document.

Commenter Number	Commenter Name	Commenter Organization
1	James Sandoe	--
2	Johan Ashrafzadeh-Kian	--
3	James Sandoe	--
4	Caitlin McCoy	Center for Coalfield Justice
5	Davitt Woodwell	Pennsylvania Environmental Council
6	Lindsay Baxter	ReEnergize Pittsburgh Coalition
7	Jim Welty	Marcellus Shale Coalition
8	Anne Germain	National Waste & Recycling Association
9	Tracy Carluccio	Delaware Riverkeeper Network
10	Robert Altenburg	PennFuture
11	Liz Deardorff	American Rivers, Clean Water Supply - PA
12	Evan Endres	PA Chapter of the Nature Conservancy
13	John Kulik	Pennsylvania Petroleum Association
14	Tim O’Donnell	Pennsylvania Waste Industries Association

General Comments

1. **Comment:** I am writing to express our support of the state's efforts to address greenhouse gas (GHG) emissions, and to submit the following comments on the *Draft 2015 Climate Change Action Plan Update.* (5, 6, 10, 12, 13, 14)

   Response: The Department appreciates the support and thanks the commenters for submitting their comments on the Draft 2015 Climate Change Action Plan Update.

2. **Comment:** The commenter appreciates the opportunity to comment on the Draft Climate Change Action Plan (CCAP). As policymakers consider the data and recommendations contained in the draft plan, it is important that we recognize the significant strides and trends which have already contributed to a significant decline in carbon dioxide and methane emissions. (7)

   Response: The Department agrees with the commenter on the importance of recognizing the reductions which have already occurred in GHG emissions and thanks the commenter for submitting their comments on the Draft 2015 Climate Change Action Plan Update.

3. **Comment:** We commend the Climate Change Advisory Committee for drafting such a comprehensive update. One concern we have is that the plan does not set a target for GHG reductions. While not explicitly required by law, without a specific target, and timeline for achieving it, the recommendations in the plan are of limited significance. Only with a meaningful, and actual target, can decision makers then assess what combination of actions from the plan will be the most cost-effective means for achieving sufficient GHG reductions. At a minimum, the state should be focusing on a goal of 80% reduction in GHG emissions by mid-century. The commenter recommends a strategy of deep decarbonization, with a particular focus on electricity generation and use, which has historically been the largest contributor of GHG emissions in the state accounting for over one-third of statewide gross GHG emissions in 2012. (5)

   Response: The Department appreciates the comment. Setting a goal along with an implementation timeline is not part of Act 70 and thus not included in the Climate Change Action Plan Update.

4. **Comment:** There is general consensus among experts that the goals of the Clean Power Plan will not be sufficient to achieve the carbon reductions necessary to prevent irreparable harm from climate change. Strategies chosen to meet a twenty or thirty-percent goal may not be the most cost-effective options for reaching a fifty or eighty percent target. In fact, they could lock us into pathways that make it more expensive to eventually achieve deeper reductions. (5)

   Response: The Department acknowledges that strategies will be different depending on the amount of targeted reductions. The work plans put forth in the Draft 2015 Climate Change Action Plan Update should be considered as initial actions that are achievable in the near future and though related, separate from compliance with the Clean Power Plan.

5. **Comment:** The commenter submits these comments in response to the Department's request for feedback regarding the second Draft Climate Change Action Plan Update ("draft 2015 Update"[1]) published in the PA Bulletin and the Department's eComment system. It is our understanding that the Department is neither required to solicit nor accept comments on the draft 2015 Update; therefore, The commenter appreciates the Department's efforts to provide as many avenues as possible for participation in development of the final 2015 Update, including this public comment period. The commenter recognizes the hard work that the Department's staff and Climate Change Advisory Committee ("CCAC") members have put into development of the draft 2015 Update, and we offer these comments in the spirit of cooperation and improving an already impressive document. (14)

   Response: The Department appreciates the support of the commenter and thanks the commenter for submitting their comments on the Draft 2015 Climate Change Action Plan Update.

6. **Comment:** The commenter submits the five attached documents in support of our position that DEP's stated target of a 30% reduction in greenhouse gas emissions (GHG) by 2020 is neither sufficient if Pennsylvania is to make meaningful progress towards reducing the Commonwealth's contribution to global climate change nor is it achievable if natural gas development, including extraction, storage, transmission and end use, continues in Pennsylvania. We agree that it is clear that we need to reduce GHG emissions but we do not agree that it is acceptable or possible to reach a goal of reduction by following the proposed climate change action plan. The attached documents and peer-reviewed papers explain that the Commonwealth must get off fossil fuels as quickly as possible, that no new GHG emitting power plants can be justified in the Commonwealth and the use of fossil fuels in all energy sectors must be replaced by energy efficient renewable energy sources to provide an effective climate change action plan. (9)

   Response: The Department acknowledges the comment and links to the documents are provided in the appendix of this document.

7. **Comment:** The commenter advocates that Pennsylvania adopt a much more aggressive plan that does not include fossil fuel development and relies on energy efficiency, conservation, and renewable energy sources that can be sustained over the long term. The commenter supports the development of a Climate Change Action Plan that adopts a hierarchy of goals that places clean air, water, and a healthy environment for communities and workers, including healthy and biologically diverse habitats and ecosystems, as the top priority based on the tenants of the Environmental Rights Amendment – Article 1, Section 27 – of the Pennsylvania Constitution. Pennsylvania Constitution Article 1, Section 27: "The people have a right to clean air, pure water, and to the preservation of the natural, scenic, historic and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all the people, including generations yet to

[1] The original Climate Change Action Plan was issued in 2009 ("Original Plan"), and the first Climate Change Action Plan Update was issued in December, 2013 ("2013 Update").

come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people." (9)

Response: The Department appreciates the comment and will continue to consider energy efficiency, conservation, and renewable energy strategies while developing the 2018 Climate Change Action Plan Update.

8. **Comment:** For decades, the United States has been a leading emitter of the carbon pollution that causes climate change. As a nation, we have a moral and ethical responsibility to also be part of the solution. This presents an opportunity for Pennsylvania. Rather than a business as usual model where pollution is viewed as the cost of progress, Pennsylvania can become a leader in efficiency and clean energy technologies that will allow us to reach our goals while growing our economy. We applaud the steps DEP has already taken and hope, through this plan that work continues. In that spirit, we submit the attached comments. (10)

   Response: The Department agrees that Pennsylvania can become a leader in efficiency and clean energy technologies. The Department appreciates the support of the commenter and thanks the commenter for submitting their comments on the Draft 2015 Climate Change Action Plan Update.

9. **Comment:** The depth of content and attention to climate change in Pennsylvania is welcome. And I welcome the opportunity to bullet brief comments because, while I respect the enormous amount of effort evident by this Plan, I believe Pennsylvania has a long way to go to develop a Plan that will deliver adequate mitigation, resiliency or adaptation. (11)

   Response: The Department appreciates the comment and will continue to consider additional topics such as mitigation, resiliency, and adaptation while developing the 2018 Climate Change Action Plan Update.

10. **Comment:** Sadly water impacts are briefly and lightly noted but no specific plan is included. As a priority resource, planning should be moved up the priority list for both infrastructure resiliency and natural waterbody conservation. It is important to note that PA will likely (already does) experience both seasonal variations and episodic (greater occurrence of higher intensity events) which may have the greatest impact and should be addressed by land use management and infrastructure planning responses. (11)

    Response: The Department acknowledges the comment and will consider infrastructure resiliency and natural waterbody conservation while developing the 2018 Climate Change Action Plan Update.

11. **Comment:** We commend the Climate Change Advisory Committee (CCAC) and the DEP for developing a carbon reduction strategy for Pennsylvania. We also applaud the Committee for the rigor of its analysis of the cost and benefits of many of the prescribed actions. While we believe the recommendations contained in the Action Plan represent a reasonable starting place for carbon reduction, we think more can, and should, be done, especially given that Pennsylvania ranks third among states for carbon emissions. We encourage the CCAC and

the DEP to increase both the breadth and depth of the Action Plan, including developing a more aggressive action menu and incorporating additional adaptation and resilience-related activities and work plans. (12)

Response: The Department appreciates the support of the commenter and will consider the suggestions when developing the 2018 Climate Change Action Plan Update.

12. **Comment:** Pennsylvania is home to many industry organizations, non-profit entities, trade groups, academic institutions, foundations, and economic development organizations. Many of the work plans set forth in the Action Plan are relevant to the missions of these groups and may align with efforts currently underway by these groups. Initiating a process by which these groups could be engaged to refine and implement the work plans will result in making the plans actionable over a more immediate timeframe, while conserving time and financial resources. This process can be initiated through a Request for Proposal (RFP) process and/or the convening of stakeholder groups tasked with advancing elements of individual work plans. (12)

    Response: The Department appreciates the comment and welcomes the input from organizations throughout the Commonwealth in developing and implementing the work plans.

13. **Comment:** The comments we provide below offer suggestions to refine the existing work plans and policy recommendations; increase capacity through partner engagement; and further develop the work plan and policy menu. Our focus includes opportunities to broaden the scope of the Climate Change Action Plan to incorporate adaptation strategies and assess opportunities to include nature-based solutions as practical components of the Plan, supporting both human and natural systems. (12)

    Response: The Department will consider incorporation of adapting strategies and nature-based solutions when developing the 2018 Climate Change Action Plan Update.

14. **Comment:** The commenter applauds the Action Plan for identifying options to reduce greenhouse gas emissions in Pennsylvania. In addition, we urge that the Action Plan be expanded to include comprehensive consideration of ways to build resilient and adaptive systems in the face of a changing climate, both for our communities and for the natural systems that serve them, including our waterways, forests, and other natural spaces. Use of natural systems as a tool to build resilient human communities and maintain services is a cost-effective approach to mitigating impacts associated with a changing climate in Pennsylvania. Finally, Pennsylvania's Climate Change Action Plan should also account for the value and cost-effectiveness of carbon sequestration via natural systems. (12)

    Response: The Department acknowledges the comment and will consider including adaptation topics, including using natural systems, in the 2018 Climate Change Action Plan Update.

15. **Comment:** In 2010, at the urging of the Climate Change Advisory Committee, DEP issued the *Climate Change Adaptation Planning Report: Risks and Practical Recommendations*. In preparing this report, several working groups charged with issuing recommendations were convened. Topics for these working groups included:
    - Infrastructure (transportation, energy, water, buildings, communications, land use);
    - Public Health and Safety (public health, emergency management);
    - Natural Resources (forests, freshwater, plants and wildlife, agriculture); and
    - Tourism and Outdoor Recreation (fishing, boating, sports, adventure, golf, skiing, gardening).

    Green infrastructure practices are no-regrets strategies that have multiple benefits for improved capture of stormwater, water conservation, decreased sedimentation and pollution to waterways, and less adverse impacts to the built environment and wildlife. This innovative approach increases resilience to impacts resulting from climate change, such as greater precipitation and more frequent severe storm events, heat waves and droughts. Green sustainable practices include broad adoption of rain barrels and rain gardens, wetland development, green roofs, and bio-retention and green streetscapes to retain runoff and filter pollutants cost effectively. Walkable communities, particularly sidewalks, trails, and bike lanes, are growing in popular support and demand. (12)

    Response: The Department acknowledges the topics that were covered in the referenced report. The reference report was updated in 2015 and the Department is in the process of developing a white paper on adaptation issues that are currently being addressed within the Department.

16. **Comment:** Conserve wildlife and fish habitat by building resilience to the impacts of climate change. Some conservation, agriculture and outdoor recreation measures already underway should be reviewed for their potential to help meet the challenges of a changing climate Cross-cutting examples include use of riparian stream buffers, increasing native plantings, small dam removals, and providing areas for refuge and connecting habitat corridors for species migration. (12)

    Response: The Department appreciates the comment on conserving wildlife and fish habitat and the information provided on meeting the challenges of climate change.

17. **Comment:** Integrate adaptation and mitigation strategies as part of planning and operations of government agencies, non-profit organizations, businesses, farms and academic institutions. These can provide cost savings while also resulting in numerous other benefits. (12)

    Response: The Department acknowledges the comment on integrating adaptation and mitigation strategies.

18. **Comment:** The CCAC should include climate adaptation, including public health response, as a key component of future climate change action plans. Adaptation planning plays a key role for Pennsylvania in its climate change strategy. (12)

Response: The Department appreciates the comment and will consider climate adaptation while developing the 2018 Climate Change Action Plan Update.

19. **Comment:** In order to be successful with implementation, the stakeholders of all four working groups recommend that the commonwealth should support the establishment of a climate adaptation team within state government to provide technical expertise, resources and enlist the services of stakeholders needed to implement plans for each of the sectors. (12)

    Response: The Department appreciates the comment and will consider climate adaptation while developing the 2018 Climate Change Action Plan Update.

20. **Comment:** The commenter believes that these recommendations identified in the 2010 Adaptation Planning Report are still very relevant and deserve consideration in the *2015 Climate Change Action Plan Update*. We strongly urge the Advisory Committee to pick up where the 2010 effort left off and take steps to update, improve, and make actionable any recommendations that emerge. (12)

    Response: The Department appreciates the comment and worked closely with the CCAC to develop work plans that are actionable and will result in a reduction of greenhouse gas emissions.

21. **Comment:** This report was created as stakeholder feedback and background information from the commenter to the Pennsylvania Department of Environmental Protection (DEP) for the Pennsylvania Climate Change Act (ACT 70 OF 2008 OR ACT) 2015 Draft Update Report in order to provide clear and accurate data with respect to the implications of public policies leading to incentivizing and/or cross-subsidizing fuel switching from heating oil/biodiesel blends to natural gas. (13)

    Response: The Department appreciates the commenter submitting the prepared report dealing with the fuel switching work plan.

22. **Comment:** Both wellhead production and local distribution company delivery system leakage have been the subjects of numerous studies and reports. It should be noted that the calculations within this report were based on the conservative ICF[2] approach using EPA data. But, there will be more to come on this issue which could increase the impact of CO_{2e} of natural gas. (13)

    Response: The Department acknowledges that natural gas leakage issues will continue to be the focus of many studies and reports. The Department appreciates the commenter noting the

[2] ICF International of Fairfax, Virginia authored "Final Resource Analysis of Energy Use and Greenhouse Gas Emissions from Residential Boilers for Space Heating and Hot Water (Rev. 2/2009)" which was the basis for the oil and natural gas heating energy and emissions data in this report and "Assessment of New York City Natural Gas Market Fundamentals and Life Cycle Fuel Emissions", 7/31/2012 providing shale gas emissions data for this report.

basis of the calculations involved within the report, which is a significant difference than the basis of the calculations used within the 2015 Climate Change Action Plan Update.

23. Comment: The UT (University of Texas) study contains a major a major internal contradiction. The well sites were selected with substantial input from the oil and gas industry, which volunteered specific sites, and the vast majority of the wells studied used leak-control technology that has yet to be adopted at many, if not most, oil and gas wells, while others were wells that produced very little gas and consequently even serious leaks would produce relatively small emissions – specifically, the authors noted, those wells had the potential to emit only 0.55% as much as an average well. Although the study's authors acknowledged that their measurements were by no means representative of the average gas well nationwide, they nonetheless chose to use that skewed data to estimate gas leaks nationwide. The methodology that UT chose for making that estimate also has drawn heavy fire from others in the research community. (13)

Response: The Department appreciates the information provided in regards to the cited research.

24. Comment: According to a new study released November 25, 2013[3], Harvard University concluded methane from fossil fuel extraction and refining activities in the South Central United States are nearly five times higher than previous estimates. The new study takes a top-down approach, measuring what is actually present in the atmosphere and then using meteorological data and statistical analysis to trace it back to regional sources. NOAA and the U.S. Department of Energy collect observations of methane and other gases from the tops of telecommunications towers, typically about as tall as the Empire State Building, and during research flights. The team combined this data with meteorological models of the temperatures, winds, and movement of air masses from the same time period, and then used a statistical method known as geostatistical inverse modeling to essentially run the model backward and determine the methane's origin. The team also compared these results with regional economic and demographic data, as well as other information that provided clues to the sources — for example, data on human populations, livestock populations, electricity production from power plants, oil and natural gas production, production from oil refineries, rice production, and coal production. In addition, they drew correlations between methane levels and other gases that were observed at the time. For example, a high correlation between levels of methane and propane in the south-central region suggests a significant role for fossil fuels there. (13)

Response: The Department acknowledges that natural gas extraction and processing emissions will continue to be researched.

25. Comment: This research was undertaken to provide DEP and others with validated economic and environmental data with respect to current residential heating oil and biodiesel

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[3] PNAS http://www.pnas.org/content/early/2013/11/20/1314392110

customers in the Commonwealth, economic indifference conversion thresholds and environmental impact of residential fuel switching from oil to natural gas. (13)

Response: The Department acknowledges the report that was provided and appreciates the information it contained with respect to residential fuel switching from oil to natural gas. The work plan provided in the 2015 Climate Change Action Plan Update addresses homeowners using 100% heating oil, not any blend including biodiesel.

26. **Comment:** This report seeks to lay out the case for ultra-low sulfur biodiesel blends as an important and valuable residential heating fuel for Pennsylvania residents that should be supported by DEP. In fact, ultra-low sulfur biodiesel blends support DEP's stated purposes of identifying: economic opportunities for the Commonwealth created by the potential need for alternative sources of energy, climate-related technologies, services and strategies, carbon sequestration technologies, capture and utilization of fugitive GHG emissions from any source and other mitigation strategies. (13)

    Response: The Department acknowledges the report that was provided and the information it contained with respect to residential fuel switching from oil to natural gas.

27. **Comment:** As part of the draft 2015 Update process, the CCAC members re-evaluated the workplans, based on each plan's feasibility (including cost effectiveness), emission reduction potential, and the specificity of the implementation steps set forth in the 2013 Update (if any). Ultimately, the CCAC recommended approximately 10 workplans to the Department for a more in-depth development.[4] Several workplans were subsequently added by the Department after Governor Wolf took office. Most importantly, all of the remaining workplans in the 2013 Update remained endorsed by the CCAC and the Department, and should be considered integral to the draft 2015 Update. (14)

    Response: The Department appreciates the comment and agrees with the importance of previous plans developed in the 2013 Update. The Department continues to support the work plans included in the 2013 Climate Change Action Plan Update.

28. **Comment:** The commenter recommends that the Department include a discussion of the process used to select workplans for inclusion in the draft 2015 Update that were developed in more depth, as well as explicitly reaffirming the importance and validity of the workplans that were not further developed for the draft 2015 Update. (14)

    Response: The Department appreciates the comment and has made a revision to the 2015 Climate Change Action Plan Update to clarify the process used to select work plans.

[4] See CCAC meeting minutes, dated February 11, 2014; April 8, 2014; and June 24, 2014.

Climate Change Impacts

29. Comment: The UCC also includes provisions to improve resiliency in the face of increasing natural disasters and flooding. The state's 2015 Pennsylvania Climate Impacts Assessment Update indicates flooding, such as that seen during Hurricane Sandy and Hurricane Ivan, will increase. The costs of these disasters are borne by our state's homeowners and taxpayers. The 2015 codes include many flood-related provisions, including changes to the 2015 International Residential Code supported by the U.S. Federal Emergency Management Agency's Superstorm Sandy analysis report. (6,10)

Response: The Department appreciates the comment and agrees that updating building codes in the Commonwealth with help improve resiliency to natural disasters.

30. Comment: As noted in Pennsylvania's Climate Change Impacts Report,[5] the Commonwealth faces two fundamental threats related to climate: 1) Sea level rise and its impact on communities and cities in the Delaware River Basin, including the city of Philadelphia; and 2) more frequent extreme weather events, including large storms, periods of drought, heat waves, heavier snowfalls, and an increase in overall precipitation variability.

The way we have engineered many of our human-scale systems assumes that weather events will occur with a frequency that follows a predictable path based on historical data. Climate change threatens that predictability and therefore threatens the predictive functions (*i.e.*, useable life, maintenance schedules, replacement frequency) of the infrastructure that supports our commerce, communities, and citizens. (12)

Response: The Department appreciates the commenter's concern for sea level rise and more frequent extreme weather events, especially those described in the 2015 Pennsylvania Climate Change Impact Assessment Report. We acknowledge these comments and agree that climate change threatens the predictability of weather events. The Department is currently taking steps to ensure environmental regulations are in place to meet the challenges of greater unpredictability of weather events.

31. Comment: As the DEP is aware, since 2010, additional examples of resilience and adaptation planning have been undertaken by Pennsylvania communities and agencies. In addition, clearinghouses have emerged for coordinated, state-wide planning and implementation efforts and recommendations for best practices in executing those efforts. The Committee and DEP should consider tracking these efforts and seek opportunities to learn from stakeholders and understand the tools and protocols used to make the assessments.

The City of Pittsburgh: Pittsburgh was named to the Rockefeller 100 Resilient Cities Network in 2014. Since then, the City has undertaken efforts to encourage internal, cross-department collaboration on how best to deal with heat-related stresses, riverine flooding,

[5] http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-108470/2700-BK-DEP4494.pdf

and impacts associated with stormwater management. The community has taken steps to identify and convene non-government related assets and organizations that would benefit from operational literacy as it pertains to city services, as well as coordinating collaborative planning in the community. Further documentation of Pittsburgh's efforts can be found at this link: http://www.100resilientcities.org/cities/entry/pittsburgh#/-_/.

The City of Philadelphia: Philadelphia issued a comprehensive vulnerability assessment in its Climate Adaptation report, "Growing Stronger: Toward a Climate Ready Philadelphia." The analysis identified risks and vulnerabilities associated with heat waves and flooding - including sea level rise, storm surges, and increased heavy precipitation events. The report identified these risks and vulnerabilities through the lens of directing smart investments that the city can implement now in order to improve the resiliency of systems and services to respond to climate related vulnerabilities in the future. A copy of that report can be found at this link: http://www.phila.gov/green/PDFs/Growing%20Stronger.pdf.

City of Chester: In 2013, the Chester Hazards and Climate Adaptation Project Team conducted a vulnerability assessment of the City of Chester's critical assets using existing plans and relevant spatial and demographic data, to examine the city's vulnerabilities to extreme heat, severe storms, flooding, and sea-level rise. Chester's climate action plan can be found at the following link: http://www.chestercity.com/wp-content/uploads/2015/09/2014-06-25_Vision_2020_Climate_Adaptation_Elements.pdf.

SEPTA (Southeastern Pennsylvania Transit Authority): In 2010 and 2011, SEPTA participated in a Federal Transportation Administration (FTA) pilot effort to formalize the process of considering disruptions related to extreme weather in decision making; inform existing adaptation efforts with climate science and risk analysis; better understand costs and impacts; and develop a comprehensive strategy that could be applied across the entire system. The pilot effort involved an analysis of SEPTA's current and future risk over several types of extreme weather events. ICF International, SEPTA, and the Delaware Valley Regional Planning Commission collaborated to carry out this work. A copy of SEPTA's study is available at through the following link: https://www.fhwa.dot.gov/environment/climate_change/adaptation/case_studies/septa/index.cfm.

Other Pennsylvania entities that are engaged in adaptation and resilience planning or risk assessments include PennDOT, the Pennsylvania Department of Health, DCNR, and PEMA. (12)

Response: The Department acknowledges that other entities within the Commonwealth are engaged in adaptation and resilience planning, and appreciates their work and the information provided through those endeavors.

32. Comment: In addition to local efforts, the Committee can reference the comprehensive list of guidance, resources, and examples provided by Georgetown University through its Climate Central initiative and "Adaptation ClearinghouseTM". This index provides examples and progress reports from every state that has engaged in adaptation planning efforts and execution of those plans. Pennsylvania is included in the index due to the above mentioned efforts: http://www.georgetownclimate.org/adaptation/overview.

Most relevant to Pennsylvania may be California's efforts and accompanying report, "Safeguarding California: Reducing Climate Risk - Update to the 2009 CA Climate Adaptation Strategy." As the title suggests, California built this plan as an update to an earlier effort started in 2009. It stands out in addressing all sectors and departments and for identifying a comprehensive set of actions. A copy of California's plan can be found at the following link: http://www.georgetownclimate.org/adaptation/state-information/overview-of-californias-climate-change-preparations. (12)

Response: The Department appreciates the information provided in regards to planning being done at Georgetown and in California.

33. Comment: As mentioned previously, nature-based solutions deploying natural infrastructure are a cost-effective way to build resilience and protect communities. These solutions often have the additional benefit of sequestering carbon - a cost-effective strategy to augment carbon reduction goals. Solutions that deploy natural infrastructure support ecosystem health while adding economic, recreation, and scenic value. The following are some examples of how stakeholders in Pennsylvania, and elsewhere, are deploying nature-based solutions. Many of the methods discussed below have the dual benefit of allowing natural systems to thrive while improving the resiliency of infrastructure to climate related impacts. (12)

Response: The Department appreciates the comment and will consider nature-based solutions for resiliency to the impacts of climate change in the 2018 Climate Change Action Plan Update.

34. Comment: As clean water is a critical resource for community health, and may be an even more critical asset in the face of increased heat events, droughts, and other climate-related impacts, we urge the Committee to identify opportunities related to resilience and adaptation needs associated with waterways and watershed systems. Strategies that build resilience into these systems provide greater flood management and mitigation potential. Specific examples of actions may include:

- Building / retrofitting of more flood-resilient infrastructure, specifically culverts and bridges. Massachusetts has an excellent statewide program that assesses and prioritizes road/stream crossings for redesign, using a set of design standards that enable aquatic organisms to move freely and reduces the risk that the redesigned structure will be damaged in future floods.
    - The Climate-Friendly Stream Crossings Toolkit describes how assessment, prioritization, design, and training are used to improve stream habitat in Massachusetts: https://streamcontinuity.org/resources/crossings_toolkit/index.htm.
    - Aquatic Connectivity and Flood Resilience focuses on the mutual benefit of designing for aquatic organism passage and flood resiliency.
- Reducing risk of flood damage to waterways. As the frequency and severity of floods increases, understanding which areas in the river corridor are most at risk to flood

damage will help prepare for floods and design restoration that mitigates future hazards.
    - The Association of State Floodplain Managers (ASFPM) recently produced a white paper that outlines the benefits of assessing riverine erosion hazards: http://www.floods.org/ace-images/ASFPMRiverineErosionWhitePaperFeb2016.pdf.
    - Indiana and Vermont have good examples of state-level programs that address flood damage. Indiana: http://feh.iupui.edu/about-feh/natural-processes/; Vermont:http://floodready.vermont.gov/flood_protection/river_corridors_floodplains#Problem.
- Increasing the extent of forest cover along streams and rivers. In addition to providing shade to reduce thermal impacts, forested riparian areas can help prevent erosive damage to stream channels during flood conditions. Increasing the amount of riparian forest buffer should be part of a climate adaptation plan. The strategy has the dual benefit of providing carbon sequestration.
- Incorporating climate projections into planning for water use and availability. In addition to risks posed by increased flooding under future climate scenarios, there is an increased likelihood of local water stress and increased demand for water during summer months, which is typically the driest season. The Nature Conservancy and many other agencies in the Commonwealth have invested in scientific research to determine the habitat needs of fish and other aquatic species of concern. This information, coupled with improved predictions of how stream flows are likely to change under future climate scenarios, should be used in assessing ecological risks associated with water usage and for land development planning to minimize climate impacts.
- Including natural infrastructure as one of the options for reducing risk of flood damage. New York State's Local Flood Analysis addresses flood risk planning at the local level using a suite of options including natural infrastructure: http://catskillstreams.org/lfa/. (12)

Response: The Department appreciates the comment and will consider the role of nature based solutions in resilience and adaptation in the 2018 Climate Change Action Plan Update.

Greenhouse Gas Emissions Inventory

35. Comment: We are concerned that the greenhouse gas ("GHG") emissions data relied on in creating the Plan is from 2012. The total GHG emissions calculated for the "residential, commercial, industrial, transportation, electricity production, agriculture, waste management, forestry, and land use" sectors in the Plan were "primarily obtained from the U.S. Environmental Protection Agency (EPA) State Inventory Tool (SIT)." 2015 Draft Climate Change Action Plan ("Plan") at 19. The Plan explains, "2012 is the latest year with complete data available from the SIT." *Id.* Therefore, the Plan does not account for changes in GHG emissions over the last four years. In particular, we are concerned about the electricity production sector because this sector "has historically been the largest contributor of GHG emissions." Plan at 28. In Pennsylvania, coal, nuclear, and natural gas are the largest sources of electricity production. *Id.* The Plan states that in 2012, "coal produced over 79% of the GHG emissions while producing 39.0% of the electricity, natural gas produced 20.6% of the GHG emissions while producing 23.75% of the electricity, and nuclear fuel produced no GHG emissions while producing 33.65% of the electricity." Plan at 30. However, data from the U.S. Energy Information Administration demonstrates that 2014 and 2015 figures are different.[6] In 2014, Pennsylvania obtained 35.5% of its net electricity generation from nuclear power and 36.1% from coal.[7] As of December 2015, nuclear power generated 7,266 GWh net electricity, natural gas generated 5,016 GWh, and coal generated 3,689 GWh.[8] The Plan's reliance on data which is four years old and differs from the current energy mix calls into question the accuracy of projections made in this update and the efficacy of the Plan itself as it is based on outdated information. We believe the Plan should build on the data obtained from the EPA SIT and incorporate data from the Energy Information Administration and other sources to create a realistic and up-to-date account of GHG emissions and emission sources in the Commonwealth. (4)

Response: The Department appreciates the comment. As the inventory takes into account emissions from all sectors, the Department will continue to use the State Inventory Tool when compiling the inventory data. The Department agrees that the accuracy of the projections in some sectors may be impacted due to the age of the data and feel the level of confidence in the projections is accurately discussed in the Update.

36. Comment: The commenter supports the use of the US EPA State Inventory Tool (SIT) for the Climate Plan. The DEP already uses it to calculate the annual greenhouse gas (GHG) emissions inventory. The SIT is based upon sound science providing an objective analysis of statewide GHG emissions. According to US EPA, "The SIT and Projection Tool…is most appropriate for use by state agencies or other groups seeking to develop a State GHG inventory."[9] Using the SIT for the Climate Plan ensures that DEP's previous emission inventories are comparable to the Climate Plan results because the same methodology is used for both. (8)

Response: The Department appreciates the support of the commenter and agrees with the commenter in the appropriateness of using the State Inventory Tool in compiling the annual inventory for the Commonwealth.

37. Comment: We understand that other commenters have recommended other methodologies for emission inventory purposes, including life-cycle analysis-type analyses such as US EPA Waste Reduction Model (WARM). WARM is a powerful life-cycle based tool for determining the GHG benefits from various end-of-life waste scenarios. However, it is not an

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[6] U.S. EIA, *Pennsylvania Profile Overview*, http://www.eia.gov/state/?sid=PA#tabs-4 (last updated May 21, 2015).
[7] Id
[8] Id
[9] US EPA, *State Inventory and Projection Tool*, http://www3.epa.gov/statelocalclimate/resources/tool.html (accessed Feb. 23 2016).

appropriate model for calculating annual GHG emissions as stated by US EPA, "This [WARM] life-cycle approach is not appropriate for use in inventories because of the diffuse nature of the emissions and emission reductions within a single emission factor."[10] Use of life-cycle analyses is clearly not appropriate for annual emission inventory purposes because its fundamental basis—analyzing the emissions of an activity over its lifetime—is incompatible with the purpose of an annual emission inventory, which calculates the emissions that occur in a specific year. (8)

Response: The Department appreciates the comment and continues to evaluate ways to improve the inventory. The Department's main priority is to provide an accurate inventory that is consistent from year to year and for each of the sectors involved. The Department continues to feel that the State Inventory Tool provides the best pathway to meet these priorities.

38. Comment: In its inventory development process, the Department based its calculations on methane (CH4) having a global warming potential (GWP) of 25 times that of CO2. The 2007 Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC)[11] used a GWP of 25 for the 100 year time horizon and a GWP of 72 for the 20 year time horizon, but more current information is now available. The Department should consider updating the global warming potential estimate used in this analysis.

In 2015 the IPCC released its fifth assessment report (AR5). This report found that over a 20 year time horizon CH4 has a global warming potential of 86 times that of CO2 when you consider climate carbon feedbacks or 84 times CO2 without feedbacks. Over the longer 100 year time horizon CH4 has a potential of 34 times CO2 with feedbacks and 28 times CO2 without feedbacks.[12] In updating to the AR 5 estimates, the Department should consider including climate carbon feedbacks, which have recently been confirmed.[13] Addition of these feedbacks results in a 2% increase in GWP over for a 20 year time horizon. Over the 100 year time horizon the feedbacks have an even more significant impact raising the GWP of CH4 by over 20%. If the Department elects to continue reporting using the 100 year time horizon, inclusion of feedbacks is increasingly important. (10)

Response: The Department appreciates the comment. The GWP for each of the Greenhouse Gas used in the inventory is the default value provided in the State Inventory Tool by EPA.

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[10] US EPA, Subsection Note to *Waste Reduction Model, (WARM)*, https://www3.epa.gov/warm/index.html (last updated Feb. 23, 2016). It is our understanding that this model has been suggested for use to the DEP as it relates to emissions from the waste management industry.

[11] Forster, P. *et al. "Changes in Atmospheric Constituents and in Radiative Forcing" . I n: Climate Change 2007: The*Physical Science Basis. IPCC AR4, WG1, Chap. 2, pg. 212.

[12] Mygre, G. *et al. "Anthropogenic and Natural Radiative Forcing" In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* . pg 715.

[13] Egbert H. van Nes, Marten Scheffer, Victor Brovkin, Timothy M. Lenton, Hao Ye, Ethan Deyle, George Sugihara. " *Causal feedbacks in climate change* " Nature Climate Change, 2015; *available at;* http://www.nature.com/nclimate/journal/v5/n5/full/nclimate2568.html

Should EPA make any adjustments in the global warming potential in future editions of the State Inventory Tool, the Department will use those adjustments.

39. **Comment:** The Department should consider reporting using a 20 year time horizon. The Plan does not discuss the rationale for selecting a 100 year time horizon over a 20 year time horizon in its calculations, so we are unable to provide feedback on the decision making process. We recommend the Department include a justification to support the time horizon it selects.

    We note that the projections included in the action plan elements extend to 2030 (15 years). We agree that this is a reasonable target year because it aligns with the federal Clean Power Plan. We also recognize the difficulty to make accurate projections beyond such a time frame. We question however why the Department chose a global warming potential time horizon of 100 years when The 20 year horizon was available, aligned more closely with the time frame used in the Department's projections, and has a lower uncertainty range than the 100 year estimate[14]. (10)

    Response: The Department appreciates the comment and has made adjustments to the 2015 Climate Change Action Plan Update to address justification for the time frame and GWP used in the inventory. As stated in Chapter 3 of the 2015 Climate Change Action Plan Update, "In order to provide consistency with previous updates and other state inventories using the SIT, the default values were not changed in compiling the inventory".

40. **Comment:** We noted several issues with the inventory estimates that raise questions concerning the accuracy of the numbers reported. Recent research used satellite data and surface concentrations to suggest that "U.S. methane emissions have increased by more than 30% over the 2002–2014 period."[15] The inventory presented, on the other hand, shows an almost 12 percent decrease in CO2e over that period. While we understand Methane and CO2e are not directly comparable, a large increase in methane emissions should be noticeable in key sectors. (10)

    Response: The Department appreciates the comment. The Department acknowledges the commenters concerns for the accuracy of the numbers reported in the inventory. The Department intends to address the specific concerns of the commenter throughout this document. The Department consistently used numbers provided by the State Inventory Tool and feels confident in their accuracy. As stated in the 2015 Climate Change Action Plan Update, the inventory data is specific to Pennsylvania and is complete up through 2012. The Department feels it is unsound to use national data from 2012-2014 to question data provided in the State Inventory Tool.

[14] Joos, F., et al., *Carbon dioxide and climate impulse response functions for the computation of greenhouse gas metrics: a multimodel analysis* , Atmos. Chem. Phys. Discuss, (Mar. 8, 2013)
[15] Turner, A. J., D. J. Jacob, J. Benmergui, S. C. Wofsy, J. D. Maasakkers, A. Butz, O. Hasekamp, and S. C. Biraud (2016), A large increase in U.S. methane emissions over the past decade inferred from satellite data and surface observations, Geophys. Res. Lett., 43, 2218–2224, doi:10.1002/2016GL067987.

41. **Comment:** In the Plan, the Department used emission factors to estimate natural gas production emissions for the entire industry at 5.65 MMTCO2e for 2012.[16] The Department has published a separate 2012 emissions inventory based on self-reported data from just the unconventional natural gas operators which reported 6.76 MMTCO2e of emissions in 2012.[17] Both of these inventories appear to be basing their estimates on outdated emission factors rather than direct observation.

In the case of the later inventory, for example, the guidance document containing instructions on estimating fugitive emissions from natural gas production was released in November, 1995.[18] This estimation methodology predates the development of unconventional natural gas extraction, raising questions as to its accuracy. While this likely impacts the results, it is difficult to judge the magnitude of the problem as reporting companies are not asked details regarding the methodology they used. (10)

Response: The Department has edited the 2015 Climate Change Action Plan Update to explain the decision to use the State Inventory Tool data for the Natural Gas sector. As stated in section 3.4 of the 2015 Climate Change Action Plan Update, "In order to provide consistency from previous years, this inventory continues to use default SIT emission factors for Natural Gas Production for all years".

42. **Comment:** Despite projected increases in population[19], declining costs for natural gas from 11 its peak in 2006[20], and programs to subsidize natural gas development and use, the inventory data is showing a 17 percent decline in residential natural gas use from 1990 to 2012. This once again raises a question as to the accuracy of the inventory data. (10)

Response: Several factors contribute to the amount of GHG emissions for a given year for the residential sector. One of the most important factors is the weather experienced in the Commonwealth for the given year, especially during the Summer and Winter seasons. Improvements in building codes have also made residential structures more energy efficient since 1990. Combinations of these and other factors can account for the yearly variability in residential natural gas usage.

43. **Comment:** We recommend the department continue its efforts to develop accurate inventories, but where there are deficiencies, we suggest the department highlight those issues and clearly document the methodologies used. (10)

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[16] Plan at 27.
[17] *Available at* : http://www.dep.pa.gov/Business/Air/BAQ/BusinessTopics/Emission/Pages/MarcellusInventory.aspx
[18] US EPA, OAQPS, Protocol for Equipment Leak Emission Estimates, EPA436/R95017 (November, 1995).
[19] PA State Data Center Estimates. See: *https://pasdc.hbg.psu.edu/Default.aspx*
[20] U.S. Energy Information Administration, Pennsylvania Price of Natural Gas Delivered to Residential Customers. (Feb. 29, 2016) available at: https://www.eia.gov/dnav/ng/hist/n3010pa3a.htm.

Response: The Department is committed to developing the most accurate and consistent inventory possible. An effort has also been made to highlight issues regarding the source of data within the 2015 Climate Change Action Plan Update.

44. **Comment:** The subject of GHG emissions remains a rapidly evolving science. In fact, as of this writing, the IPCC has published a fifth draft report. The IPCC report[21], increased the GHG multiplier for methane from 25 (100 Year Atmospheric lifetime) and 72 (100 Year Atmospheric lifetime) times CO_2[22] to 28 and 84[23] respectively. This amounts to a 12% (100 year) and 17% (20 year) increase in GHG impact. (13)

    Response: The Department appreciates the comment. The GWP for each of the Greenhouse Gas used in the inventory is the default value provided in the State Inventory Tool by EPA. Should EPA make any adjustments in the global warming potential in future editions of the State Inventory Tool, the Department will use those adjustments.

45. **Comment:** A recent Harvard University study[24] concluded that regional methane emissions due to fossil fuel extraction and processing could be 4.9 ± 2.6 times larger than in EDGAR, the most comprehensive global methane inventory. These results cast doubt on the U.S. EPA's recent decision to downscale its estimate of national natural gas emissions by 25–30%. These two factors alone render the findings in this report conservative. The complete basis for the ULS HO and natural gas findings are found in Appendix C. (13)

    Response: The Department appreciates the information in the referenced study. Emission estimates related to fossil fuel extraction will continue to researched and improved in the near future. The work plan contained in the 2015 Climate Change Action Plan Update did not use ultra-low Sulfur in the analysis when determining the greenhouse gas reduction potential in switching from regular home heating oil to natural gas.

46. **Comment:** The United Nations Intergovernmental Panel on Climate Change (IPCC) developed the concept of global warming potential (GWP) as an index to help policymakers evaluate the impacts of greenhouse gases with different atmospheric lifetimes and infrared absorption properties, relative to the chosen baseline of carbon dioxide (CO_2). Scientific advancements have led to corrections in GWP values over the past decade, and it is imperative that our policy decisions reflect this new knowledge. In the mid-90s, policymakers for the Kyoto Protocol chose a 100-year time frame for comparing greenhouse gas impacts using GWPs. The choice of time horizon determines how policymakers weigh the short- and long-term costs and benefits of different strategies for tackling climate change.

[21] The final draft Report, dated 7 June 2013, of the Working Group I contribution to the IPCC 5th Assessment Report "Climate Change 2013: The Physical Science Basis" was accepted but not approved in detail by the 12th Sessin of Working Group I and the 36th Session of the IPCC on 26 September 2013 in Stockholm, Sweden.
[22] IPCC AR4
[23] IPCC AR5
[24] Anthropogenic emissions of methane in the United States, Scot M. Miller et al, Proceedings of the National Academy of Sciences, November 25, 2013

According to the IPCC, the decision to evaluate global warming impacts over a specific time frame is strictly a policy decision—it is not a matter of science:

> *"the selection of a time horizon of a radiative forcing index is largely a 'user' choice (i.e. a policy decision)" [and] "if the policy emphasis is to help guard against the possible occurrence of potentially abrupt, non-linear climate responses in the relatively near future, then a choice of a 20-year time horizon would yield an index that is relevant to making such decisions regarding appropriate greenhouse gas abatement strategies."*

Short-lived pollutants that scientists are targeting today which actually warm the atmosphere are methane and hydrofluorocarbons (HFCs) which are greenhouse gases like CO_2; trapping radiation after it is reflected from the ground. Black carbon and tropospheric ozone, an element of smog, are not greenhouse gases, but they warm the air by directly absorbing solar radiation. Black carbon remains in the atmosphere for only two weeks and methane for no more than 15 years.

Focusing on near term targets for GHG impacts is both an effective strategy and recommended policy as it can have a more dramatic effect in the short term than reductions in carbon dioxide, thus providing more time to develop appropriate carbon dioxide reduction strategies. This renewed focus on 20-year GHG targets stimulated a reassessment of the ICF life-cycle study using the AR4 20-year numbers for methane emissions in the production, transportation, delivery and combustion of heating oil, ultra-low sulfur diesel, bio-blends, natural gas and shale gas.

Fuel Cycle GHG Emissions – The fuel cycle GHG emissions comparison shows the amount of CO_2 equivalent emissions that is associated with delivering each MMBtu of the selected fuels to the burner-tip. These comparisons are presented for both 2006 and 2020. Changes in emissions intensity that occur over this time frame reflect changes in energy use and emissions for the various fuel cycle stages for each fuel, as well as changes in the supply base (e.g., changes to both domestic supply areas and LNG imports for natural gas) for each demand region. (13)

Response: The Department appreciates the comment and has made adjustments to the 2015 Climate Change Action Plan Update to address justification for the time frame and GWP used in the inventory. Should EPA make any adjustments in the global warming potential in future editions of the State Inventory Tool, the Department will use those adjustments. The analysis provided in this comment is not consistent with the analysis that was performed for each of the work plans contained in the 2015 Climate Change Action Plan Update.

47. **Comment: Error! Reference source not found.** shows the delivered burner-tip fuel-based CO_2e emissions based on the information available at the time the report data was compiled. This data suggests that in the year 2020 a 6.6% biodiesel blend with ULS would be equivalent to natural gas (CO_2, CH_4 and N_2O). However, there remains several important updates and analysis that dramatically change this and substantially change the conclusion.

Table 1 ICF Base Report - Fuel Cycle GHG Emissions Findings -100 Year View

	lb CO_{2e}/MMBtu
Natural Gas	156.11
ULS	192.16
B100	38.73
Blend	156.11

The ICF study utilized a National Renewable Energy Laboratory (NREL) study to develop the biodiesel fuel cycle energy and emissions data. Concurrently, the Biodiesel Board studied the issue and published updated findings shown in 2008.

Table 2 ICF Base Report with Updated Biodiesel Efficiencies and Emissions - Fuel Cycle GHG Emissions Findings

	lb CO_{2e}/MMBtu
Natural Gas	156.11
ULS	192.16
B100	28.27
Blend	156.11

The ICF study used the United Nations Intergovernmental Panel on Climate Change's Third Assessment Report (IPCC-TAR, 2001) on the effects of GHGs over a 100-year time horizon. This assessment weights the methane GHG impact at 23 times CO_2 over the 100-year timeframe.

Table 3 IPCC Third Assessment Report (2001) TAR

	20 year	**100 year**	**500 year**
Carbon dioxide	1	1	1
Methane	62	23	7
Nitrous oxide	275	296	156

The IPCC Working Group 1 presents GWP values based on the most up-to-date science, but does not recommend any rules on application of those values. Note that the latest science presented in the Fourth Assessment Report (AR5) released in 2007 rates the 100-year impact of methane at 28[25] times CO_2.

Table 4 IPCC Fifth Assessment Report (2013) AR5

	100 Year Time Horizon			*20 year Time Horizon vs AR4*	
	ICF Report	AR5	Correction	AR5	Correction
CO2	1	1	1	1	1
CH4	23	28	1.22	84	3.00
N2O	296	265	0.90	264	1.00

[25] The report also notes that the methane multiplier maybe as high as 38 times

Updating the ICF report data to the AR5 findings further reduces the biodiesel blend for equivalence with natural gas GHG emissions to 22.2% in 2020 (**Error! Reference source not found.**).

Table 5 ICF Base Report with Updated IPCC Findings from AR3 to AR5 100 Year Time Horizon

	lb CO_{2e}/MMBtu
NG LNG at Margin	157.32
ULS	192.71
B100	28.27
Blend	157.32

The 2009 ICF Base Report predated an understanding of the impact of Marcellus Shale gas on the region. A second report ICF International provided to the City of New York assessing shale gas forms the basis of this final delivered fuel GHG assessment based on the UN IPCC AR4 100-year time horizon.

Table 9 presents the natural gas mixture differences between the 2009 ICF report and the 2012 ICF report with respect to natural gas mixture GHG emissions characteristics as the industry moves from LNG to shale gas. Table 10 provides the 2020 delivered fuel bio/ULS mixture is 24.5%. This blend number will be examined further by assessing end use efficiency and then by examining atmospheric time horizons.

Table 6 Delivered Natural Gas Mixture (NYC) with Shale Gas at the Margin (100-year Time Horizon)

	2010	2020	Units
ICF NYC Report Mix with Shale Gas (P48)	72.00	70.80	kg CO_{2e} / MMBtu
ICF NYC Report Mix with Shale Gas (P48)	158.40	155.76	kg CO_{2e} / MMBtu
ICF Base Report NG Mix with LNG AR4 Adjust	152.96	156.41	kg CO_{2e} / MMBtu

Table 10 Updated IPCC AR4 100 Year Time Horizon Shale Gas at the Margin

	lb CO_{2e}/MMBtu
NG LNG at Margin	157.32
ULS	192.71
B100	28.27
Blend	157.32

Focusing on near term targets for GHG impacts is both an effective strategy and recommended policy as it can have a more dramatic effect in the short term than reductions in carbon dioxide, thus providing more time to develop appropriate carbon dioxide reduction strategies. This renewed focus on 20-year GHG targets stimulated a reassessment of the ICF life-cycle study using the AR4 20-year numbers for methane emissions in the production, transportation, delivery and combustion of heating oil, ultra-low sulfur diesel, bio-blends, natural gas and LNG. **Error! Reference source not found.** shows that, based on a 20-year atmospheric time horizon, both #2 oil and ULS emit less CO_2e emissions than the natural gas mixture modeled by ICF in the base study with LNG at the margin. As DEP goes through this study and works to increasing the development of greener energy resources, it must describe the time frame that such greener energy resources are evaluated over.

Table 7 AR4 20 Year Time Horizon Shale Gas at the Margin Including End-Use Efficiency

	Lb CO_{2e} / MMBtu	MMBtu/year	Biodiesel Blend Level
NG Shale Gas at Margin	179.76	20,169	
ULS	205.40	19,759	
B100	49.36	4,748	
Blend	179.76	19,759	0.0 %

Response: The Department appreciates these comments and has made appropriate adjustments to the 2015 Climate Change Action Plan Update to address justification for the time frame and GWP used in the inventory. The work plan contained in the 2015 Climate Change Action Plan Update did not consider ultra-low sulfur diesel or biodiesel in its analysis.

48. Comment: The draft 2015 Update includes the annual greenhouse gas ("GHG") emission inventory that the Department is required to prepare under Act 70 of 2008. The Department's use of the U.S. EPA State Inventory Tool ("SIT") is sound science and provides an objective analysis of statewide emissions. In fact, *according to U.S. EPA*, the SIT is the *best* method of calculating state-level emission estimates, "The SIT and Projection Tool calculate U.S. state-level estimates only, and is most appropriate [model] for use by state agencies or other groups seeking to develop a State GHG inventory."[26] [emphasis added]. Use of the SIT in the draft 2015 Update also ensures that previously prepared emission inventories by the Department can be compared to the latest inventory on an "apples-to-apples" basis because the same methodology, the SIT, has been used for each. (14)

Response: The Department appreciates the support of the commenter and agrees with the commenter on the consistent basis the use of the State Inventory Tool provides when comparing inventory trends over a particular timeline.

49. Comment: It is our understanding that in the past, at least one group suggested privately to the Department the use of various inappropriate methodologies for waste industry emission inventory purposes, including life-cycle analysis-type analyses and specific U.S. EPA models that U.S. EPA *explicitly states are not appropriate for emission inventory purposes*.[27] Use of

[26] U.S. EPA, *State Inventory and Projection Tool*, http://www.epa.gov/statelocalclimate/state-inventory-and-projection-tool (last updated Mar. 25, 2016).

[27] For example, U.S. EPA's Waste Reduction Model (WARM) is a powerful life-cycle based tool for determining the GHG benefits from various end-of-life waste scenarios. It is, however, not an appropriate model for calculating annual (or any other) type of emission inventory. U.S. EPA explicitly disclaims use of WARM for emission inventory purposes, "This [WARM] life-cycle approach is not appropriate for use in inventories because of the diffuse nature of the emissions and emission reductions within a single emission factor." U.S. EPA, Subsection Note to *Waste Reduction Model, (WARM)*, https://www3.epa.gov/warm/index.html (last updated Feb. 23, 2016). It is our understanding that this model has been suggested for use to the Department as it relates to emissions from the waste management industry.

life-cycle analysis is clearly not appropriate for annual emission inventory purposes because its fundamental basis—analyzing the emissions of an activity over its *lifetime*—is incompatible with the purpose of an *annual* emission inventory, which calculates the emissions that occur in a specific year. (14)

Response: The Department appreciates the comment and is committed to developing the most accurate and consistent inventory possible. The Department feels the State Inventory Tool provides the most consistent method for determining emission estimates in all sectors.

Energy – Electricity Generation and Transmission

50. Comment: This is a step in the right direction, but just a small one. Where is the discussion on green energy? Where is the discussion of pricing carbon? You have ducked the hardest questions. Pennsylvania needs an honest, all-inclusive climate discussion. (1)

Response: DEP intends for the Climate Change Action Plan to be an all-inclusive and cohesive outline of cost-effective strategies for reducing or offsetting Pennsylvania's GHG emissions. Chapter 4.A "Electricity Generation and Transmission" includes several suggestions for increasing "green" (renewable) energy production in PA. Included in this discussion are increasing the AEPS (Alternative Energy Portfolio Standard), reinvesting in the "PA Sunshine" solar deployment program, and investing in wind and solar storage. While a separate plan for carbon pricing was not included, there is a discussion of that concept in the Carbon Capture and Sequestration and Carbon as a Commodity in Chapter 11. Additionally, the "Create a Feed-in Tariff for Carbon-free Renewables" work plan allows for the inclusion of a cost of carbon in setting generation rates. Early in the development of the first CCAP, a carbon tax plan was considered, but not deemed practical or economically viable as a state policy. At that time, it was determined that carbon taxation would need to be implemented at a national level in order to not financially disadvantage individual states adopting such policies. A further examination of this policy will be suggested.

51. Comment: I did not see any discussion of a revenue-neutral carbon tax in the draft climate change action plan update, but I think as a policy tool it merits some consideration. It would involve a reduction in personal income and corporate taxes funded by imposing a tax on fossil fuel usage. The approach has already enjoyed considerable success in British Columbia, for example. (https://en.wikipedia.org/wiki/British_Columbia_carbon_tax) (2)

Response: A carbon tax work plan was considered in the first CCAP, but not deemed practical or economically viable as a state policy. As Pennsylvania is a net exporter of electricity and energy, it was believed that the economic impacts of carbon taxation would disproportionately and adversely impact PA residents and companies. It was determined that carbon taxation would need to be implemented at a national level in order to not financially disadvantage individual states adopting such policies. A further examination of this policy will be suggested.

52. Comment: I am disappointed by the lack of an organized plan for solar and wind power. This needs to be a big part of the CPP and yet here the discussion is very limited. Why hasn't the council called for testimony from climate scientists in the state? We have some of the top climate scientists in the world right here in Pennsylvania, why aren't you asking for their testimony? And finally, where is the discussion about a price on carbon? There are many ways to do this, but they are all missing from your report. (3)

Response: Increasing the AEPS (Alternative Energy Portfolio Standard), reinvesting in the "PA Sunshine" solar deployment program, and investing in wind and solar storage are all part of the Electricity Generation and Transmission discussion in Chapter 4.A. While there are many common threads and objectives, this document and the work of the PA Climate Change Advisory Committee (CCAC) is not part of the federal Clean Power Plan (40 CFR Part 60, October, 2015), which came out seven years after the creation of Pennsylvania's CCAC (PA Act 70 of 2008). As the DEP is the responsible state entity for both the CCAP and the CPP, there should be many opportunities for continuity and collaboration as both are further developed. The Commonwealth is still in the early stages of developing its final clean power implementation plan so it is not a component of the Climate Action Plan. However, many of the carbon strategies for electricity within this document should ultimately support the development of the state's Clean Power Plan. All members of the public are permitted and encouraged to provide testimony. A further examination of carbon pricing and policies will be suggested.

53. Comment: We agree that "there are immense opportunities for renewable energy in Pennsylvania, such as wind and solar power," and Pennsylvania should take full advantage of these opportunities. Plan at 38. Accordingly, we support increasing AEPS Tier 1 and Solar requirements, reinvesting in the PA Sunshine Program, creating a feed-in tariff for carbon-free renewables and Re-light PA. We further believe that it is imperative for Pennsylvania to invest in wind and solar storage technologies. Pennsylvania must increase the amount of energy supplied by renewables because the continued use of fossil fuels, such as coal and natural gas, is not sustainable long term and contributes significantly to climate change. Converting to renewable resources for our energy needs will both strengthen energy security and improve human and environmental health. As demand for power from wind and solar energy increases, storage technology feasibility and capacity are critical in order to provide consistent energy from renewable sources. Plan at 44. Additionally, Pennsylvania should provide funding for demonstration and deployment projects in order to more widely deploy energy storage. *Id.* (4)

Response: Thank you for your comments and support of the CCAP. We agree that increased development of renewables and storage strategies are important for PA. If additional funding sources could be secured, the commonwealth has other mechanisms in place, such as the Pennsylvania Energy Development Authority (PEDA). The PEDA grant program could offer funding for advanced energy projects, and for businesses interested in locating or expanding their alternative energy manufacturing or production operations in the Commonwealth. In addition, DEP is currently pursuing a collaborative grant with the DOE to address solar development regulation and ratemaking; business models; and operations and systems integration.

54. **Comment:** We support the recommendation to increase the generation of renewable energy in the state, including increasing the Alternative Energy Portfolio Standard (AEPS) targets. Any re- visitation of AEPS should ensure that only non-emitting or carbon-neutral sources are included in Tier I or II. (5)

    Response: While the AEPS does not mandate exactly which resources must be utilized and in what quantities, certain minimum thresholds must be met for the use of Tier I, Tier II, and solar photovoltaic resources.

    Tier I resources include solar thermal, wind, low-impact hydropower, geothermal energy, biologically derived methane gas, fuel cells, biomass and coal mine methane. Tier II resources include by-products of pulping, wood manufacturing, waste coal, distributed generation systems, demand side management, large-scale hydropower, municipal solid waste, and integrated combined coal gasification technology.

55. **Comment:** However, it is important to understand that because of the intermittency of renewable sources like solar and wind, increases in renewable sources do not always result in GHG reductions. To guarantee carbon reductions, we must ensure that the base load power during times renewables are not available is as clean as possible. It is important that clean energy incentives are structured to achieve the best possible overall fuel mix, and do not have the unintended impact of disadvantaging existing zero- and low-emitting sources, including nuclear. (5)

    Response: Leveling base load supply generation is one of the intended outcomes of adopting a Feed-In Tariff and Investing in Wind and Solar Storage Technologies which can help reduce the intermittency of those renewable energy source technologies. Both are discussed in Chapter 4. Optimal fuel mix and economic viability are indeed critical to effective comprehensive planning. Integral Fast Reactor and Nuclear Fusion are among the numerous Potential Future Technologies discussed in Chapter 11.

56. **Comment:** Obviously there are co-benefits to Pennsylvanians of increased renewable energy opportunities, such as clean job creation, air quality improvements, and cost-savings. However, the purpose of this plan is to prevent further climate change, and as such, the recommendations contained herein should prioritize reductions in GHG emissions. (5)

    Response: Thank you for your comments. All plans were evaluated on both their potential GHG reductions and economic impacts.

57. **Comment:** To the extent that programs and incentives are offered to encourage solar photovoltaics, it is our understanding that the availability of low-interest, long-term financing may be more effective in increasing adoption of solar technology than a limited time rebate program such as PA Sunshine. We urge the DEP to consider whether a more cost-effective program might be developed to attract private capital. One example could include state support in the form of a loan loss reserve fund for independent lenders, such as credit unions and community banks, to create financing options specifically for solar. (5)

Response: The Property Assessed Clean Energy (PACE) work plan includes a capitalization and payment mechanism to finance energy efficiency, renewable energy, and water conservation upgrades to buildings. The DEP and the CCAC will continue to investigate and evaluate other programs, such as the Keystone HELP (Home Energy Loan Program), which uses a loan loss reserve fund, and GELF (Green Energy Loan Fund) as potential strategies within the CCAP.

58. Comment: Feed-in-tariffs (FIT) could also be an effective mechanism for attracting private capital for distributed renewable energy. However, they must be carefully structured to ensure costs stay under control, and that rates are reviewed and adjusted on a regular basis in line with any rise or fall of both grid electricity rates and solar equipment costs – not only to limit costs to ratepayers, but also to continue to drive innovation in the industry. We strongly encourage the state to seek expert advice on whether a FIT is the most cost-effective mechanism for achieving GHG reductions, which is the intent of this plan. (5)

Response: Thank you for your comments and support of the CCAP. Additional advice and expert testimony is encouraged and welcome.

59. Comment: There is data demonstrating that it is unnecessary for us to continue to rely on fossil fuels for our energy needs. A study conducted by Stanford University determined that by 2030 New York State could produce the energy it needs from solar, wind, and water power to meet its power demand for all sectors.[28] The study found that although converting to these sources for energy may increase energy costs at first, the elimination of fuel costs would make up for the initial rise in costs and more.[29] Similarly, another study concluded that by 2030 "carbon dioxide emissions from the US electricity sector can be reduced by up to 80% relative to 1990 levels, without an increase in the levelized cost of electricity. The reductions are possible with current technologies and without electrical storage."[30] Additionally, researchers at the University of Delaware and Delaware Technical College found that "[r]enewable energy could fully power a large electric grid 99.9 percent of the time at costs comparable to today's electricity expenses."[31] In 2014, renewable sources only "accounted for 4% of Pennsylvania's net electricity generation"[32] and only "about 10% of total U.S. energy consumption and 13% of electricity generation."[33] We have already contributed far more than our proportionate share of GHG emissions to the world's

[28] Rob Jordan, *Stanford researcher maps out an alternative energy future for New York* (March 12,2013), http://news.stanford.edu/news/2013/march/new-york-energy-031213.html.
[29] Id
[30] MacDonald ET AL., *Future cost-competitive electricity systems and their impact on US CO2 emissions*(2016), http://www.nature.com/nclimate/journal/vaop/ncurrent/pdf/nclimate2921.pdf.
[31] Teresa Messmore, *Wind, solar power paired with storage could be cost-effective way to power grid*, University of Delaware (Dec. 10, 2012, 8:51 AM),
http://www.udel.edu/udaily/2013/dec/renewable-energy-121012.html
[32] U.S. EIA, *Pennsylvania Profile Overview*, http://www.eia.gov/state/?sid=PA#tabs-4 (last updated May 21, 2015).
[33] U.S. EIA, *How much U.S. energy consumption and electricity generation comes from renewable sources?* (last updated March 31, 2015), http://www.eia.gov/tools/faqs/faq.cfm?id=92&t=4.

atmosphere. Now we need to stop hiding behind claims that it is too difficult to switch over to renewables or that other countries may still be using fossil fuels into the future and instead take the initiative to switch over from fossil fuels as expeditiously as possible. (4)

Response: The Department agrees with the importance of renewables and are pursuing programs and policies to incentivize and encourage their use as an important component of PA's generation mix. Reducing GHGs and our impact on the environment is a critical necessity for our commonwealth. One of the key components in moving towards a carbon-free or carbon-neutral economy is finding the source funding and financing required to implement suggested strategies. In addition, one must have the political will and fortitude to follow through with measures. Unfortunately, the CCAC has neither the funds nor the authority to force action. The strategies proposed in the CCAP require the support of the general public, the private sector, entrepreneurs, business, industry, and their representatives.

60. Comment: We support suggestions in the Plan to expand clean renewable generation. While we are supportive of reinvesting in the PA Sunshine program, we note that solar installation companies favor self-sustaining programs over short-term grant programs. While both can be effective at increasing the number of clean energy systems that are installed, we believe longer term programs are more effective at developing local clean energy business and expanding jobs in this area. (10)

Response: Thank you for your support. Both the Feed-in Tariff and PACE work plans provide additional, long term, self-sustaining options for increasing the installed number of clean energy systems.

61. Comment: We also note that on February 11, 2016 the PA Public Utility Commission (PUC), by a 3-2 vote, approved changes to the net metering provisions within the PUC regulations. These provisions echo many of the restrictions on net metering being promoted nationwide by groups opposing expansion of clean renewable energy. These will not only create direct limits on the size of renewable energy systems that may be installed, but they will also create a chilling effect on new installations. In general, we oppose any changes to the rule that are contrary to the statutory goals of expanding the deployment of renewable energy within Pennsylvania. We are particularly concerned with those provisions that negatively impact small business and residential customers. Key provisions we oppose include the following:

- Adding additional caps on the size of net metered systems.
- Opening the door for new fees to be charged to customer-generators denying them the full retail value of the power they generate.
- Adding restriction impacting virtual net metering and community solar.

Should these changes survive the regulatory review process and go into effect, we ask the Department consider recommending legislative changes that would ensure Pennsylvania regains its position as an attractive location to site clean renewable energy. (10)

Response: NOTE: Comment is directed toward PUC actions, not the CCAP.
Thank you for your comments. We concur that opportunities for the implementation of clean renewable energy systems need to be expanded rather than limited. The DEP continues to

work with the PUC and other state agencies, developing collaborative partnerships to advance the goals of the CCAP. On May 19th, the Independent Regulatory Review Commission (IRRC) held a public meeting to hear, among other items, PUC's new regulations related to implementation of the Alternative Energy Portfolio Standards Act of 2004. The arguments focused mostly on the limit of 200% of annual electric consumption that the PUC set on the size of the generator to qualify for net metering. The Commissioners unanimously rejected the new regulations, primarily on the basis that the PUC did not convince them that they had the authority to set limits that were not set forth in the statute.

62. Comment: We are encouraged by the inclusion of recommendations associated with deployment of solar and other distributed energy resources. The commenter is particularly interested in opportunities to accelerate use of distributed renewable energy systems as a carbon reduction strategy. An emphasis on distributed sources delivers multiple benefits to Pennsylvania's ratepayers and has the potential to direct more energy-related construction and production to already developed locations (*e.g.*, rooftops and parking lots). Benefits to ratepayers include the reduction of overall line losses and reduced congestion. Distributed generation has the potential to provide additional value by adding capacity during periods of peak demand, a phenomena known as peak shaving, which also drives down energy costs. In some cases, distributed renewable deployment, coupled with targeted energy efficiency, may also forestall the need for new transmission and distribution infrastructure, further reducing costs to ratepayers while increasing reliability. (12)

Response: Thank you for your support and comments. Microgrids and distributed generation could be incorporated into both the Feed-in Tariff and PACE work plans.

Energy – Natural Gas Production, Transmission, and Distribution

63. Comment: We support reducing methane emissions from natural gas infrastructure. Accordingly, we agree with strengthening DEP's "comprehensive methane emissions reduction program for the oil and gas industry, regulating air contaminants including VOCs and methane emissions from sources located at well pad and mid-stream operations." Plan at 48. (4)

Response: The Department appreciates the comment and the support of the commenter in reducing methane emissions in the natural gas sector.

64. Comment: The Plan acknowledges that "[l]eaks from natural gas infrastructure are a major source of methane emitted into the atmosphere." Plan at 47. We are concerned that "Pennsylvania does not currently" require "methane monitoring, leak detection, or measures to control or prevent fugitive emissions from gathering, transmission or distribution pipelines." *Id.* However, the task of establishing "best practices for methane monitoring, leak detection and repair aimed at controlling or preventing fugitive emissions from gathering, transmission, or distribution pipelines" was given to the Pennsylvania Pipeline Infrastructure

Task Force ("PITF"), a taskforce that is dominated by the oil and natural gas industries.[34] The Public Accountability Initiative ("PAI") conducted a study of PITF in which it found that 23 out of 25, or 92%, of non-government representatives on PITF have ties to the oil and natural gas industries.[35] "Additionally, several government representatives on [PITF], including two aides to Gov[ernor] Wolf, have strong revolving door ties to the industry."[36] This dominance of industry on the taskforce raises serious questions about its ability to objectively set the best practices for environmental protection. Rather, it is far more likely that the taskforce's primary concern is saving the oil and gas industry money and will therefore choose the cheapest practices with minimal enforceability. (4)

Response: Pennsylvania DEP regulates new sources of emissions of CH4 from oil and gas extraction activities under the Air Pollution Control Act and regulations adopted under the act; its Air Quality Permitting Program; and by implementation of federal regulations codified at 40 CFR Part 60, Subpart OOOO (relating to Standards of Performance for Crude Oil and Natural Gas Production, Transmission and Distribution). These regulations are adopted and incorporated by reference in their entirety at 25 *Pa. Code*, Chapter 122.

In addition to implementing and enforcing stringent laws and regulations, the air quality permitting program is one of DEP's key tools in preventing and reducing air pollution. Since February 2013, Pennsylvania's regulation of CH4 emissions from compressor stations has been achieved through the revised GP-5. This general permit for non-major sources establishes BAT requirements for reducing emissions including CH4 and VOC emissions from new sources, and contains terms and conditions requiring periodic inspection, a Leak Detection and Repair (LDAR) program, performance testing, and recordkeeping and reporting obligations for affected owners and operators.

GP-5 was the first general permit in the nation to require LDAR programs for mid-stream gathering and compression facilities. Pennsylvania's current LDAR program requires operators to conduct LDAR inspections monthly using audible, visual, and odor detection methods. Based on the re-evaluation of GP-5, including BAT requirements for new sources, the general permit requirements will be strengthened by DEP, as appropriate and necessary.

The Department also requires comprehensive LDAR requirements for sources at natural gas transmission stations that is determined on a case-by-case basis.

Since August 10, 2013, Pennsylvania has regulated CH4 emissions from unconventional natural gas wells through the implementation of conditional permit exemption criteria (Category No. 38) set forth in DEP's "Air Quality Permit Exemptions" technical guidance (Document No. 275-2101-003). These permit exemption criteria were issued by DEP for

[34] Public Accountability Initiative, *Pennsylvania's Pipeline Infrastructure Task Force is dominated by the oil and gas industry*, http://public-accountability.org/2015/10/pennsylvanias-pipelineinfrastructure-task-force-is-dominated-by-the-oil-and-gas-industry (last visited March 20, 2016).
[35] Id.
[36] Id.

conventional wells, unconventional wells, wellheads and all other associated equipment including engines, storage vessels/tanks, flaring activities, and equipment leaks. Sources at these natural gas well sites are currently exempt from permitting requirements if the owner or operator meets all applicable requirements established in the Category No. 38 exemption criteria including LDAR inspection requirements for well pads. The owner or operator must also comply with all applicable federal and state requirements. On August 10, 2013, the DEP also issued conditional permit exemption criteria (Category No. 33) for Compressed Natural Gas Dispensing Facilities, including LDAR inspection requirements, similar to the Category No. 38 conditional permit exemption criteria.

Pennsylvania does not generally require CH4 monitoring, leak detection, or measures to control or prevent fugitive emissions from transmission or distribution pipelines. Working through the Pennsylvania Pipeline Infrastructure Task Force (PITF), DEP intends to establish best practices for CH4 monitoring and LDAR aimed at controlling or preventing fugitive emissions from transmission or distribution pipelines.

65. Comment: The "best practices" for curbing methane emissions established by PITF must be enforceable in order to ensure that measures will be taken to prevent methane leakage from natural gas infrastructure. It is not clear whether these best practices would be enforceable or merely voluntary. Furthermore, it seems uncertain whether the DEP would have the funding necessary to enforce these best practices. The Secretary of DEP John Quigley recently admitted to the Senate Appropriations Committee that the DEP "does not have enough staff to meet the needs of any of its programs because of persistent and continuous budget cuts over the last decade."[37] (4)

Response: Some of the best practices found in the PITF Final Report are already required by law or regulation. Others are being considered for inclusion in regulations and permits now under development. While staffing at DEP is less than optimal in many programs we believe we have sufficient resources to properly oversee the oil and gas industry.

66. Comment: We are also concerned about the enforceability of the timelines for repairing well pad leaks.[38] The Plan states, "[o]n well pads, leak detection and repair must be conducted within 60 days after a well is put into production, and annually thereafter, and include the entire well pad, not just the natural gas liquids tanks and piping as required by the EPA for the oil and gas sector. Any detected leaks on well pads in Pennsylvania are currently required to be repaired within 15 days." Plan at 49. However, it is uncertain whether DEP has enough

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[37] David E. Hess, *DEP Budget Hearing: DEP Does Not Have Enough Staff To Meet Needs In Any Of Its Programs*, PA Environment Digest (Feb. 26, 2016, 1:35 PM), http://paenvironmentdaily.blogspot.com/2016/02/dep-budget-hearing-dep-does-not-have.html .

[38] Dep't of Evtl. Protection, *Whitepaper on Methane* (2016), http://files.dep.state.pa.us/Air/AirQuality/AQPortalFiles/Methane/DEP%20Methane%20Strategy%201-19-2016%20PDF.pdf; *See also*, David E. Hess, *Gov. Wolf Announces New Methane Regulations On Oil & Gas Industry*, PA Environment Digest (Jan. 19, 2016, 3:43 PM), http://paenvironmentdaily.blogspot.com/2016/01/gov-wolf-announces-new-methane.html (describing Governor Wolf's new methane regulations for the oil and gas industry).

staff to implement these ambitious timelines considering that DEP is currently having problems "perform[ing] basic functions like evaluating permit applications in a timely fashion."[39] We are also concerned about the lack of funding for plugging abandoned wells because these wells could be "a significant source of continuing methane emissions." Plan at 50. However, "there is limited funding available to plug the[se] [abandoned] wells." (4)

Response: The category No. 38 of conditional exemption criteria requires the owner or operator to perform Leak Detection and Repair (LDAR) for all sources on the well pad within 60 days after a well is put into production, and annually thereafter. The owner or operator must demonstrate compliance with the Category No. 38 exemption criteria within 180 calendar days after the "well completion" as defined in 40 CFR Part 60, Subpart OOOO or installation of a source. The Department has been receiving Compliance Demonstration Reports (CRDs) from owner or operators and the DEP staffs have been reviewing these CDRs as they are received.

The Department has recently started a study of abandoned wells, both plugged and unplugged within the Commonwealth. It is the goal of the Department that at the end of this study, adequate funding can be obtained to address the greenhouse gas emissions associated with abandoned wells.

67. Comment: In order to ensure that methane and other emissions are properly controlled beyond the well site, natural gas compressor stations that predate August 2013 must be brought into compliance with the best available technology for emissions control ("BACT"). "[N]atural gas compressor stations that predate August 2013 were permitted under a general permit that included best available technology at the time of permitting. Those compressor stations do not employ what is considered to be best available technology for emissions control today." Plan at 48. Currently, in Greene and Washington counties there are approximately 75-79 active compressor stations.[40] Almost half (34) of these compressor stations predate August 2013 and therefore do not employ the current BACT. The commenter is very concerned about the effects these compressor stations have on the health of people in our community. One example of negative health effects due to a compressor station is Brigich Compressor Station, which has been operating in Washington County since 2010. Over the years of its operation, residents near Brigich Compressor Station have repeatedly and consistently complained to the Agency for Toxic Substances and Disease Registry ("ATSDR") about a variety of health effects including "nausea, headache, lethargy, burning and irritation of upper respiratory tract, nose bleeds, stinging eyes, and metallic tastes on the tongue."[41] In 2012, ATSDR investigated and analyzed air samples to determine the amount of exposure to various air pollutants that residents living near this compressor station were experiencing. ATSDR concluded that while "exposure to the detected levels of chemicals in

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[39] Hess, *supra* note 13.

[40] Frack Tracker Alliance, http://www.fractracker.org/; *See also* Clean Air Council, Gas Infrastructure Map of Pennsylvania, http://wikimapping.net/wikimap/gas.html .

[41] U.S. Dep't of Health & Human Services, *Exposure Investigation* 2 (Jan. 29, 2016), www.atsdr.cdc.gov/HAC/pha/Brigich_Compressor_Station/Brigich_Compressor_Station_EI_HC_01-29-2016_508.pdf.

the ambient air from residences surrounding Brigich compressor is not expected to harm the health of the general population...some sensitive subpopulations (e.g., asthmatics, elderly) may experience harmful effects from exposures to hydrogen sulfide and PM2.5. Some individuals may also be sensitive to aldehyde exposures, including glutaraldehyde."[42] One of ATSDR's recommendations included "reducing exposures to PM2.5, carbonyls, and hydrogen sulfide in ambient air by taking steps to control releases from the emission sources of these chemicals to protect the health of sensitive populations living near the site."[43] In order to protect public health, all compressor stations must employ the current BACT. We should not be grandfathering in facilities that are only a few years old. It not unreasonable to require compliance with the best available technology for emissions control, especially when the health of sensitive populations is at risk. (4).

Response: On August 18, 2015, the EPA released Draft Control Techniques Guidelines (CTG) for the Oil and Natural Gas Industry and a model rule to reduce VOC and CH4 emissions from certain existing oil and natural gas industry emission sources in ozone nonattainment areas classified as "Moderate" or higher and the Ozone Transport Region. Notice of the "Release of Draft Control Techniques Guidelines for the Oil and Natural Gas Industry" was published in the *Federal Register* on September 18, 2015 (80 FR 56577). The proposed CTG recommendations apply to existing VOC emission sources (including pneumatic controllers, pneumatic pumps, compressors, storage vessels, equipment leaks and fugitive emissions) in the onshore production and processing segments of the oil and natural gas industry. The final CTG, expected in the summer of 2016, will establish Reasonably Available Control Technology (RACT) recommendations for existing VOC sources located in ozone nonattainment areas and the Ozone Transport Region, which include the entire Commonwealth.

DEP intends to expeditiously pursue the adoption of a regulation for existing sources that will enhance EPA's final RACT recommendations for each VOC emission source category or process in the oil and natural gas sector that will be covered by EPA's final guidelines. Pennsylvania's final-form regulation will be due to EPA as a State Implementation Plan (SIP) revision within two years after EPA's issuance of the final CTG.

68. Comment: The commenter is also concerned about the extensions of periods of temporary operation for compressor stations. During temporary operation, the emissions of new or modified compressor stations are tested. Applicable regulations and current DEP practice appear to allow for multiple six-month extensions of periods of temporary operation before the operating permit is issued.[44] It further seems that there is no limit to the number of times these temporary operation periods can be extended, thereby allowing GHG and other emissions from compressor stations to go unchecked for years. (4)

[42] Id. At 33.
[43] Id. At 34.
[44] 25 Pa. Code § 127.12b(d).

Response: Generally, sources at natural gas compression or processing facilities are authorized to operate under General Permit (GP-5). GP-5 is served as a Plan Approval as well as Operating Permit. The owners or operators of sources authorized to operate under GP-5 must comply with all applicable requirements. The owners or operators of these sources are required to test the sources within 180 days after initial start-up of the source and are not granted an extension for six-month extension as implied by the comment.

The owners or operators of sources at natural gas compression or processing facilities that are authorized to construct and operate through Plan Approval and subsequently Operating permit may request an extension to accommodate testing during temporary operation or shake-down period. The DEP evaluates such request on a case-by-case basis.

69. **Comment:** Given Pennsylvania's extraordinary natural gas footprint, it is imperative that the state undertake a comprehensive approach to reducing methane emissions from active and abandoned wells. Pennsylvania is currently the second largest producer of natural gas in the country, and our landscape is littered with an untold number of orphaned and abandoned wells from more than a century of unregulated development. (5)

    Response: The Department has recently started a study of orphaned and abandoned wells, both plugged and unplugged, within eight counties of the Commonwealth. It is the goal of the Department that at the end of this study, adequate funding can be obtained to address the greenhouse gas emissions and other environmental concerns associated with abandoned wells.

70. **Comment:** The commenter supports the Methane Reduction Strategy announced by Governor Wolf on January 19, 2016. This Strategy will bring the Commonwealth in line with other leading states like Colorado for unconventional sources of emissions. However, Pennsylvania must pursue a similar strategy with conventional oil and gas operations. Timing is critical for this effort, as methane's most damaging contributions to climate change occur within the first twenty years. (5)

    Response: The Department appreciates the comment and the concern for the emissions from conventional oil and gas operations. Conventional oil and gas operations are currently regulated by implementation of federal regulations codified at 40 CFR Part 60, Subpart OOOO (relating to Standards of Performance for Crude Oil and Natural Gas Production, Transmission and Distribution). These regulations are adopted and incorporated by reference in their entirety at 25 *Pa. Code*, Chapter 122.

71. **Comment:** The Commonwealth should also pursue renewed funding for identifying and plugging abandoned and orphaned wells. There are efforts in other producing states, like Oklahoma, where operators have a vested role in well identification and plugging. Pennsylvania should consider incentives to active operators to help locate and address abandoned wells. (5)

    Response: The Department is currently in the process of trying to determine the magnitude of funding that will be necessary for addressing the orphaned and abandoned wells within the

Commonwealth and exploring various funding options that may be available in the near future. Since 1989, the Commonwealth has spent nearly $31 million dollars in plugging thousands of orphaned and abandoned wells.

72. **Comment:** In December 2011, Pennsylvania became one of the first states in the nation to require unconventional natural gas producers to submit data on emissions such as carbon monoxide, sulfur dioxide, volatile organic compounds, particulate matter and others. The Pennsylvania General Assembly codified this annual reporting requirement as part of Act 13 of 2012, which is the Commonwealth's comprehensive environmental protection law related to oil and gas development.0

    For calendar year 2012, the Pennsylvania Department of Environmental Protection (DEP) expanded reporting requirements to include methane, as well as additional sources such as compressor stations serving conventionalnatural gas and coal-bed methane production. With respect to methane, the 2013 emissions inventory data,which was released by DEP in April 2015, showed a 13% decrease in total cumulative methane emissions fromthe natural gas industry in Pennsylvania. This decrease is significant, particularly given the fact that the numberof well sites reporting data for 2013 increased by over 18%, while the number of midstream facilities reportingdata increased by over 8% and natural gas production itself increased in 2013 by nearly 52% over the prior year. This phenomenon of decreased methane emissions in spite of increased activity can be seen across the nation. This is a testament to voluntary efforts and new and innovative technologies and operational practices thatindustry has implemented over the past several years. (7)

    Response: The Department acknowledges the comment and agrees with requiring unconventional natural gas producers to submit emission data and the statistics provided concerning the number of reporting sites and Natural gas production within the Commonwealth. The data provided compares 2012 and 2013 values and will continue to be monitored and evaluated by the Department going forward.

73. **Comment:** It is important to underscore as well that as we collect and analyze emissions data from a growing array of sources within the oil and natural gas industries in Pennsylvania, overall ambient air quality in the Commonwealth is substantially improving. This is due, in large part, to the significant increase in the use of natural gas for electric generation in Pennsylvania. For reference, in 2000 Pennsylvania generated approximately 1% of its electricity from natural gas. This figure rose to 15% by 2010, and is expected to exceed 25% next year.

    This dramatic increase in electric generation from natural gas has substantially offset emissions from the power generation sector since 2008, when natural gas production from the Marcellus Shale formation began to ramp up. For example, since 2008 sulfur dioxide emissions are down nearly 75%; nitrogen oxide emissions are down nearly 25% and particulate matter emissions are down over 45%. This increased use of natural gas and the corresponding reduction of key emissions within the power generation sector translates to an approximate $14 billion to $37 billion annual public health benefit just from sulfur dioxide reductions alone, based on U.S. EPA methodologies. (7)

Response: The Department acknowledges the comment and the information provided on the amount of electricity produced by extracted gas in Pennsylvania since 2000 and the associated public health impacts. A significant amount of ambient air quality monitoring takes place throughout the Commonwealth and a general decrease in various criteria pollutants over time has been documented. The cause of the improved ambient air quality can be attributed to several factors.

74. Comment: In addition to comprehensive data inventories, Pennsylvania has adopted aggressive permitting standards for natural gas-fired engines and equipment at midstream compressor stations, as well as new criteria for unconventional well owners and operators. A key component of Pennsylvania's requirements is a robust Leak Detection and Repair program (LDAR) to identify, document and fix fugitive sources of methane and VOC emissions. This initiative, included as part of Pennsylvania's 2013 revisions to its air quality permit Exemption 38 criteria and its General Permit 5 (GP5) for Natural Gas Compression and/or Processing Facilities, requires all unconventional natural gas operators to implement an LDAR program. Leaks must be repaired within 15 days of detection, in accordance with the relevant DEP requirements. Additionally, this same program includes requirements which are more stringent than the proposed federal rules for other sources, such as engines and tanks.

Emission data in the draft CCAP and published by DEP for Pennsylvania demonstrates that the existing programs, along with industry advancements in technology and operating practices for natural gas production and gathering, are achieving highly significant emissions reductions of methane, VOC and C02e. The majority of these reductions have been fostered by industry or through cooperation with industry and regulatory agencies. Strong examples of this cooperation are EPA's Gas Star program and the LDAR requirements in the GP5 and Exemption 38. (7)

Response: The Department appreciates the comment and agrees with the commenter on the description of the permitting standards in the Natural Gas industry.

75. Comment: At the same time DEP is proposing additional LDAR requirements and other regulatory requirements on natural gas operations, EPA has expended a great deal of time and effort proposing similar regulations on an accelerated basis. The commenter is concerned that this may result in a duplication of effort and believes the best path forward is for DEP to take advantage of EPA's efforts. Specifically, the commenter cautions DEP against proposing any additional changes in advance of the upcoming federal rules for new, modified and existing sources. As always, the natural gas industry is committed to working with its state regulators to develop reasonable and beneficial requirements for the Oil & Gas industry, but we see no benefit in rushing into something that is already being done at the federal level. (7)

Response: The DEP intends to finalize the air permitting requirements for sources for natural gas well sites and revision to the BAT requirements for sources at natural gas compression and processing facilities after EPA will finalize its requirements for Oil & Gas industry.

76. Comment: As an additional means of reducing methane emissions, the commenter does believe that abandoned wells requiring plugging and capping should be investigated and a method for their closure determined. Such a process should involve discussion with industry and other stakeholders as to the most effective and efficient means of doing so. The commenter also observes that significant new funds through the Pennsylvania Impact Fee paid by natural gas producers have been generated to help plug historic abandoned and orphan wells. (7)

Response: The Department has recently launched a study of orphaned and abandoned wells, both plugged and unplugged within the Commonwealth. It is the goal of the Department that at the end of this study, adequate funding can be obtained to address the greenhouse gas emissions associated with abandoned wells. Surcharges have been added to all new well permits to enhance plugging efforts in the future.

77. Comment: The shale gas being developed now here in Pennsylvania emits methane, a GHG that is 100 times greater in absorbing heat than carbon dioxide and 86 times greater when averaged over a 20 year time frame. Globally, meeting the COP 21 Paris goal to limit warming to below 2degree C requires zero GHG emissions from power generation after 2017. Here in Pennsylvania, the Commonwealth must not attempt to incentivize natural gas (or any fossil fuel) development by the exemption of new plants from its Draft Clean Power Plan that is currently under development. Coal, oil, and natural gas all need to be left in the ground. (9)

Response: The Department feels there are a number of ways to meet the COP 21 Paris goal and that it is not necessary to have zero GHG emissions from the power generation sector after 2017.

78. Comment: A report prepared for Sen. Edward J. Markey and issued August 1, 2013 titled "Natural Gas Pipeline Leaks Cost Consumers Billions[45]" highlighted the fact that "Federal and state regulators explained in interviews for this report that there isn't a consistent methodology for calculating lost and unaccounted for gas, and data quality problems are common." This may clearly lead to inaccurate leakage reporting to EPA.

The issue of natural gas extraction and processing emissions remains a hot topic. Balancing the latest reports, one can only conclude the University of Texas (UT) narrow focused study was not helpful and the Harvard study continues to question methane emission levels form processing and production.

UT and the Environmental Defense Fund study[46] released September 16, 2013 that directly measured methane emissions at 190 onshore natural gas production sites throughout the United States, including 27 wells being prepared for continuous production and 489 wells

[45] http://www.markey.senate.gov/documents/markey_lost_gas_report.pdf
[46] Proceeding of the National Academy of Sciences of the United States of America (PNAS) http://www.pnas.org/content/110/44/17768

that underwent hydraulic fracturing. The authors found that the emissions measured at wells during completion varied over a large range but were, on average; nearly 50 times lower than previously estimated by the Environmental Protection Agency (EPA). By contrast, measurements of methane emissions from equipment on wells in routine production were comparable to or higher than EPA estimates. The authors used the measurements of methane emissions to estimate that the nation's total annual methane emissions from well completions, pneumatic devices, chemical pumps, and equipment leaks are between 757 and 1,157 Gg, comparable to the EPA estimate of approximately 1,200 Gg. (13)

Response: The Department acknowledges that natural gas extraction and processing emissions will continue to be the focus of a significant amount of research.

Energy – Consumption Reduction

79. Comment: Pennsylvania must reduce its dependence on fossil fuels in order to become "a leader at combating the causes of climate change." Plan at 143. The Plan states that "[e]ven when it is assumed that current policy and government commitments around the globe to tackle climate change are all implemented, it is expected that fossil fuels will still account for 75 percent of the world's energy demand by 2035." Plan at 137. Assuming that expectation turns out to be true, it does not provide a convincing justification to continue to depend heavily on fossil fuels. An insistence upon continuing down the same path of reliance on fossil fuels with the same inertia that has exacerbated climate change reveals a persistent, willful ignorance of our role in global climate change. The United States, and Pennsylvania specifically, have historically been major producers of GHG emissions. Pennsylvania alone is responsible for 1% of the emissions of greenhouse gases *worldwide*. [47] That number does not include methane emissions from natural gas drilling, processing, and transportation activities. As a state that has contributed so significantly to global climate degradation, we should reduce our GHG emissions into the future and lead the way in reducing contributions to climate change. (4)

Response: DEP concurs that reducing our GHG emissions and being a leader in climate mitigation strategies are in the Commonwealth's best interests. According to the latest report from the Energy Information Administration[48], between 2000 and 2013, PA reduced energy-related carbon dioxide emissions by 12.1% and continues to develop programs, plans and policies to achieve even greater reductions.

80. Comment: Energy efficiency represents the cleanest, cheapest, and fastest method of emissions reduction. The cheapest kilowatt is the one that is not used. The benefits of demand-side energy efficiency include reduced energy costs for consumers, reduced demand

[47] Dep't of Envtl. Protection, *2009 Pennsylvania Climate Change Action Plan* (2009), www.elibrary.dep.state.pa.us/dsweb/Get/Document-75375/7000-BK-DEP4252.pdf.

[48] U.S. Energy Information Administration, Energy-Related Carbon Dioxide Emissions at the State Level, 2000-2013 www.eia.gov/environment/emissions/state/analysis/pdf/table1.pdf, October 26, 2015

on the grid, job creation, workforce development, and improved health of our citizens and our environment. We applaud the DEP for including recommended actions related to energy efficiency in this plan. (6)

Response: The Department recognizes that Energy Efficiency and Energy Conservation are essential components of any plan to reduce emissions and our impact on the environment.

81. **Comment:** Buildings in the United States account for 39% of total energy consumption and 38% of total carbon dioxide emissions. The older building stock of Pennsylvania's buildings, with many built prior to the implementation of building codes in the mid-1970s, further exacerbates the environmental impact of buildings. Increasing energy efficiency in Pennsylvania's buildings is a win-win for the state. Not only do energy savings reduce greenhouse gas emissions, but also have the opportunity to grow the economy. A 2014 KEEA study shows that the Commonwealth is home to over 4,200 clean energy businesses, many of which are small, local businesses that combined employ a total of over 57,000 workers. Pennsylvania is already home to more than a dozen manufacturers of energy efficient products, solar PV modules, wind turbines, and solar thermal collectors. (6)

    Response: Thank you for your support and comments. DEP recognizes that PA's building stock is the 2nd oldest in the nation and we agree that this presents us with a great opportunity to significantly reduce our buildings' energy consumption. Several of our workplans (#3: Adopt Current Building Energy Codes, #5: Heating Oil Conservation, # 7: High-Performance Buildings, 8: Re-Light Pennsylvania) address improving the performance of our new and existing building stock. In addition, the DEP sponsors programs specifically targeted toward improving the performance of existing buildings such as our BOC (Building Operator Certification) and BRT (Building Retuning Training) programs. We are also striving to increase our production and adoption of renewables through programs like PEDA (Pennsylvania Energy Development Authority) and GELF (Green Energy Loan Fund) whenever funding is available. The improvement of building performance and the increased production and adoption of renewable energy sources represent great economic and environmental opportunities for Pennsylvania.

82. **Comment:** The National Efficiency Screening Project (NESP) is a group of organizations and individuals that are working together to improve the way that electricity and natural gas energy efficiency resources are screened for cost-effectiveness. The purpose of this initiative is to improve efficiency screening practices throughout the United States, and to help inform decision-makers regarding which efficiency resources are in the public interest and what level of investment is appropriate. NESP has prepared an initial framework called the Resource Value Framework (RVF) and is in the process of designing a new Standard Practice Manual to assist states in improving their efficiency screening. (6)

    Response: Thank you for your support, suggestions and comments. We look forward to consulting with these resources as they develop.

83. **Comment:** Finally, up-to-date codes spur innovation and investment in the manufacturing sector. Pennsylvania is home to building sector manufacturing companies like Eaton, Tyco

and Lutron, contributing jobs for Pennsylvania residents and tax dollars to the municipalities in which they are located. In fact, Pennsylvania manufacturer members of the National Electrical Manufacturers Association alone represent over 14,000 jobs. We should be doing all we can to encourage this sector, rather than deferring to investment in other states that are embracing safer, greener building practices. (6)

Response: The Department agrees that Pennsylvania businesses would benefit from adopting the most up-to-date building codes as well as the energy savings that could be achieved with up-to-date building codes.

84. Comment: Finally, an additional recommendation not included in the plan that should be considered is increasing access to utility consumption data, and interval meter data, where available. Access to real-time data allows new devices to interpret smart meter data to identify the energy used in the home at specific times, with some devices disaggregating the data to give more granular detail about each energy-using device in the home. This plethora of energy data can in some cases provide direct recommendations to consumers, such as adjusting the thermostat to save money or upgrading appliances to ENERGY STAR. In addition, it will be a crucial component of utilizing time-of-use pricing for electricity in the future. (6, 10)

Response: The Department appreciates the comment and will take the concept of increase in access to utility consumption data into consideration when developing the 2018 Climate Change Action Plan Update.

85. Comment: In addition, we encourage the sharing of data with efficiency programs and providers, to gauge the effectiveness of various features and programming. While we respect the sensitive nature of an individual account holder's data, we urge the state's utilities to find an acceptable means of sharing data, such as aggregated totals, to allow efficiency providers to better communicate energy reduction and impact to stakeholders. (6)

Response: The Department appreciates the comment and will consider expanding efficiency program data sharing when developing the 2018 Climate Change Action Plan Update.

86. Comment: The commenter is a member of the Pennsylvania Energy Code Collaborative and our current focus is increasing compliance with the 2009 codes. Current numbers suggest that Pennsylvania could see about $1.2 million in savings in the first year alone if we achieve greater compliance with the existing energy codes. More efficient buildings also reduce the need for more generation from power plants which in turn reduces CO_2 and other pollutant emissions. (10)

Response: Thank you for your support and comments. We agree that improving compliance (as well as implementing higher performance building energy codes, see workplan #3: Adopt Current Building Energy Codes) can lead to great economic and energy savings as well as significant environmental benefits. The DEP continues to support and encourage the work of the PA Energy Codes Collaborative and to sponsor codes training throughout the commonwealth.

87. Comment: The DEP also mentions the Tenant Star program in its recommendations. While we support this recommendation and believe that the program has potential, it has not been put into practice. (10)

Response: The Department agrees with the comment and feels the Tenant Star program's history has been accurately described in the Update.

88. Comment: This 2015 draft update report states that it *"…aims to replace or upgrade inefficient equipment that utilize fuel oil with more energy-efficient natural gas models, thereby decreasing energy consumption and reducing emissions… By encouraging … fuel switching to natural gas where available, additional greenhouse gas reductions can be achieved. The PA PUC's Fuel Switching Workgroup recommendations include the allowance of Electric Distribution Companies to consider fuel switching for their low income customers…Thus, a huge opportunity exists for greenhouse gas reductions through fuel switching from heating oil to natural gas."*[49]

The above public policy conclusion assumes the following:

- #2 heating oil is the only residential liquid fuel being supplied in Pennsylvania. This is not a correct conclusion. In fact, many residential customers use a 5% biodiesel/#2 oil blend and some are receiving 20% and higher blends.
- Heating oil boilers and furnaces are always less efficient than natural gas boilers and furnaces. This is not a correct conclusion. Both energy sources can use condensing and non-condensing appliances of similar efficiency.
- Simple combustion of fuels[50] is sufficient to underpin climate change public policy.[51] This is not a correct conclusion. Ignoring the lifecycle emissions of all energy streams can misdirect policymakers. This is particularly true when methane emissions are involved with respect to their potent Green House Gas impact.
- A huge opportunity exists for greenhouse gas reductions through fuel switching from heating oil to natural gas.

This is not a correct conclusion. Using combustion only generated CO_2 emissions ignores, among other important factors, the impact of fugitive methane emissions in the refining process for oil and in the production and transportation process for natural gas. Equally important, only comparing GHG emission from #2 heating oil and natural gas, and not

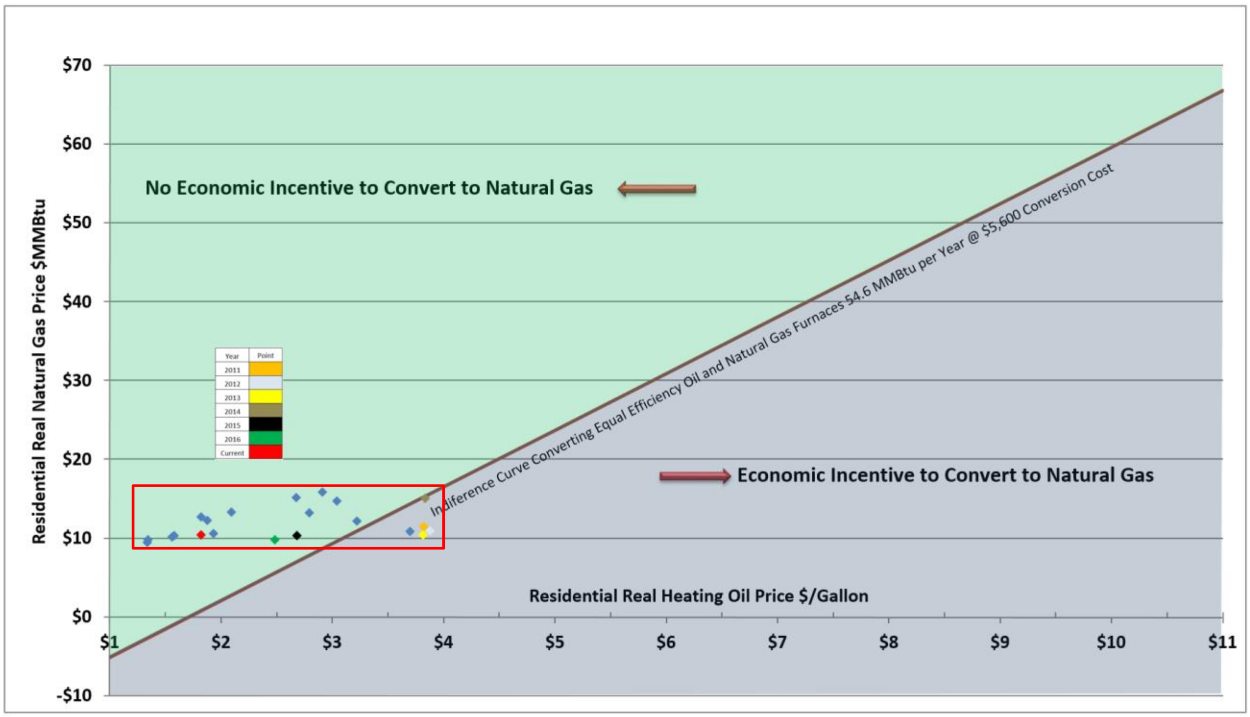
[49] Excerpted from pages 67 and 68 of the Pennsylvania Climate Change Act (ACT 70 OF 2008 OR ACT) 2015 Draft Update Report emphasis added.

[50] The draft report states: "[T]his initiative recognizes the potential for additional greenhouse gas (GHG) reductions through fuel switching from heating oil to natural gas. Please note that the work plan is a simple analysis of combustion and does not include an analysis of methane leakage. This analysis only evaluated residential sector greenhouse gas savings." rom page 182 of the Pennsylvania Climate Change Act (ACT 70 OF 2008 OR ACT) Draft 2015 Update Report,

[51] The amount of CO_2 produced when a fuel is burned is a function of the carbon content of the fuel. The heat content, or the amount of energy produced when a fuel is burned, is mainly determined by the carbon (C) and hydrogen (H) content of the fuel. Heat is produced when C and H combine with oxygen (O) during combustion. Natural gas is primarily methane (CH_4), which has a higher energy content relative to other fuels, and thus, it has a relatively lower CO_2-to-energy content. Water and various elements, such as sulfur and non-combustible elements in some fuels reduce their heating values and increase their CO_2-to-heat contents.

evaluating biodiesel blends with heating oil misses an important segment of Pennsylvania homeowners.

The economic indifference curve (**Error! Reference source not found.**) is the red line and reflects an oil/biodiesel to natural gas conversion cost of $5,600[52], which was assumed in the 2015 DEP report update, plotted against the price of the two fuels, assuming equivalent efficiencies. Points above the line indicate that there is no economic incentive to convert to natural gas, and in fact no action is appropriate. Points below the line indicate there is an economic incentive to convert to natural gas. The red box contains the price for natural gas and heating oil for the last two decades. Of particular reference are the brown, yellow, grey, and orange points that represent recent years. These points would favor a conversion, however, that pricing must last the ten years of the amortization of the conversion cost. However, the red, green and black diamonds are the most current pricing, and they indicate not converting is the appropriate economic choice.



ES Figure 1 Economic Indifference Curve for Conversion from Heating Oil to Natural Gas

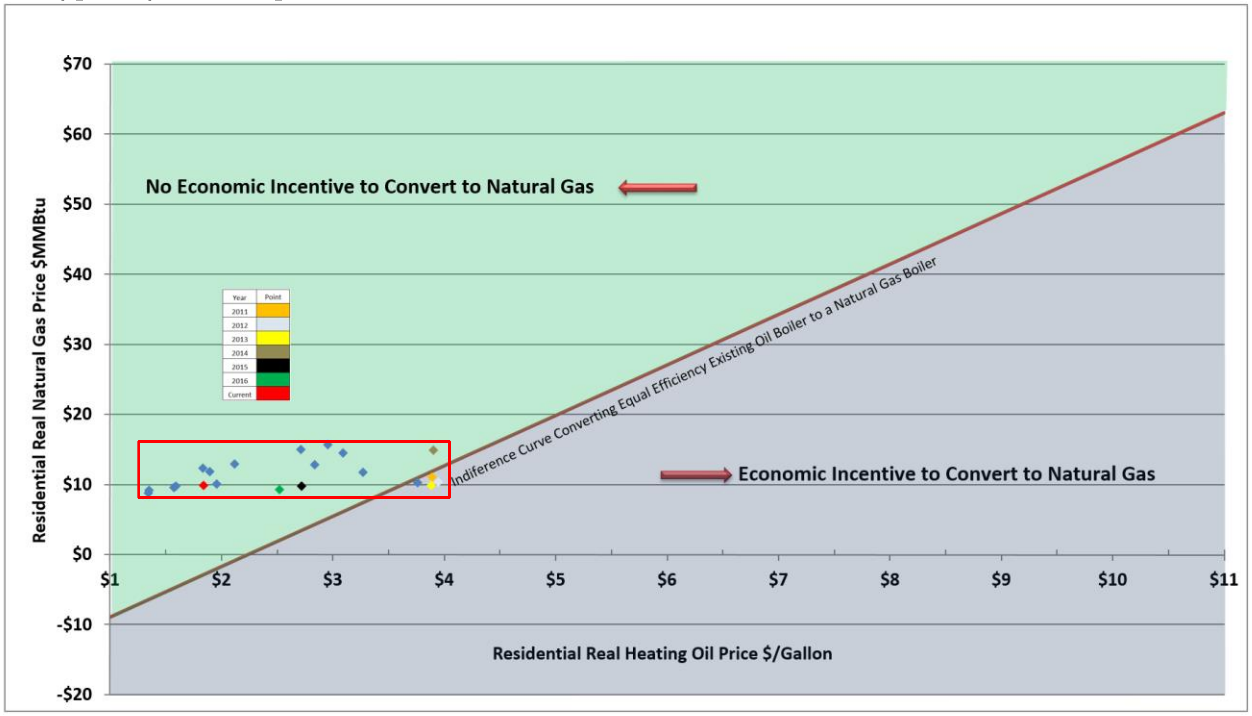
Local Pennsylvania HVAC contractors[53] provided oil/biodiesel to natural gas boiler conversion estimate of $12,670 based on their experience for a baseline sized system on a comparable basis. The economic indifference curve for this conversion (ES Figure 2) is the red line. Points above the line indicate that there is no economic incentive to convert to

[52] Page 183 of the Pennsylvania Climate Change Act (ACT 70 OF 2008 OR ACT) 2015 Draft Update Report "The cost of conversion is assumed to be $5,600- the estimated cost of a furnace conversion and a gas connection to a home."

[53] See Appendix A: Cost of Conversion Estimate for details

natural gas, and in fact no action is appropriate. Points below the line indicate there is an economic incentive to convert to natural gas. The red box contains the price for natural gas and heating oil for the last two decades. Of particular reference are the brown, yellow, grey, and orange points that represent recent years. These points would favor a conversion, however, that pricing must last the ten years of the amortization of the conversion cost. However, the red, green and black diamonds are the most current pricing, and they indicate not converting is the appropriate economic choice. (13)

Response: Thank you for your comments. The DEP model used a residential furnace conversion, not a boiler, as a basis of comparison. We concur that boiler systems are typically more expensive, but were not used as the basis for evaluation.



ES Figure 2 Consumer Economic Indifference Curve High Estimated Conversion Cost (Non-condensing boilers)

89. Comment: The report states: *"[a]ccording to the U.S. Energy Information Administration (EIA), the average Pennsylvania home fueled by heating oil uses approximately 516 gallons per year, whereas the average home fueled by natural gas uses approximately 53,000 cubic feet per year."* This is based on statistical averages and does not take into account age of the home, age of the equipment, number of people in the home or lifestyle, etc. This is not a good characteristic on which to build public policy. Especially when practitioners know that heating oil and natural gas technologies can be designed to have the same combustion and hot water/air delivery efficiency. See Tables ES 1 and ES 2 below.

The mid-Atlantic region EIA data for 2015 predicts that the average delivered cost of natural gas to the residential sector was $11.55 per MMBtu. The average price of heating oil in the mid-Atlantic region for the same time period was $25.10 per MMBtu.[54]

The current EIA (February 2016) price for Pennsylvania residential heating oil is $1.80/gallon. This calculates to $12.90/MMBtu =

$$\frac{\$1.80 \ x \ 1{,}000{,}000 \ Btu/MMBtu}{139{,}500 \ Btu/gal}$$

The current EIA (November 2015) price for Pennsylvania residential natural gas is $10.56/1,000 cu ft. of MMBtu.

Calculating the potential annual savings from the original report data yields an annual energy savings of about $1,177.

Table ES1 Draft Report Energy Economics

	Gallons	Price/Gal	Btu/gal	MMBtu	$/MMBtu	Cost
#2 Oil	516	$3.50	139,500	72.0	$25.10	$1,807
	cu ft	Price/cu ft	Btu /cu ft	MMBtu	$/MMBtu	Cost
Natural Gas	53,000	10.56	1,030	54.6	$11.55	$631
						$1,177

Correcting the technology performance data for an equal system efficiency comparison and updating the energy prices yields a very different conclusion with an annual energy savings of only $144.

Table ES 2 Corrected Energy Economics
(Equal Technology Efficiency and Updated Energy Costs

	Gallons	Price/Gal	Btu/gal	MMBtu	$/MMBtu	Cost
#2 Oil	391	$1.80	139,500	54.6	$12.90	$705
	cu ft	Price/cu ft	Btu /cu ft	MMBtu	$/MMBtu	Cost
Natural Gas	53,000	10.56	1,030	54.6	$10.25	$560
						$145

Given the corrected and updated economics of fuel switching there is limited energy savings dollars available to the consumer by factor greater than 10 less than presented in the report. (13)

Response: Thank you for your comments. The fuel cost estimates used in the CCAP evaluations were based upon the best available data at the time of the evaluation.

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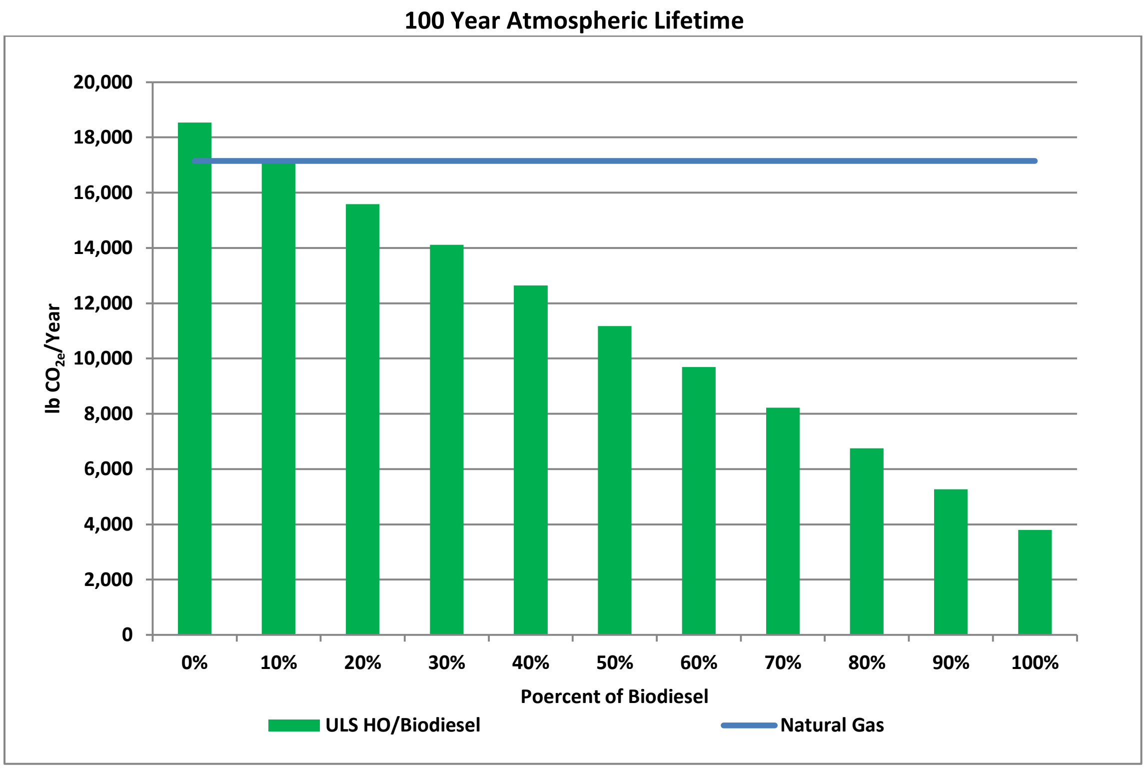
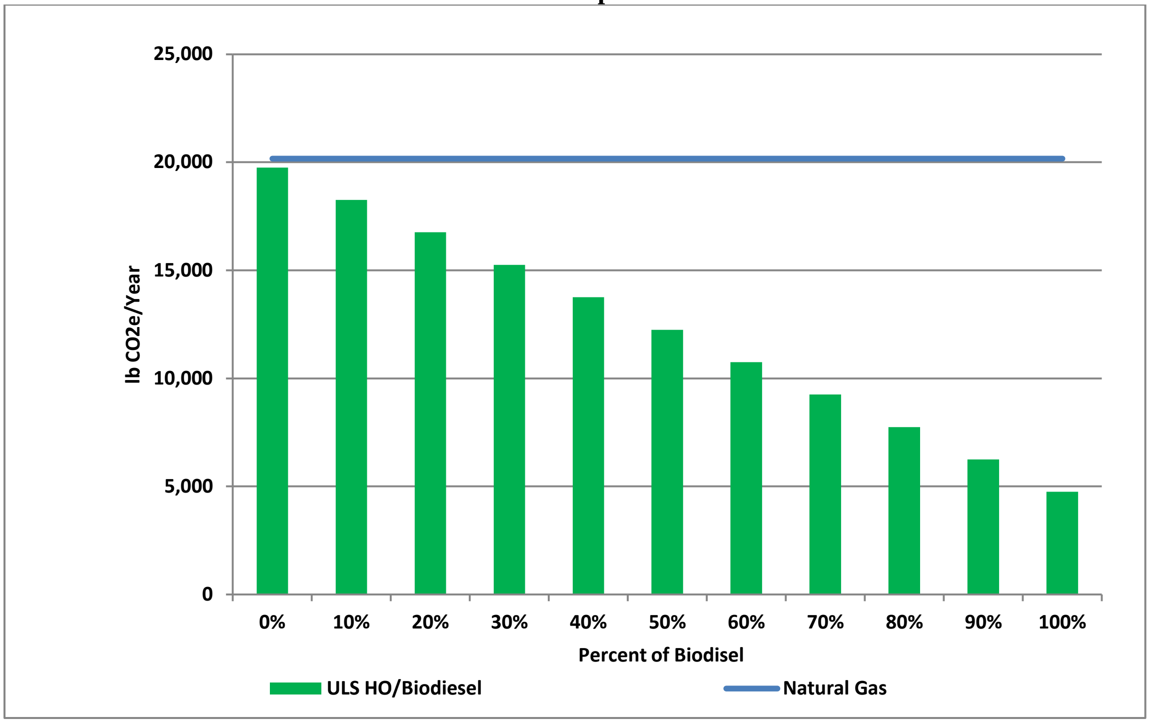
[54] Excerpted from page 178 of the Pennsylvania Climate Change Act (ACT 70 OF 2008 OR ACT) 2015 Draft Update Report

90. Comment: Error! Reference source not found. shows that a biodiesel blend less than 20% is equivalent to natural gas with respect to CO_2e[55] emissions even accounting for the impact of indirect land use according the latest EPA data from RFS2. Short-lived pollutants that scientists are targeting today which actually warm the atmosphere are methane and hydrofluorocarbons (HFCs) which are greenhouse gases like CO_2, trapping radiation after it is reflected from the ground. Black carbon and tropospheric ozone, an element of smog, are not greenhouse gases, but they warm the air by directly absorbing solar radiation. Black carbon remains in the atmosphere for only two weeks and methane for no more than 15 years. Focusing on near term targets for GHG impacts is both an effective strategy and recommended policy, as it can have a more dramatic effect in the short term than reductions in carbon dioxide, thus providing more time to develop appropriate carbon dioxide reduction strategies. Using the IPCC Fifth Technical Report's 20-year atmospheric lifetime assessment, ES Figure 2 shows that a #2 oil actually lower than natural gas with respect to CO_{2e} emissions, irrespective of the impact of indirect land use. Given the biodiesel GHG reduction promise of Ultra Low Sulfur Heating Oil (ULS HO) blended with biodiesel, there is no Climate Change policy reason for fuel switching from oil to natural gas.

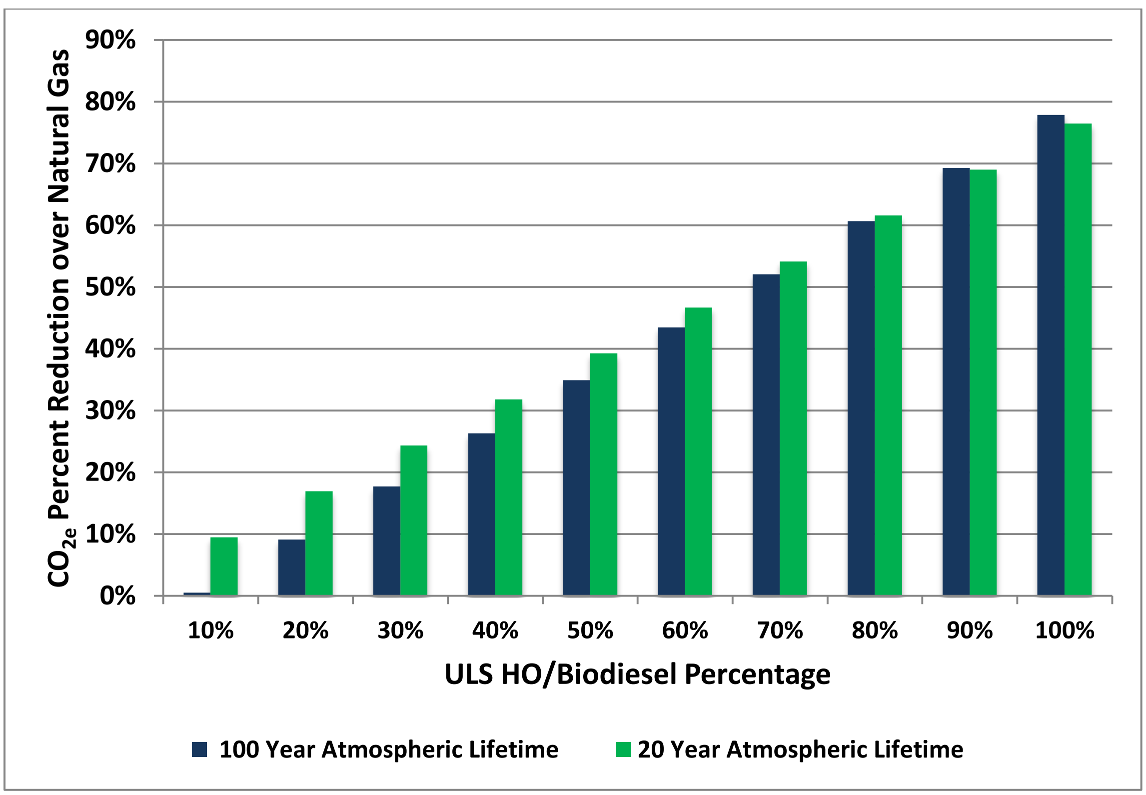


[55] Carbon dioxide equivalency is a quantity that describes, for a given mixture and amount of greenhouse gas, the amount of CO_2 that would have the same global warming potential (GWP), when measured over a specified timescale (e.g. 20 or 100 years). Carbon dioxide equivalency thus reflects the time-integrated radiative forcing of a quantity of emissions or rate of greenhouse gas emission—a flow into the atmosphere—rather than the instantaneous value of the radiative forcing of the stock (concentration) of greenhouse gases in the atmosphere described by CO_{2e}

91. 20 Year Atmospheric Lifetime



92. ES Figure 3 Biodiesel GHG Emissions by Blend Percent versus Natural Gas



ES Figure 4 ULS HO/Biodiesel CO_{2e} Reduction versus Natural Gas – 100 and 20 Year Atmospheric Lifetimes

Error! Reference source not found. shows that, as technology advances, biodiesel CO_{2e} reduction can far exceed conventional natural gas and shale gas.

Given that biodiesel matches and can easily be lower than natural gas GHG emissions, there is no climate change reason for fuel switching from oil to natural gas. (13)

Response: Thank you for your comments. The combined work plan (CCAC Workplan 5: Heating Oil Conservation and Fuel Switching) included both conservation measures (such as air-sealing and insulation) as well as fuel switching. Conservation efforts (over 96%), rather than fuel switching (less than 4%) constitute the majority of the GHG emissions reductions.

93. **Comment:** It is important to note the potential economic development implications of fuel switching from oil and biodiesels to natural gas. The residential and commercial heating oil and biodiesel industry is an important and vital component of the Pennsylvania economy and the energy mix statewide. According to the National Oilheat Research Alliance (NORA), there are 722 retail heating oil businesses in Pennsylvania. These companies employ employing about 4,700 people with a payroll approaching $178,000000 annually and provide energy services to approximately 950,000 households and thousands of commercial operations that use heating oil, diesel fuel and bio-blended distillate for space heating, manufacturing and power generation. A state sponsored fuel switching would eliminate many of these jobs which would not be replaced in kind.

Incentivizing fuel switching from oil to natural gas does not appear to be consumer friendly, economical, or environmentally cleaner and will clearly erode the business strength of over 700 retail operations, and eliminate many of the more than 4,700 jobs in the state's oilheating/bioheating industry. There appears to be no good public policy reason (consumer economics, future energy price, GHG emissions or criteria pollutant emissions) for the Commonwealth of Pennsylvania to promote fuel switching from heating oil to natural gas.

However, public policies that encourage upgrading older, inefficient oil-fired and natural gas boilers and furnaces, as well as encouraging the use of ULS HO and biodiesels will save energy, reduce cost, reduce pollution and increase jobs.

It is well known that energy efficiency improvements are most effective public policy measures. Demonstrable progress has been made in oil heated homes in Pennsylvania in this regard. According to a 2011 report commissioned by NORA, "Since the establishment of the National Oilheat Research Alliance in 2000, the organization's programmatic efforts in research, training and education, have contributed to substantial savings for consumers over the past decade." Because of these efforts, the oil heating industry in Pennsylvania and in 22 other states has improved residential oil heat efficiency by 30% or 120 gallons per home. Based on the U.S. average heating oil price in 2016 winter season, the volume reduction over this period has reduced oil-heat consumer's energy costs by about $299 per household.

For example, the cost of converting to natural a gas boiler requires at a minimum:

- replacement of the boiler or furnace
- chimney replacement or relining

- gas main
- service line extension and meter set
- gas water heater
- removal and disposal of the existing fuel storage tank

Error! Reference source not found. presents one oil/biodiesel to natural gas conversion estimate based on discussion with local Pennsylvania HVAC contractors[56]. Each element estimate is equally valid as there are many variables when factoring the economics for fuel switching from oil/biodiesels to natural gas.

Table 8 Oil to Natural Gas Conversion Cost Estimates

	Cost Estimates
Boiler	$5,980
Tank Removal	$660
Chimney liner	$1,500
In house piping	$642
Indirect	$2,260
Gas line & meter set	$1,933
Sub-total	$11,945
Add ins	$725
Total	$12,670

The total conversion costs in **Error! Reference source not found.** are amortized over a ten-year timeframe at 3% simple annual interest into annual conversion capital payments. Natural gas and oil boilers were modeled by Brookhaven National Laboratory (BNL) (see paragraph below) providing annual fuel consumption data that is easily converted to annual fuel costs. The annual natural gas fuel cost plus an annual conversion cost payment is compared to the annual oil/biodiesel fuel cost to develop and economic indifference curve.

BNL developed an accurate method to determine system efficiency for integrated heating and domestic hot water residential systems[57, 58]. The BNL model is more accurate in predicting actual building heating and DHW performance than the commonly used AFUE methodology. Three boiler configurations were examined: an average efficiency boiler (based on sales), a high efficiency boiler and a condensing boiler. The comparison was performed on a 2,500 ft^2 ranch home with a basement and typical "code" construction. **Error! Reference source not found.** and **Error! Reference source not found.** provide the total annual resource energy requirements to provide heating and hot water services to the modeled 2,500 square foot house (including energy use along the fuel cycle and end use equipment efficiency) for 2006 and 2020 respectively. Total energy requirements to provide the annual heating and hot water services is higher for natural gas for both the average, high efficiency non-condensing boilers

56 See Appendix A: Cost of Conversion Estimate for details

57 Performance of Integrated Hydronic Systems, Project Report, May 1, 2007, Thomas A. Butcher, Brookhaven National Laboratory.

58 AFUE leads to low estimates of the energy savings potential of modern, integrated systems, particularly where advanced controls are used.

because oil and biofuel blends less hydrogen content[59]. Furthermore, non-condensing boilers are a more likely replacement than condensing boilers largely because existing residential hydronic loops were designed based on high return water temperatures which do not allow for condensing during most operating conditions.

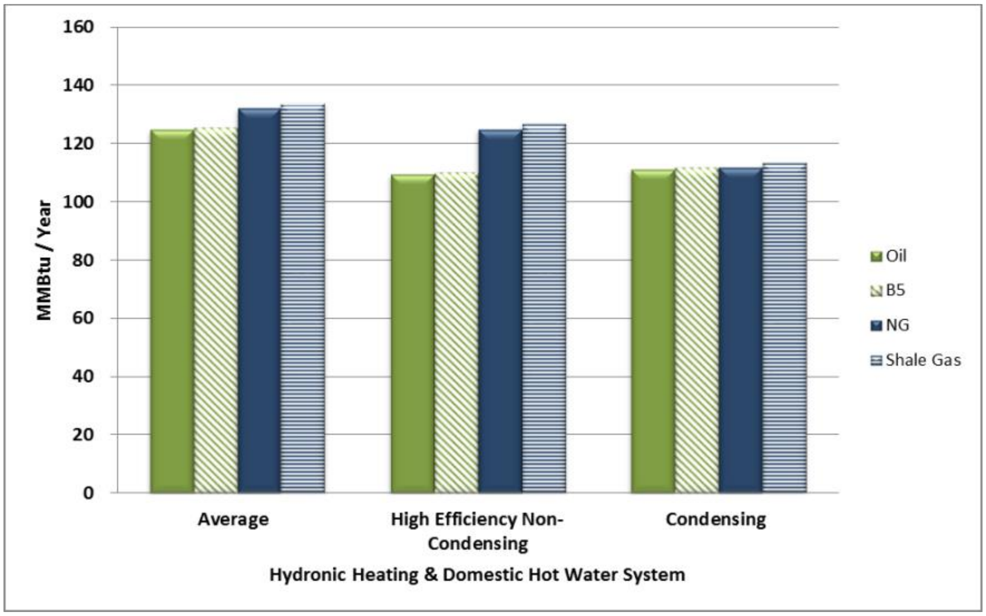


Figure 1 2006 Fuel Cycle Energy

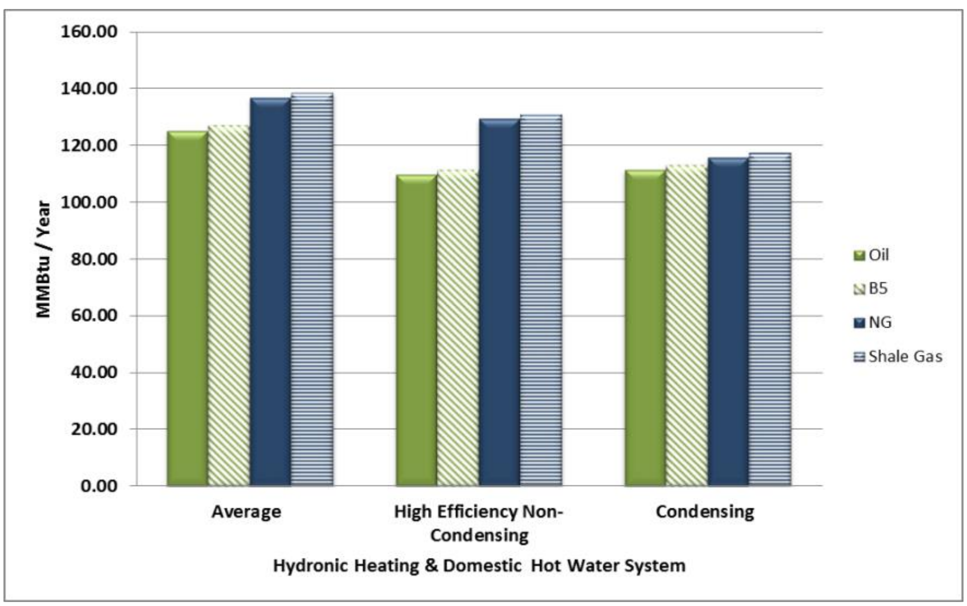


Figure 2 2020 Fuel Cycle Energy

[59] With respect to current non-condensing appliances - natural gas maximum boiler AFUE efficiency is 83% and oil maximum boiler AFUE efficiency is 88% with the reason for this differential being the hydrogen content in the fuel and resultant combustion gas dew point affecting performance.

Error! Reference source not found. presents the economic indifference curve based a 92 MMBtu residential energy use per year boiler conversion. The economic indifference curve (**Error! Reference source not found.**) is the red line and reflects a conversion cost of $12,670, plotted against the price of the two fuels, assuming equivalent efficiencies. Points above the line indicate that there is no economic incentive to convert to natural gas, and in fact no action is appropriate. Points below the line indicate there is an economic incentive to convert to natural gas. The red box contains the price for natural gas and heating oil for the last two decades. Of particular reference are the brown, yellow, grey, and orange points that represent recent years. These points would favor a conversion, however, that pricing must last the ten years of the amortization of the conversion cost. However, the red, green and black boxes are the most current pricing, and they indicate not converting is the appropriate economic choice.

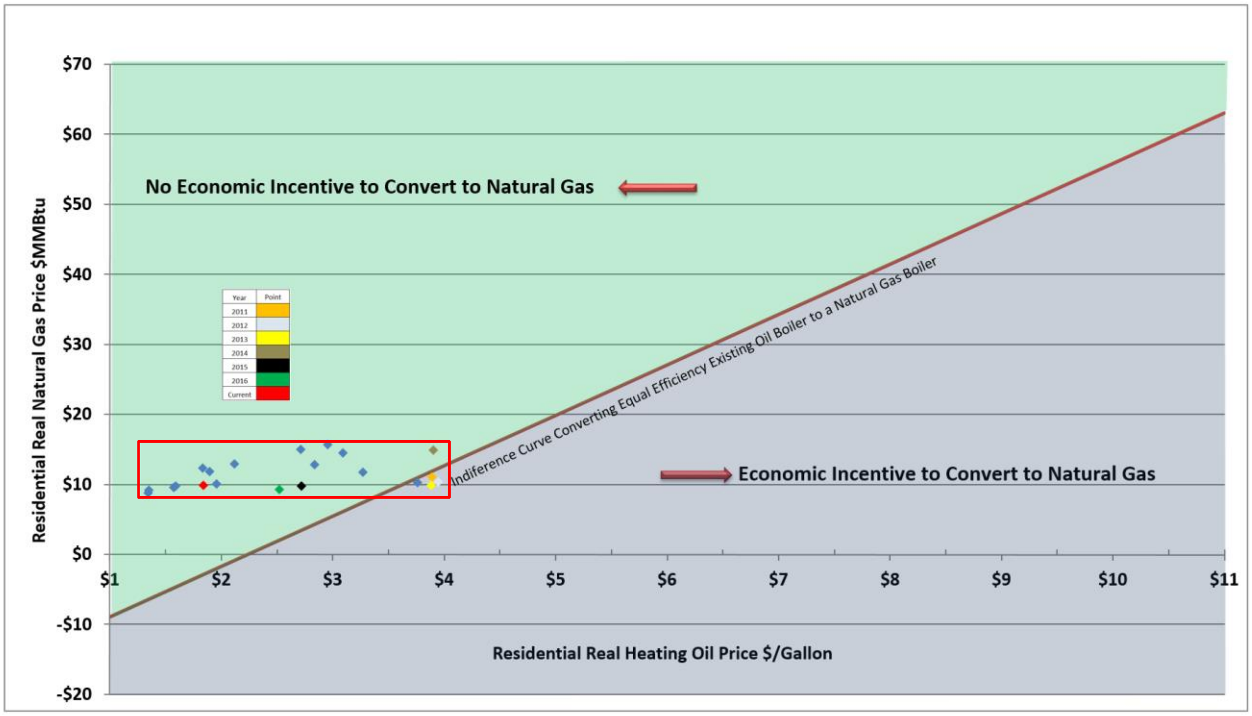


Figure 3 Consumer Economic Indifference Curve High Estimated Conversion Cost (Non-condensing boilers)

Error! Reference source not found. presents the economic indifference curve based a 54.6 MMBtu (equivalent to 53,000 cu ft. of natural gas referenced in the DEP Draft report) residential energy use per year boiler conversion. The economic indifference curve is the red line and reflects an oil/biodiesel to natural gas conversion cost of $5,600, which was assumed in the 2015 DEP report update, plotted against the price of the two fuels, assuming equivalent efficiencies. Points above the line indicate that there is no economic incentive to convert to natural gas, and in fact no action is appropriate. Points below the line indicate there is an economic incentive to convert to natural gas. The red box contains the price for natural gas and heating oil for the last two decades. Of particular reference are the brown, yellow, grey, and orange points that represent recent years. These points would favor a conversion, however, that pricing must last the ten years of the amortization of the conversion cost.

However, the red, green and black diamonds are the most current pricing, and they indicate not converting is the appropriate economic choice.

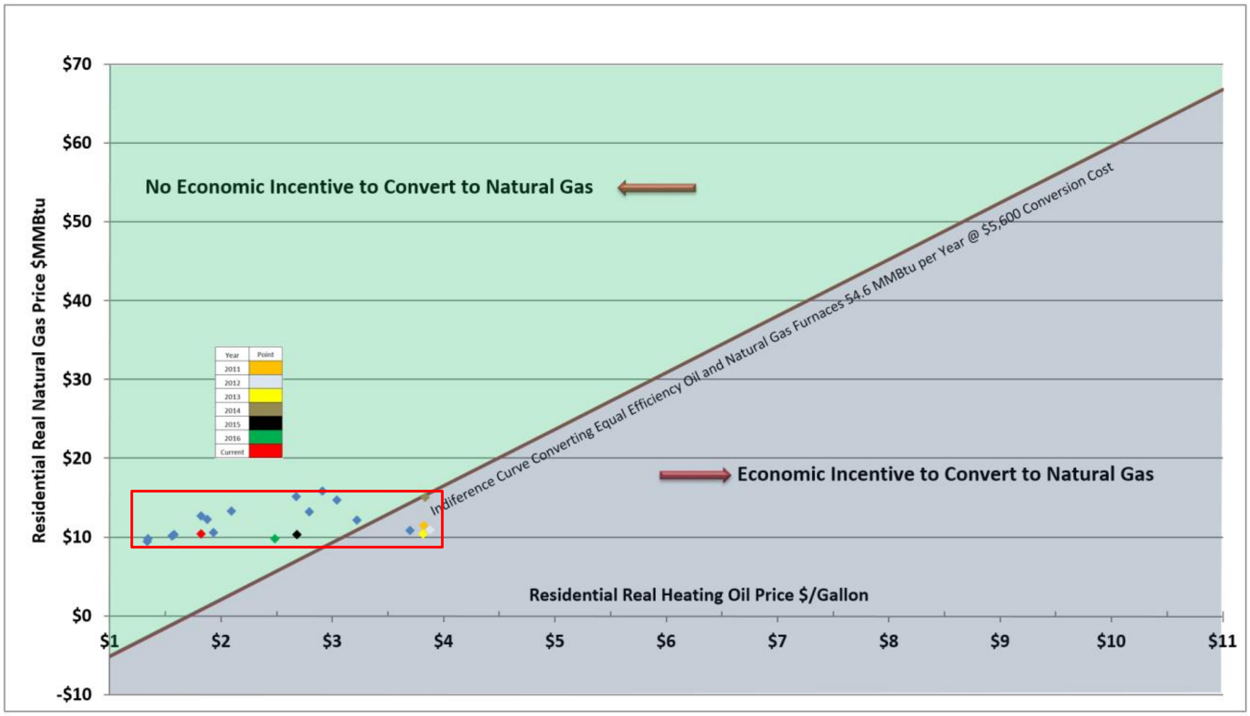


Figure 4 Consumer Economic Indifference Curve High Estimated Conversion Cost (Equal Furnace Efficiency)

Sussex Energy Advisors surveyed 450 consumers collecting demographics (including current fuel, age of heating system, perceived replacement date); current perceptions of natural gas; price perceptions and effect on fuel choice; value of price and incentives to conversion decision. Consumers commented:

- "Unless there is some incentive that can pay it back in 2-3 years, forget it."
- "My formula is this. If it's paid back in savings in 5 years or less and cost less than $15,000, then I will deal with it."
- "If you really save me 50% on my energy bill and it cost less than $10,000, it will be worth it."
- "I had my furnace replaced in my other house when they brought gas to my neighborhood. What a mess. It was late spring. My yard was ripped up, mud all over the house from the workers, they had to cut up my old oil tank, days of cleaning up after they left. In the end it was well worth it, but what a mess."
- "We have enough going on in our life. People in and out all day…who is going to get rid of the old furnace, the oil tank and all that."

Error! Reference source not found. shows that 54% of the consumers surveyed believe that the process of conversion is difficult or very difficult. This means that the economic indifference curve must be viewed with a bias toward not converting.

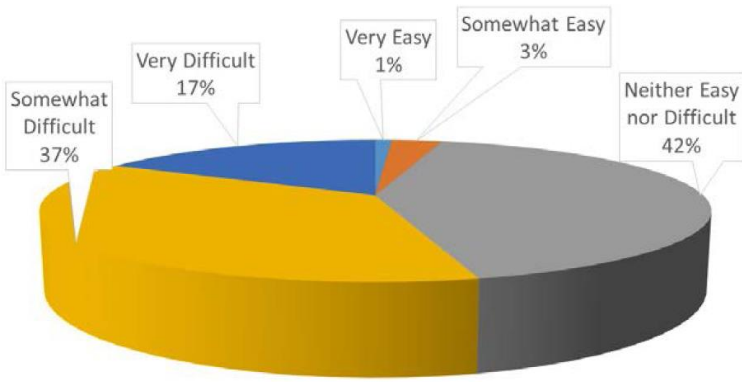


Figure 5 Sussex Energy Advisors Study[60]

Based on this economic indifferent curve analysis and the general bias consumers against conversion, there is no apparent reason for a consumer to convert at this time, which begs a question: Are there other near-term reasons to convert from oil to natural gas? The following sections will explore potential societal benefits:

- GHG Emissions
- Criteria Pollutant Emissions
- Future Energy Price (13)

Error! Reference source not found. presents the equivalent biodiesel required to equal natural gas being combusted in high efficiency non-condensing boilers which is the most likely hydronic replacement system in Massachusetts. The biofuel data comes from the National Biodiesel Board.

Table 9 Equivalent CO_{2e} Emissions for Natural Gas and ULS HO/Biodiesel

Updated Biodiesel Production Efficiency 100 Year Atmospheric Lifetime without Indirect Land Use			
2020			
	lb CO_{2e}/MMBtu	lb CO_{2e}/Year	Bioblend equal emissions to natural gas
Natural Gas	152.89	17,154	
ULS	192.71	18,539	
B100	39.50	3,800	
ULS HO/Biodiesel	178.31	17,154	**9.4%**
Updated Biodiesel Production Efficiency 20 Year Atmospheric Lifetime without Indirect Land Use			
2020			
	lb CO_{2e}/MMBtu	lb CO_{2e}/Year	Bioblend equal emissions to natural gas
Natural Gas	179.76	20,169	
ULS	205.40	19,759	
B100	49.36	4,748	
ULS HO/Biodiesel		19,759	**0.0%**

The results show that, using the conventional 100-year basis, approximately a 9.4 ULS HO/biodiesel is equivalent to natural gas. While 100-year atmosphere lifetime is an important factor, the scientific community is starting to focus more on short-term carbon forcers as a more important problem to solve. In this case, using 20-year atmospheric lifetime data no biodiesel is required to achieve equivalence to natural gas.

[60] Sussex Economics Advisors, DOER Natural Gas Expansion Study 2nd Stakeholder Meeting October 13, 2013

Increasing the biodiesel fraction over time will dramatically reduce the GHG emissions well below natural gas. Keeping in mind that natural gas suppliers are pursuing various types of biogas, there is no current technology on the horizon that is economically viable.

All the above is not to say that natural gas is not a good fuel, but to create public policies in place to coerce conversion from heating oil (ULS HO/biodiesels) may, in fact, may increase GHG emissions.

Long term natural gas price forecasts are revised annually and/or periodically by significant amounts. The U.S. Energy Information Agency (EIA) began forecasting prices for the year 2025 in 2003. By 2009 the price forecast for 2025 increased by 56 percent. By 2013 the forecast price for 2025 had fallen back to the same level projected in 2003. (**Error! Reference source not found.**). Figure 5 clearly conveys that estimates of future prices and future prices have a low level of correlation.

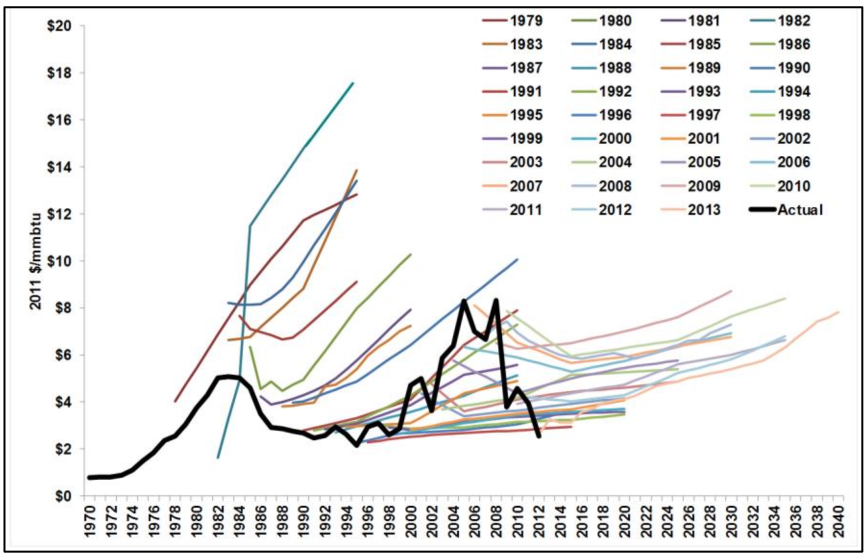


Figure 6 EIA Historical Long-term Wellhead Natural Gas Price Forecasts

North American wellhead natural gas prices have fallen to the lowest levels in over a decade due to rising supplies of low-cost shale gas. In general, the North American natural gas market is now demand constrained; e.g., there isn't enough demand to absorb rising supplies. As a result, natural gas wellhead prices have fallen to low enough levels to replace coal in power generation and prevent new coal and nuclear plants from being built as seen in **Error! Reference source not found.**.

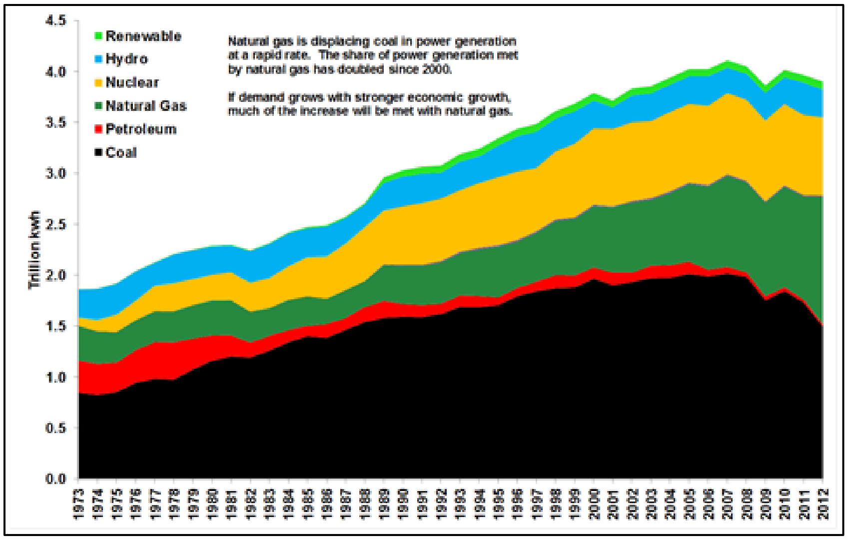


Figure 7 EIA U.S. Power Generation Fuel Mix

Since 2002, residential and commercial demand has fallen by 12 percent and industrial, electric power and the export sector have increased by 10 percent. Demand in the electric sector is driven by low cost natural gas which is displacing coal. Demand in the industrial sector is due to economic growth, as well as, low cost natural gas which is providing U.S. industrials a competitive advantage over international competitors.

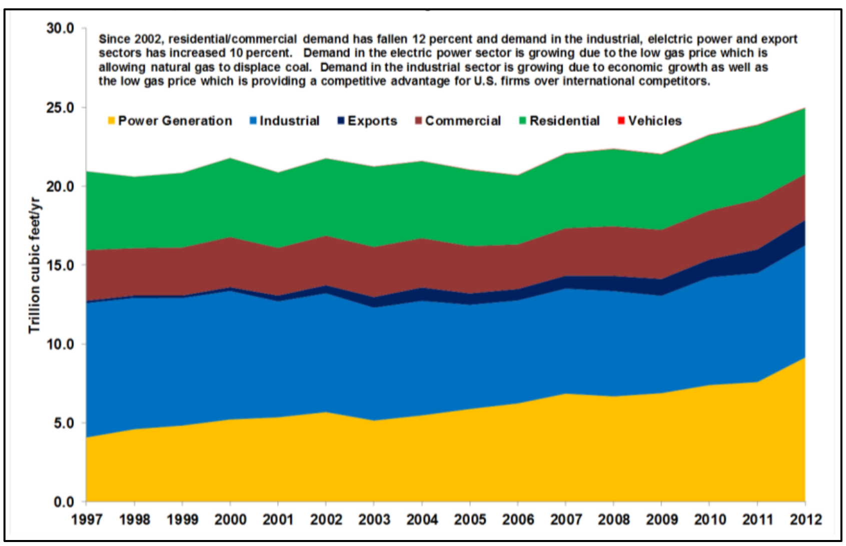


Figure 8 EIA U.S. Natural Gas Demand: Growth in Power Generation, Industrial Sector and Exports

James Henderson properly captured the driving force behind the flurry of LNG export activity in North America by stating; "[w]ith U.S. spot gas prices falling to a level of $2-3/MMBtu in the first half of 2012 compared to European long-term contract prices of around $12/MMBtu and Asian spot LNG prices close to $18/MMBtu, it is obvious that an arbitrage opportunity exists for North American producers who can construct or gain access to new liquefaction facilities." [61] This global LNG price disparity will undoubtedly lead to construction of some of the 31 LNG export terminals (note projects 1, 4 are import terminals) identified on **Error! Reference source not found.** and in Appendix E. At least 21 LNG export projects have been proposed with a combined capacity of 27 Bcf/d (over 40 percent of current U.S. natural gas demand).

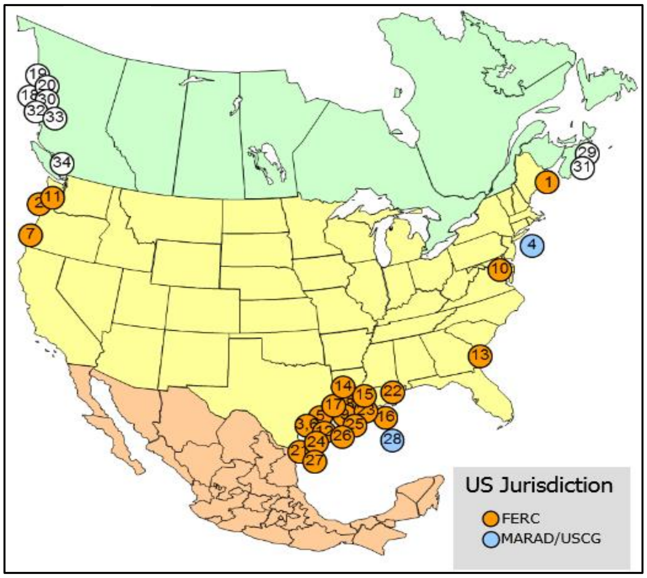


Figure 9 FERC Office of Energy Projects: North American Proposed/Potential LNG Import/Export Terminals

Rising natural gas demand from power generation and future LNG exports will likely cause natural gas prices to rise from the recent low levels.

To better understand the heating oil price forecast it is necessary to understand supply demand trends for the region. New England markets require very little diesel and heating oil supply from non-Canadian sources, as shown in **Error! Reference source not found.**. In fact, East Coast imports of diesel fuel and heating oil into the market have been falling since 2004. (**Error! Reference source not found.** and **Error! Reference source not found.**)

[61] The Potential Impact of North American LNG Exports, James Henderson, October 2012, Oxford Institute for Energy Studies

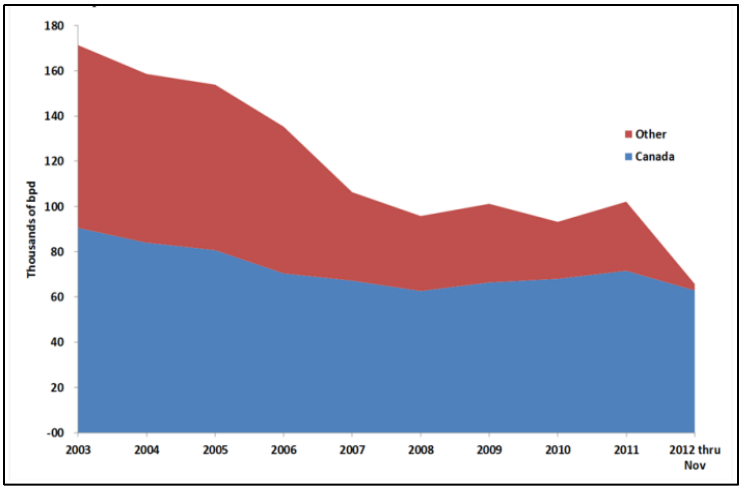


Figure 10 EIA New England Distillate Imports

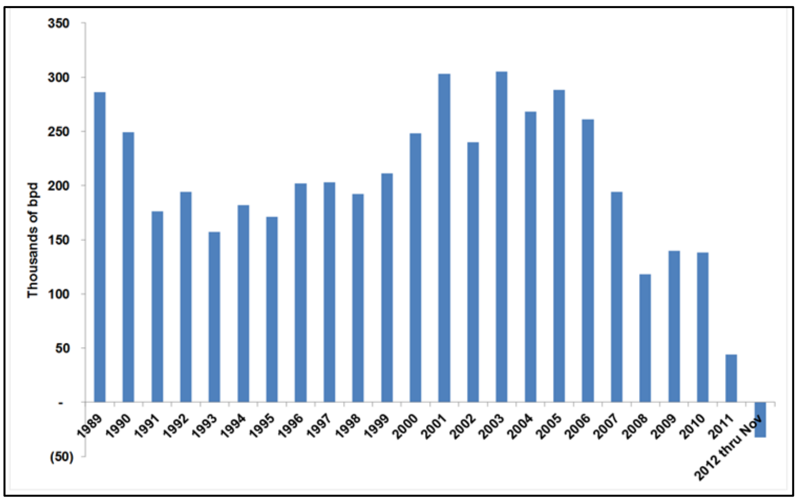


Figure 11 EIA East Coast Distillate Net Imports

For much of the year, the U.S. east coast refining industry is a significant exporter of diesel fuel and heating oil to the international market. The U.S. East Coast refining industry has become a supplier of diesel and heating oil to the Atlantic Basin market over the past few years. With weak demand and supply likely to rise further as refineries continue to restart, distillate exports from the region could increase. (**Error! Reference source not found.**)

The U.S. Gulf Coast refining industry is a major exporter of diesel fuel and heating oil to the international market. Pipelines supplying the east coast from the U.S. Gulf Coast are slowly expanding. Crude oil supplies in the U.S. are growing rapidly and causing a significant decrease in waterborne crude oil imports. The combined effects of vehicle efficiency, biofuels, rising imports from Canada, and rising domestic production will continue to reduce U.S. crude oil imports (ex. Canada) for years to come.

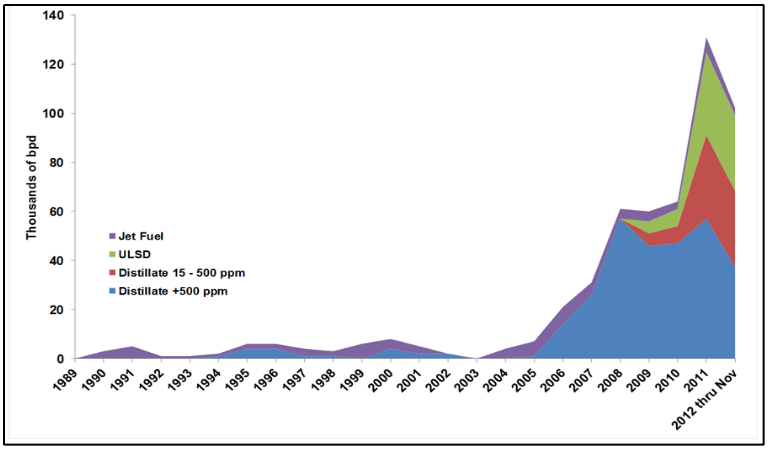


Figure 12 EIA Distillate Exports from the U.S. East Coast

Error! Reference source not found. shows the U.S. crude supply, including Canadian and Mexican resources, has been rising rapidly and is expected to increase at the recent pace for several years. The combination of rising oil sands[62] production in Canada, oil from shale across North America, renewable fuels and biofuels could result in self-sufficiency for the region by 2020.

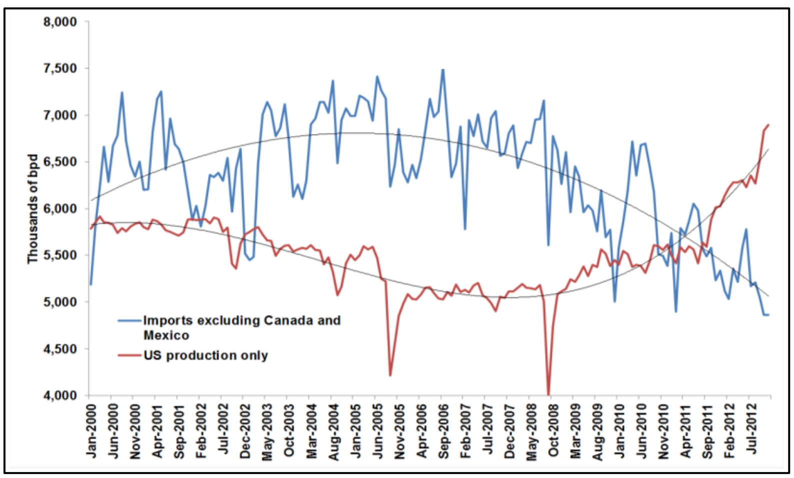


Figure 13 EIA U.S. Crude Oil Supply Including Canada and Mexico

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[62] Two comments with respect to GHG emission from the production of oil sands are required. 1) According to Environment Canada, GHG emissions per barrel of oil from the oil sands have been reduced by an average of 26 percent between 1990 and 2010. 2) With respect to price in North America, oil sands will be produced and purchased throughout the region regardless of local jurisdiction bans on importation as other states and localities will allow importation. However, note that Massachusetts residents will benefit from lower heating oil as a result of oil sands entering other markets.

Jim Patterson, of Kiplinger stated on July 3, 2013 that; "[a]fter nearly a decade of unrelenting gains, oil prices are poised for a drop. New sources of supply and slowing demand both at home and abroad will combine to push prices down by 20% to 30% by 2016."[63]

Long-term oil and gas price forecasts have changed dramatically over the years and are revised every year as perceptions about the future change. There are a growing number of signposts from both the oil and natural gas markets indicating that oil and gas prices may actually begin to converge back on each other over the next several years. Should the price premium for oil fall relative to natural gas, any fuel cost savings from switching to natural gas will erode. Global and North American oil reserves are rising at historically rapid rates as the upstream industry responds to high oil prices, and technology allows shale oil resources to be developed. Reserves are rising at a rate that is consistent with weaker oil prices. Demand growth worldwide has not been sufficient to absorb rising production. OPEC spare capacity as a percent of global demand is rising to a level that is consistent with oil price declines.

North American natural gas prices have fallen to the lowest levels in over a decade due to rising supplies of low-cost shale gas. In general, the North American natural gas market is now demand constrained; e.g., there isn't enough demand to absorb rising supplies. As a result, natural gas prices have fallen to low enough levels to replace coal in power generation and prevent new coal and nuclear plants from being built. At least 21 LNG export projects in the U.S. lower 48 and Canada have been proposed by 2020. These total over 27 Bcf/d of natural gas demand which is equivalent to 40 percent of 2011 U.S. gas demand. Rising natural gas demand from power generation and future LNG exports could cause natural gas prices to rise from the recent low levels.

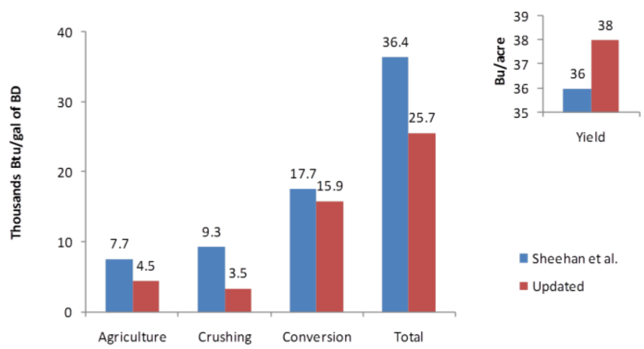

Figure 14 Energy Balance: An Update[64]

[63] http://www.kiplinger.com/article/business/T019-C021-S005-lower-oil-prices-on-the-horizon.html#xB6wlSmPzCmh8JgY.99

[64] "Energy Balance: An Update", Dev Shrestha Co-Authors, A. Pradhan, D. S. Shrestha, A. McAloon, M. Haas, W. Yee, J. A. Duffield, and H. Shapouri, October 2008 Presentation

Updating the ICF base report biodiesel data yields **Error! Reference source not found.** reducing the biodiesel fraction in 2020 to 22.6% for natural gas equivalence delivered to the burner tip.

Biodiesel blends at 20% (B-20) with ultra-low sulfur heating oil (ULSHO) are lower in Greenhouse Gas Emissions (GHG) than natural gas when evaluated over 100 years, while heating oil is lower in GHG than natural gas when evaluated over twenty years. Any ULSHO and biodiesel blend is equally clean in criteria pollutants and particulates. With future research and applications, increasing the biodiesel blend reduces GHG emissions even further. Biodiesel blends for heating oil are a clean responsible alternative to natural gas heating systems and perform admirably against all other heating systems.

In summary, the accurate, traceable and credible comparison shown in **Error! Reference source not found.** and 7 comparable results between natural gas emissions and a 1.6% biodiesel and ULS blend. These two figures assume IPCC AR4 20 year time horizon, shale gas at the margin and high efficiency non-condensing boiler end-use as the most likely existing residential upgrade. (13)

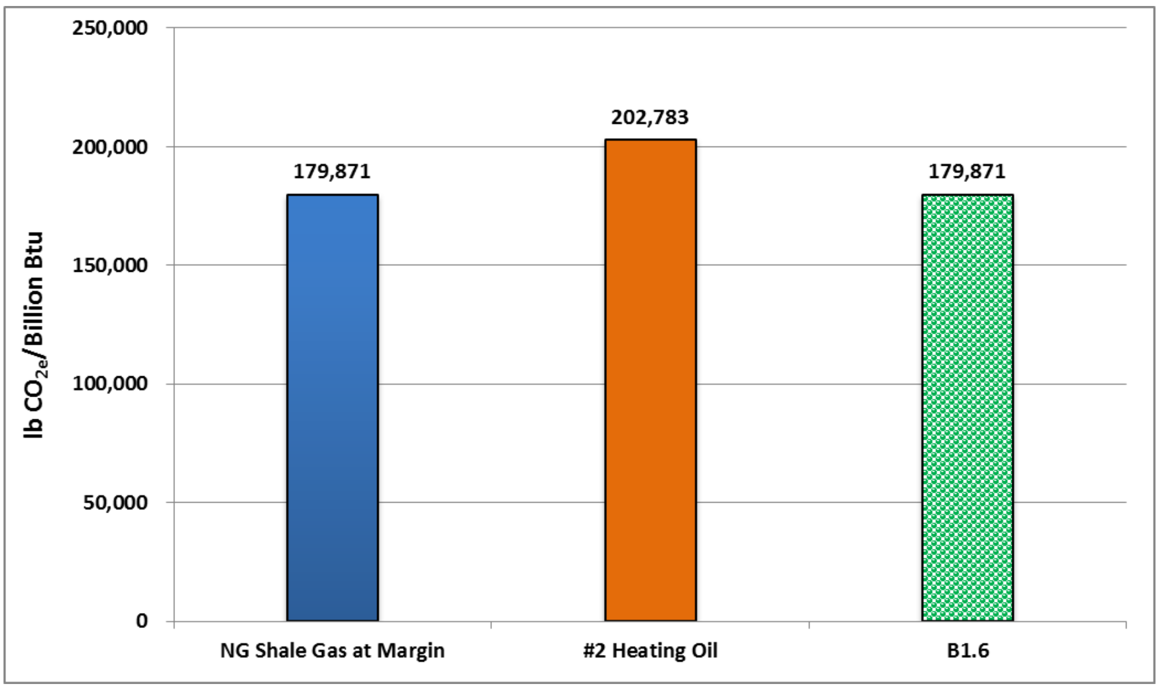

Figure 15 Comparing Natural Gas GHG Emissions versus #2 heating oil and 1.6% Bio/ULS Blend

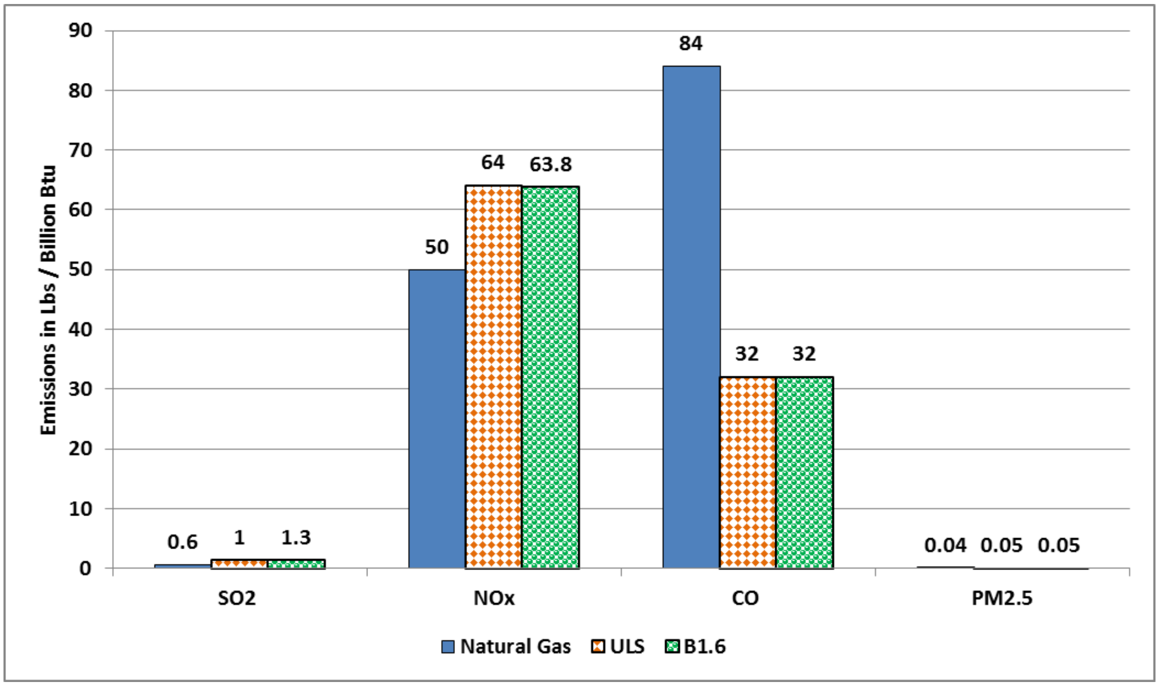

Figure 16 Comparing Natural Gas Other Emissions with ULS and a 1.6% Bio/ULS Blend

Response: Thank you for your comments. The intent of the CCAP's public policy is to encourage conservation measures and fuel switching where they are cost-effective and is not intended to exclude any one fuel. The PA PUC Fuel Switching work group recommendations do not recommend any fuel over another. Rather, it recommends that Electric Distribution Companies consider fuel switching (which does not delineate any one fuel) when it is cost-effective.

The combined work plan (CCAC Workplan 5: Heating Oil Conservation and Fuel Switching) includes both conservation measures (such as air-sealing and insulation) as well as fuel switching. It is the conservation efforts (over 96%), rather than fuel switching (less than 4%) which constitute the vast majority of the estimated GHG emissions reductions.

The workplan proposes the state sponsor a program offering various options that can be chosen to conserve energy and reduce GHG emissions related to the heating and cooling of homes and businesses in Pennsylvania. The DEP concurs that each individual home or business should be evaluated individually and that the economic analysis will depend upon many unique factors.

Energy – Energy Efficiency Financing

94. Comment: While energy efficiency improvements can result in significant monetary savings, the upfront cost can be an insurmountable barrier for many projects. We are greatly encouraged by recommended actions in the plan such as funding the Keystone HELP/WHEEL programs, and greater use of energy efficient mortgages, on-bill repayment, property assessed clean energy (PACE), and performance contracting. We urge the state to consider efforts specifically to market these programs to “middle-income” homeowners – those individuals and families who do not qualify for low-income programs, but do not have access to capital or financing to make improvements on their own. (5)

Response: Thank you for your support, comments and suggestions. The DEP agrees that finding ways to address the needs of all commonwealth citizens will require additional consideration.

95. Comment: In addition to these measures, two that were not mentioned specifically in the plan, but should be considered, are greater adoption of the Home Energy Score (HES), and integration of energy-related fields into multi-list services. The HES was developed by the Department of Energy to be similar to a miles-per-gallon rating on a vehicle, indicating how expensive a home is to operate. The HES and/or other energy-related information can feed into the regional multi-list service (MLS), which provides realtors and homebuyers with information on the home, and allows appraisers to assess the value of energy-features when identifying comparable properties. These two measures are important steps to recognizing the value of energy efficiency in the market. (5)

Response: The Department appreciates the comment and will take the two additional measures, the Home Energy Score and energy-related fields into multi-list services, into consideration when developing the 2018 Climate Change Action Plan Update.

96. Comment: In addition to creating financing tools, the state can play an important role in integrating information on a building’s energy use into real estate transactions. While energy disclosure requirements at the time of sale are one option, voluntary options also exist, such as including “green” and energy-related fields in the multi-service listing (MLS), the regional database of available properties. Having improved information allows actors in real estate transactions to make more informed decisions. As mentioned above, it also provides an avenue for appraisers to identify comparable properties on which to justify the increased value of a home or building resulting from energy improvements, which today are not recognized in many MLS databases. (5)

Response: The Department appreciates the comment and agrees that an increase in energy related information being available to consumers will lead to more informed decisions when it comes to building energy use.

97. Comment: Although not included in the draft Climate Change Action Plan, we would like to offer a recommendation related to increasing the effectiveness of energy efficiency programs. We recommend supporting the reform of cost-effectiveness testing. Many states are applying methodologies and assumptions that do not capture the full value of efficiency resources, leading to under-investment in energy efficiency, and higher costs to utility customers and society. (6)

Response: The Department appreciates the comment and will take the concept of cost-effectiveness testing into consideration when developing the 2018 Climate Change Action Plan Update.

98. **Comment:** At the Regional Energy Efficiency Summit, hosted by ReEnergize Pittsburgh in the spring of 2015, attendees identified a lack of access to information and financial resources among the key barriers to energy efficiency improvements in the residential sector. We are encouraged to see several recommendations related to providing consumers with better information, such as providing customers information on energy usage compared to neighbors or instituting an energy disclosure for change in property ownership. (6)

While energy disclosure requirements at the time of sale are one option, voluntary opportunities also exist, such as including "green" and energy-related fields in the multi-listing service (MLS), the regional database of available properties. Having improved information allows actors in real estate transactions to make more informed decisions. It also provides an avenue for appraisers to identify comparable properties on which to justify the increased value of a home or building resulting from energy improvements, which today are not recognized in many MLS databases. At its 2015 annual conference, the Council of MLS announced that over half of its members now offer fields including energy-related information, yet this type of information is not yet available statewide in Pennsylvania.

The DOE's Home Energy Information Accelerator comprised of stakeholders from the real estate and appraisal industries are leading the national effort to incorporate residential energy efficiency data into the real estate value chain. This includes developing data strategies to allow automatic transfer of standardized data from residential program administrators to multiple listing services to increase the value of energy efficient homes.

A related opportunity is encouraging greater use of the Home Energy Score (HES), a rating developed by the Department of Energy to serve a similar purpose to the miles-per-gallon rating for a new vehicle, allowing purchasers to make informed decisions about the long-term costs of owning a home. HES uses an easy to interpret 1-10 scale that weighs the energy efficiency features of a home.

Similarly, BPI-2101 Standard Requirements for a Certificate of Completion for Residential Energy Efficiency Upgrades (published September 2013) provides another way of documenting home energy upgrade improvements in a home. This is a Building Performance Institute standard that is supported by the U.S. DOE's Home Performance with ENERGY STAR program.

1. BPI-2101 identifies a standard set of data elements for certificates that document the completion of a whole-house energy upgrade or individual energy conservation measures in the small homes sector. BPI-2101 provides homebuyers with access to consistent, comparable information about energy efficiency features in existing homes, and is aligned with several national data standards to facilitate electronic

transfer of project and building information collected by energy efficiency programs to market actors in the residential real estate value chain.[65]

The HES, BPI-2101 certificate, and/or other energy-related information about a home can feed into the regional multi-list service (MLS). These measures are important steps to recognizing the value of energy efficiency in the market. As compared to a mandated energy standard, which may be politically unpalatable, these certifications and greening the MLS allow home buyers and sellers more perfect information to make rational market decisions. (6)

Finally, in 2016, the Northeast Energy Efficiency Partnership (NEEP) led the creation of a database that will enable the automatic population of green data fields in multiple listing services in the northeast when information from rating programs like DOE's Home Energy Score is available. This database is called the Home Energy Labeling Information eXchange (HELIX). Although Pennsylvania is not a participating state in the project, it is worthwhile monitoring this project since its outcomes can be game changing for the industry. (6)

Response: Thank you for your comments and suggestions. Certainly exploring all avenues of consumer education and information dissemination will assist in achieving broader acceptance and implementation of GHG reduction strategies. We have been looking at various models of building asset scores and home performance ratings to address this need for consumer education and information.

We look forward to working with groups like the DOE, NEEP, BPI, ReEnergize Pittsburgh, MLS and appraisers to incorporate building performance data into "standard" databases of available properties.

We will continue to work with these and other like-minded groups towards the ultimate goal of achieving a uniform set of building performance measurement and labeling strategies

99. Comment: While energy efficiency improvements can result in significant monetary savings, the upfront cost can be an insurmountable barrier to the average homeowner. We support the recommended actions in the plan that will empower these homeowners to achieve greater energy savings in their homes. Those recommendations include reinvesting in the Keystone HELP program to make it ultimately self-sustaining; incentivizing the greater use of energy efficient mortgages; allowing for on-bill repayment and property assessed clean energy (PACE); and encouraging energy savings performance contracting. (10)

[65] The national data standards include the Appraisal Institute's Green and Energy Efficient Addendum (Addendum), the Real Estate Transaction Standard (RETS), BPI-2100-S-2013 Standard for Home Performance-Related Data Transfer (HPXML) and BPI-2200-S-2013 Standard for Home Performance-Related Data Collection.

Response: Thank you for your support and comments. The DEP was a long time funder and program partner with KeystoneHELP and continue to work on ways to assist in the re-launch of that program and to encourage investment in programs like PACE and ESPC (Energy Savings Performance Contracting).

100. Comment: We suggest the DEP and CCAC consider including policy recommendations and a separate work plan associated with the establishment of a Pennsylvania Green Bank. A more robust build-out of this recommendation serves both the energy efficiency and renewable energy sectors, and may provide opportunities to finance other beneficial infrastructure. As noted in the Plan, the formation of a Green Bank in Pennsylvania can rapidly grow clean energy markets with minimal public expenditure, while making energy cleaner and cheaper for citizens. In addition to growing clean energy markets, Green Banks can also produce a number of additional benefits including:

- Low-Cost Market Growth – Green Banks aim to make energy cleaner *and* cheaper, and do it by providing opportunities for low-interest financing.
- Private Sector Leverage – Green Banks seek to "crowd-in" private investment currently on the sidelines and can leverage $10 of private capital for each public dollar used.
- More Efficient Government – Green Banks can create opportunities to leverage public investment by partnering with state and local governments, providing systems to preserve and recycle public dollars through financing services.
- Job Creation & Economic Development – 100% financing reduces barriers to demand, so investment in energy efficiency and in-state renewables means more jobs and growing businesses to meet that demand.
- More Money Back in Citizens' Pockets – Green Bank financing allows more citizens to lower energy bills through deep efficiency retrofits, and offers a way for government to lower reliance on expensive grants.

Connecticut created the first Green Bank in the country in 2011, and has already achieved tremendous growth. In FY15, the Connecticut Green Bank facilitated $365 million in total clean energy investment. This is a 10-fold increase in total investment in the state in only four years.[66] Given the potential benefits, we suggest amending the Action Plan to provide greater emphasis on the potential deployment of this tool. (12)

Response: Thank you for your suggestion. We are supportive of these concepts and continue to explore options to integrate them into our CCAP strategies and work plans.

Land Use

101. Comment: We support the preservation of Pennsylvania's forests and land through forward looking, protective land use policies. It is imperative to preserve our forests because of their capacity to absorb carbon, provide wildlife habitat, offer aesthetic and recreation value to people of the Commonwealth, and contribute a range of ecosystem services. (4)

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[66] http://www.coventryct.org/AgendaCenter/ViewFile/Item/2936?fileID=3729

Response: The Department appreciates the comment and agrees that forest preservation is an integral part of any long range climate action plan which will provide multiple benefits for the environment and the citizens of the commonwealth.

102. Comment: We agree that we must restore and repurpose abandoned land mines and other damaged lands. "Pennsylvania's Statewide Comprehensive Outdoor Recreation Plan 2014-2019 recommends that the commonwealth restore and repurpose brownfields, abandoned mine lands and other damaged lands for recreation and conservation purposes through at least five pilot projects." Plan at 89. Recreation opportunities provide tremendous value to our communities by giving people a place to exercise or relieve stress. Parks offer places for people to gather and hold social activities, as well as give the community a sense of identity. (4)

Response: The Department appreciates the comment and agrees that land restoration and conservation activities comprise a crucial part of our social and environmental responsibility.

103. Comment: The 2005 destruction of Duke Lake at Ryerson Station State Park in Greene County Pennsylvania due to coal mining demonstrates the necessity of restoring and repurposing damaged lands for the health of our communities.[67] Ryerson Station State Park is the only State Park in Greene County and one of only a small number of public parks in the area. Until its destruction, Duke Lake was a pillar of the park and community. Residents and tourists gathered at Duke Lake to swim, fish, and boat. Greene County is one of the poorest counties in Pennsylvania[68] and Ryerson provided a place free of cost with exceptional opportunities for the community to gather and enjoy the outdoors. The community has been deprived of Duke Lake for 11 years and now it will never be restored. Like Duke Lake, Pennsylvania's forests and parks are major attractions for residents of the Commonwealth, as well as people from other places to visit the state. Indeed, Pennsylvania's new tourism campaign prominently features and promotes parks and outdoor recreation activities.[69] Restoring and repurposing lands damaged by coal mining and other industrial activities is necessary to encourage tourism and to improve the health of Pennsylvania's own communities. (4)

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[67] Don Hopey, *Pennsylvania says mining destroyed lake dam in park*, Pittsburgh Post-Gazette (Feb. 1,2008), http://www.post-gazette.com/local/washington/2008/02/01/Pennsylvania-says-miningdestroyed-lake-dam-in-park/stories/200802010213; *See also* C.R. Nelson, *Dryerson Festivalremembers 10 years without Duke Lake*, Observer-Reporter (June 25, 2015), http://www.observerreporter.com/apps/pbcs.dll/article?AID=/20150625/news02/150629670.

[68] *See* Hoch & Ctr. for Coalfield Justice, *Community Indicators of Environmental Justice: A Baseline Report Focusing on Greene and Washington Counties, Pennsylvania*, at 30, 33, 34, 36-41(2013), http://www.coalfieldjustice.org/files/Community-Indicators-Environmental-Justice-2014.pdf.

[69] *Pennsylvania: Pursue your happiness*, visitPA.com (March 8, 2016), https://youtu.be/rZUj0HgkBTE.

Response: DCNR made a firm commitment to Ryerson Station State Park and the surrounding communities to provide an exceptional state park with recreational improvements. It was determined that the reconstruction of the dam that formed Duke Lake could not be rebuilt due to an unstable foundation documented by additional ground movement. The Duke Lake Task Force which was established to focus on rebuilding the dam refocused their efforts on the future of the park as the Re-Vision Ryerson Station State Park Task Force.

A multi-pronged approach for public engagement was initiated to determine a variety of additional recreational opportunities and park amenities that could be added to serve the community and provide an attraction for users from outside the local area. DCNR with the help of a consultant and the Task Force led the community and park users through a robust public engagement process focusing on the possibilities for a revitalized state park. DCNR staff from across multiple bureaus formed a team committed to the efforts at Ryerson Station. Public meetings and surveys were conducted to listen to community and park visitor concerns and input. School students were also engaged to express their ideas and add input for the future of the state park.

As a result of this public engagement, a new vision for Ryerson Station State Park is emerging. Habitat and stream restoration will focus on connections and accessibility to park facilities through an improved trail system. Other amenities will include campground improvements, new pool and water features, restrooms, and pavilions providing opportunities for all of our visitors to gather and enjoy the outdoors.

104. Comment: Land use plan components should focus on integrating other plan areas-- transportation, buildings, water etc-- for the purposes of minimizing land use impacts and preserving or restoring natural land cover. This section needs much more specific objectives; as such it mentions important programs without a clear vision for implementation or benefit. (11)

Response: The Department appreciates the comments and agrees that integration of plans and addressing cross-cutting issues requires additional consideration. The Department is heavily engaged in cross agency collaboration including, but not limited to, participation in the State Planning Board, regular executive level meetings between the Department and other agencies, and constant communication between the Department's regional offices and other agency counterparts. The Department will continue to work closely with other agencies and entities to improve our CCAP (Climate Change Action Plan) going forward.

Transportation

105. Comment: The transportation sector accounts for nearly one-quarter of gross GHG emissions in Pennsylvania. Emissions reductions can result from reduction in vehicle miles traveled, mode switching, fuel switching, and smart land use planning. We are disappointed that there was not more of a focus in the plan on expanding the utility and use of public transit.

Effective and affordable public transportation serves to reduce the carbon footprints not only of transit riders, but also of other cars and trucks, as better transit allows for fewer vehicles on the road, easing congestion and minimizing idling. (5)

Response: The Department agrees with the commenter on the importance of reducing the carbon footprint from the transportation sector. Although not mentioned specifically in the 2015 Update of the action plan, the topics suggested are covered in previous action plans and are still active components of Pennsylvania's Climate Change Action Plan implementation. The DEP agrees that increased use of public transportation will help reduce emissions coming from the transportation sector.

106. Comment: In addition, the portion of the plan that refers to bicycles focuses on commuters; however, the largest opportunity for reducing car travel exists by encouraging "non-commute" trips- shopping, errands, and leisure. The majority of these trips occur within two miles of home, a reasonable distance for most people to consider biking, if they feel "safe." For many cyclists, community trails feel much safer than city streets. (5)

Response: The Department agrees with the commenter on the concept of 'non-commute" trips importance and will take this into consideration when developing the 2018 Climate Change Action Plan Update.

107. Comment: While grant funding for trail infrastructure is offered by both the Pennsylvania Department of Transportation (PennDOT), through federal funds, and the Pennsylvania Department of Conservation and Natural Resources (DCNR), these are usually seen as "either/or" funding sources. Leveraging the two, and improving coordination between the two agencies, could lead to greater impacts. Trail projects can often be realized for smaller funding investments than larger infrastructure efforts, but current transportation planning does not currently prioritize these projects. (5)

Response: The Department agrees with the commenter on grant funding and prioritizing projects. The Department will take these two items into consideration when developing the 2018 Climate Change Action Plan Update and will forward this comment onto these agencies for discussion.

108. Comment: Finally, Pennsylvania would benefit from a "Complete Streets Policy," whereby all transportation projects must show that planned projects have considered bicycle and pedestrian accommodations. The City of Portland, Oregon estimates the climate benefits of its complete streets program to be a per capita GHG reduction of 12.5%. Currently, several counties and municipalities have complete streets programs, but a statewide policy would change regional planning efforts across the Commonwealth for the better. (5)

Response: The Department agrees with the commenter on the concept of "The Complete Streets Policy" and has added information on this concept to the *Reducing Travel Demand* section of the Transportation chapter in the 2015 Climate Change Action Plan Update to reflect the comment.

Forests

109. Comment: The Commonwealth must stop allowing companies to clear-cut forests for coal mining and related activities. The forest plays multiple important roles in Pennsylvania, including providing recreation opportunities to its residents and tourists and keeping the state's ecosystem healthy and functional. Also, the forestry and land use sector "is very important in its ability to absorb GHG." Plan at 34. "In 2012, over 34 MMTCO2e of GHG was absorbed in the forestry and land use sector, more than the GHG emissions from the residential, commercial and agricultural sectors combined." *Id.* The market for coal is declining and shows little signs of bouncing back, especially as reserves in Pennsylvania are dwindling; it does not make sense to prioritize coal extraction and related activities over Pennsylvania's forests. The DEP must provide extra scrutiny for significant timbering and clear-cutting for coal mining activities like strip mines and Coal Refuse Disposal Areas, as well as other surface activities. In Southwestern Pennsylvania, Consol Energy has proposed two new Coal Refuse Disposal Areas that would span about 2,000 acres. Consol's existing six Coal Refuse Disposal Areas currently occupy about 2,000 acres. If the two new facilities are permitted and constructed, Consol alone will have clear-cut approximately 4,000 acres of land for refuse disposal activities, destroying well over one hundred thousand linear feet of streams, trees, and wildlife habitat. Extensive surface mines in Greene, Washington, and Fayette counties also represent a massive loss of forested land and the ecosystem services that those trees once provided to this region. (4)

Response: DEP recognizes the value of forestland, particular the benefits it provides to the economy, to recreation, and to the ecosystem. Revegetation, including reforestation, is a crucial component of mine-site reclamation. Current regulations require the establishment of diverse and permanent vegetation on areas impacted by mining. Tree planting has been a focus of revegetation efforts. In 2004, DEP partnered with the federal Office of Surface Mining. Reclamation and Enforcement, several universities, non-profits, and the other 10 Appalachian states to form the Appalachian Regional Reforestation Initiative (ARRI). ARRI promotes forestation on mine lands and develops best management practices to achieve highly productive forestland. Mine operators have planted approximately 1 million trees per year on reclaimed mine sites.

In addition to the efforts to reforest active mine sites, ARRI's partnership with the non-profit organization Green Forests Work promotes reforestation of mine lands that were reclaimed to a land use other than forestland. Green Forests Work partners with landowners both public and private, in support of this effort. Last year, the Governor provided a grant to the Pennsylvania Environmental Council (PEC) to establish forestland on previously mined lands. PEC successfully completed a tree planting project this year and is in the process of selecting their project for 2017. Additionally, DEP has partnered with the American Chestnut Foundation to incorporate blight resistant American chestnuts in tree planting schemes. The DEP and the American Chestnut Foundation have established several test plots across the state to study the successes of reestablishing the American chestnut in Pennsylvania as well as provide American chestnuts for use in the planting reclaimed mine sites.

Pennsylvania has a large number of abandoned mine lands. DEP's Bureau of Abandoned Mine Reclamation (BAMR) has taken an active role in working with the landowners to reclaim the abandoned mine sites to forestland. These reclamation projects have successfully established highly productive forestlands across Pennsylvania.

The landowners have control of what the post-mining land use will be when the mine site is reclaimed and in some cases the landowners desire a land use other than forestland. One aspect of the ARRI is to educate landowners on the value of reclaiming their property to forestland in order to promote the reclamation of their properties to forestland.

The efforts described above demonstrate that it is feasible to have coal mining and effectively restore high-value forest habitat on reclaimed mine lands after the mining is complete.

110. Comment: Preserving and increasing Pennsylvania forestland is critical to the storage of carbon dioxide. According to the plan, "in 2015, state forests sequestered 4.7 million tons of carbon, while storing (above ground) 143 million tons. Forest soils are also important reservoirs for storing below, ground carbon." Additionally, urban forests help to combat the head island effect, and can be strategically planted to shade buildings to reduce cooling needs and create wind breaks. (5)

Response: The Department thanks the commenter for their submission and agrees that trees and forests are important for their ability to sequester and store carbon, as well as in providing other benefits, such as reduced energy costs for homeowners.

111. Comment: It is important to remember that private landowners own and manage 70% of Pennsylvania's forests and woodlots. Focusing on state-owned forestland is important, but not enough. Independent forest owners must be engaged in climate protection efforts. (5)

Response: The Department appreciates the commenter's interest in this area and agrees with this assessment that private landowners play a significant role in the management of Pennsylvania's forests. In fact, the Governor's Green Ribbon Task Force on Forest Products, Conservation and Jobs will soon release a report with recommendations to better engage private forestland owners and give them information and technical assistance to manage their forestland to adapt to impacts of a changing climate.

112. Comment: Finally, we urge the state to consider forestry efforts that not only sequester carbon or climate protection, but also are strategically located to address other environmental challenges. Examples include riparian plantings, particularly in the Chesapeake Bay watershed, and plantings in urban areas, both of which will improve water quality by reducing runoff and help the state and its municipalities to meet Federal mandates. (5)

Response: Strategically locating tree planting and other forestry practices is a practical way to achieve multiple benefits. We agree that urban tree plantings and riparian forest buffers provide many opportunities for expansion and crossover, especially through the TreeVitalize tree planting program and the formation of a new state-level riparian forest buffer program through the departments of Environmental Protection, and Conservation and Natural Resources. Given budget constraints, a stacked-benefits approach is important.

113. **Comment:** For example, the Pennsylvania Chapter of The Nature Conservancy has leveraged voluntary carbon credit demand to drive best management practices on 30,000 acres of privately-held forest lands through our Working Woodlands program. The credits come from increasing the sequestration potential of the forests on those lands via best management practices. The program applies Forest Stewardship Council (FSC) certification and performs third-party audits to determine the potential for improved management practices to increase the carbon sequestration potential of these lands. Landowners receive financial reward via the carbon credits and FSC-related harvesting activities. (12)

Response: The Department appreciates the information provided by the commenter. Carbon markets are a potential area of growth within Pennsylvania, and the Department of Conservation and Natural Resources and others are interested in exploring how such credits and incentives could be expanded.

114. **Comment:** Recognize the value of forest carbon sequestration as a cost-effective carbon reduction strategy in the report. We applaud the recognition of forests as a vital carbon sink in the plan, but recommend the Committee and DEP work with DCNR to consider evaluating the sequestration potential of deploying best management practices across both public and private forested lands in Pennsylvania, and the cost effectiveness of such activities. DCNR has already identified that our forests have the potential to absorb 5% of our annual greenhouse gas emissions using USDA Forest Service tools such as Forest Inventory Assessment (FIA) tool .It may be advantageous to see additional scenarios that assess the potential for Pennsylvania forest lands to play a larger role in cost-effective forest-carbon sequestration. (12)

Response: The Department appreciates the comment and agrees that there is room for implementation of additional forest-related best management practices on public and private lands. The Department of Conservation and Natural Resources has engaged with DEP and the Committee to create the Urban and Community Forestry workplan and will continue to be involved in this partnership.

115. **Comment:** Recommend programs that provide tools and incentives for private landowners to manage for forest health. In addition to the Working Woodlands program mentioned above, Wisconsin's Certified Family Forest program stands out as an example**.** This program, administered by the Wisconsin Department of Natural Resources, allows private landowners to join in a single FSC certification. In the offing, private landowners embrace management practices that increase the health of the forested tracts and increase their carbon sequestration potential: http://dnr.wi.gov/topic/TimberSales/mfl.html. (12)

Response: The Department agrees that private landowners play an important role in the management of Pennsylvania's forests. The Governor's Green Ribbon Task Force on Forest

Products, Conservation and Jobs has been researching examples like Wisconsin's program to aggregate management practices across parcels of private land to benefit landowners and to address climate change as well as loss of forestland due to fragmentation and parcelization.

116. Comment: Align cross-agency programs and practices to encourage forest health. In order to maintain healthy forest systems in the face of a changing climate, the fundamental qualities of forest system complexity and connectivity need to be reinforced. Practices that encourage these qualities become even more critical. Examples include: improving regeneration, preventing forest fragmentation, conserving vital wildlife corridors, and encouraging broader adoption of forest certifications. (12)

Response: The Department agrees that forests are complex systems and that many aspects of conservation must be taken into account. The Department of Conservation and Natural Resources' Bureau of Forestry is at the nexus of forest management and research in Pennsylvania and works closely with other agencies and organizations to promote best management practices and conservation of healthy forests in the face of climate change.

Agriculture

117. Comment: As agriculture only accounts for approximately 3% of GHG emissions in Pennsylvania, we urge the state to put more emphasis on carbon-reducing actions across other sectors. To the extent that actions are taken within agriculture to reduce GHG emissions, they should be in concert with efforts to diminish waterway impacts from farm operations. For example, the use of no-till and crop rotation farming practices not only enables the soil to sequester more carbon, but reducing erosion and sedimentation. The increased use of manure digesters has the potential to lead to reduced run-off of nutrients, by improving manure management. (5)

Response: The Department appreciates the comment and agrees that an increase use of manure digesters will lead to reduced run-off of nutrients due to improved manure management. Recent action by the Pennsylvania Public Utility Commission may help increase the use of the digesters across the Commonwealth.

118. Comment: On January 6, 2015, the Climate Change Advisory Committee (CCAC) unanimously adopted the Digester Work Plan which would create renewable electricity and offset GHG emissions from fossil fuels by supporting manure digesters. The biggest threat to developing digester projects are net metering restrictions due to a regulation proposed by the Public Utility Commission (PUC) on July 5, 2014 that "eliminate[s] any reasonable possibility of future digester installation in Pennsylvania."[70]

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[70] See Appendix B of the Climate Plan, *CCAC Work Plan 13: Manure Digesters*, 248-257 http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-110839/DRAFT%202015%20Climate%20Change%20Action%20Plan%20Update.pdf .

The work plan encouraged the PUC to withdraw the net metering rulemaking, noting that it was opposed by a "broad coalition of farmers, renewable energy stakeholders, and environmental advocacy organizations and industry trade groups." The work plan also "encourage[d] single farms and combination farms to build digesters through outreach training and removal of any existing barriers to joint projects…" (8)

Response: On May 19th, the Independent Regulatory Review Commission (IRRC) held a public meeting to hear, among other items, PUC's new regulations related to implementation of the Alternative Energy Portfolio Standards Act of 2004. The arguments focused mostly on the limit of 200% of annual electric consumption that the PUC set on the size of the generator to qualify for net metering. The Commissioners unanimously rejected the new regulations, primarily on the basis that the PUC did not convince them that they had the authority to set limits that were not set forth in the statute.

119. **Comment:** Thirteen months after CCAC's adoption of the Digester Work Plan, the PUC exempted farmers located in specific parts of the state and added barriers that eliminate any possibility of joint digester projects between farmers. These actions directly contradict the DEP's and CCAC's work plan, and will suppress the generation of renewable electricity, particularly from Tier I sources under the Alternative Energy Portfolio Standards Act, thereby increasing GHG emissions statewide.

The PUC failed to recognize or acknowledge CCAC's recommendation, despite receiving formal comments on the matter and despite having a representative on the CCAC. Its actions imply that the DEP's efforts to fight climate change, including the work performed by the CCAC and the Climate Change Action Plan are not taken seriously by senior policy makers in the administration, especially by PUC Commissioners. The PUC must now forward the final rulemaking package to the Independent Regulatory Review Commission (IRRC) for final review. Given the importance of encouraging renewable energy, the commenter recommends that the DEP submit comments to the IRRC opposing this rulemaking. (8)

Response: Thank you for your support and comments. The DEP does, and will continue to, work with and comment on PUC actions and with the IRRC on issues affecting the commonwealth's environment and the protection of our land, air and water resources.

120. **Comment:** Manure digesters create renewable electricity and thereby offset GHG emissions from other sources. The CCAC unanimously adopted the Digester Workplan on January 6, 2015, implementation of which would ensure that digesters continue to be developed within the state. That workplan identified the single biggest threat to future development of manure digesters—the portion of the then-proposed regulation further restricting the net metering program beyond the explicit limits set forth in the existing statute.

This regulation was proposed by the Public Utility Commission (PUC) on July 5, 2014, and would “eliminate any reasonable possibility of future digester installation in Pennsylvania”.[71]

The work plan encouraged the PUC to withdraw the net metering rulemaking, noting that it was opposed by a “broad coalition of farmers, renewable energy stakeholders, and environmental advocacy organizations and industry trade groups”. The workplan also “encourage[d] single farms and combination farms to build digesters through outreach training and removal of any existing barriers to joint projects…”

Ultimately, the PUC tweaked its proposed regulations, and exempted only certain farmers located in specific parts of the state. The PUC also added barriers to completely eliminate any possibility of joint digester projects between farmers. Both of these actions are directly contrary to the Department’s and CCAC’s workplan, and will suppress the generation of renewable electricity, particularly from Tier I sources under the AEPS Act, thereby increasing GHG emissions statewide. (8)

Response: Thank you for your comments. We concur that opportunities for the implementation of clean renewable energy systems need to be expanded rather than limited.

121. **Comment:** The commenter notes that the PUC did not approve the new regulations until February 11, 2016, a full 13 months after the CCAC’s unanimous adoption of the workplan opposing the regulations. At no point did the PUC ever recognize or acknowledge the CCAC’s unanimous recommendation, despite it being highlighted in formal comments submitted to the PUC and the PUC’s representation on the CCAC and its representatives’ attendance, and vote in favor of the workplan, at the January 6, 2015 meeting.

The next step in the regulatory process is for the Independent Regulatory Review Commission (IRRC) to review the PUC rulemaking and determine its fate at their May 19, 2016 meeting. Numerous comments in the PUC docket,[72] *and the PUC’s own chairperson,*[73] have stated that the net metering portion of the new regulation exceeds PUC’s authority, is contrary to the plain language of the underlying statute, and/or is illegal. Given the importance of encouraging, not suppressing the generation of renewable energy in the Commonwealth, the commenter strongly recommends that the Department and/or Governor’s Office submit comments to the IRRC, at least 48 hours before their May 19th meeting, opposing this rulemaking. (8)

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[71] See Appendix B of the draft 2015 Update, *CCAC Work Plan 13: Manure Digesters*, 248-257 http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-110839/DRAFT%202015%20Climate%20Change%20Action%20Plan%20Update.pdf .

[72] PA PUC, *Proposed Rulemaking – Alternative Energy Portfolio Standards (AEPS) Act Regulations*, Docket No. L-2014-2404361 (filed Feb. 6, 2014) http://www.puc.state.pa.us/about_puc/consolidated_case_view.aspx?Docket=L-2014-2404361.

[73] Chairman Gladys M. Brown, Comment to PA PUC, *Proposed Rulemaking – Alternative Energy Portfolio Standards (AEPS) Act Regulations*, Docket No. L-2014-2404361 (filed Feb. 11, 2016) http://www.puc.state.pa.us/pcdocs/1414665.pdf.

Response: Thank you for your support and comments. The DEP does, and will continue to, work with and comment on PUC actions and with the IRRC on issues affecting the commonwealth's environment and the protection of our land, air and water resources**.**

Waste

122. Comment: The Plan fails to take into account coal ash. Coal ash is a toxic coal combustion waste product created by coal-fired power plants. Coal ash "contains contaminants like mercury, cadmium and arsenic. Without proper management, these contaminants can pollute waterways, groundwater, drinking water, and the air."[74] Coal ash is the "second largest industrial waste stream in the U.S."[75] It is important to recognize that if we invest in and increase the use of renewable energy, this would decrease coal combustion waste from coal-fired power plants that spans acres, buries streams, destroys wildlife habitat, and pollutes our air and water in perpetuity. Pennsylvania already has the distinction of being home to Little Blue Run, the largest coal ash pond in the United States, spanning 1,700 acres and visible from space, located in Beaver County.[76] The fact that it is unclear whether and how land can be reclaimed to a safe, productive use in the future once it has been used as a coal ash landfill should provide sufficient encouragement to the state to reduce the amount of these sites. Looking into the future, we should be focused on preserving the state's natural resources, like land, soil and forests, for safe use and enjoyment. (4)

Response: The Department acknowledges the impact of coal ash in many environmental areas. Coal ash and other forms of pollution by-products formed by fossil fuel combustion are fully considered by the Department.

123. Comment: Nationally, landfilling represents a small percentage of GHG emissions, and this holds true for Pennsylvania also. In fact, as shown in Table 3.8.1 of the Climate Plan, landfills had a net reduction on the total statewide GHG emissions by approximately 0.415 MMTCO2e.[77] In fact, the forestry sector and the landfill sub-sector are the only source types identified in the entire statewide emission inventory that have the overall effect of reducing GHG emissions statewide. (8)

Response: The Department acknowledges that the landfill sub-sector has an overall effect of reducing GHG emissions.

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[74] U.S. Envtl. Protection Agency, *Coal Ash Basics*, https://www.epa.gov/coalash/coal-ash-basics (last updated Jan. 15, 2016).

[75] Earthjustice, *Coal Ash Contaminated Sites & Hazard Dams*, http://earthjustice.org/features/mapcoal-ash (last visited March 20, 2016).

[76] Kristen Lombardi, *One town's recurring coal ash nightmare: Little Blue Run is anything but: WouldFederal regulation help?*, Center for Public Integrity (Nov. 17, 2010), http://www.publicintegrity.org/2010/11/17/2312/one-town-s-recurring-coal-ash-nightmare.

[77] *See* Climate Plan, tables 3.8.1to *Chapter 3: Inventory and Projections*, 33, http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-110839/DRAFT%202015%20Climate%20Change%20Action%20Plan%20Update.pdf.

124. Comment: One of the reasons driving the positive impact of landfills on climate change is the Commonwealth's historical leadership in the beneficial use of landfill gas. Pennsylvania's landfills were early adopters of technology to use landfill gas to produce renewable energy (a Tier I resource under the Alternative Energy Portfolio Standards Act) and Pennsylvania has the second highest number of landfill gas beneficial use projects in the country. In fact, as the Climate Plan notes, the White House's recent *Climate Action Plan, Strategy to Reduce Methane Emissions* cited a Pennsylvania landfill as the national case study on how to reduce GHG emissions from landfills. The commenter notes that landfills in other states have made significant strides in reducing their GHG emissions and installing renewable energy projects powered by landfill gas and that as a whole, no industry has had a greater reduction in GHG emissions over the last 20 years than landfills. (8)

Response: The Department acknowledges that converting landfill gas to energy helps reduce greenhouse gas emissions. Several landfill gas to energy plants are currently in operation within Pennsylvania.

125. Comment: The commenter believes the contributions of landfills should be more clearly and explicitly noted in the Climate Plan. (8)

Response: The Department appreciates the comment and feels the contributions of landfills in greenhouse gas emission reduction have been clearly noted in the Update.

126. Comment: As set forth in Chapter 3.8, Inventory and Projections, Waste Management of the draft 2015 Update, the total contribution to the Commonwealth's GHG emission profile from all waste related activities—disposal of MSW in landfills, combustion of MSW in waste-to-energy incinerators, and emissions from the processing of wastewater from wastewater treatment plants (WWTP)—was less than 1.5% of the statewide inventory of GHG emissions, including forestry sinks. Excluding the WWTP sector, municipal solid waste activities accounted for 0.75% of statewide emissions on the consumption basis, and just 0.66% on the generation basis. MSW disposal, whether landfilling or combustion, accounts for a very small percentage of the Commonwealth's GHG emissions.

However, a closer examination of the data contained in Table 3.8.1, shows that landfills *reduced total statewide GHG emissions* by approximately 415,000 metric tons annually on a CO2 eq. basis. The 1.913 million metric tons CO2 eq. emissions attributed to the solid waste disposal industry are comprised of 2.328 million metric tons CO2 eq. from the state's six waste-to-energy combustion facilities and -0.415 mmtCO2eq from landfills.[78] In fact, the forestry sector and the landfill sub-sector are the *only* source types identified in the entire statewide emission inventory that have the overall effect of reducing GHG emissions statewide. (14)

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[78] *See* draft 2015 Update, tables 3.8.2 and 3.8.4 to *Chapter 3: Inventory and Projections*, 33-34, http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-110839/DRAFT%202015%20Climate%20Change%20Action%20Plan%20Update.pdf.

Response: The Department appreciates the comment, agrees with the statement that a small percentage of the Commonwealth's GHG emissions are a result of municipal solid waste disposal and acknowledges that the landfill sub-sector has an overall effect of reducing GHG emissions.

127. Comment: One of the reasons driving the positive impact of landfills on climate change is the Commonwealth's historical leadership in the beneficial use of landfill gas. Pennsylvania's landfills were early adopters of technology to use landfill gas to produce renewable energy (a Tier I resource under the Alternative Energy Portfolio Standards Act ("AEPS Act")) and until recently, Pennsylvania stood alone as second in the country (behind California) in the number of operating landfill gas beneficial use projects. In fact, as the draft 2015 Update notes, the White House's recent *Climate Action Plan, Strategy to Reduce Methane Emissions* cited a Pennsylvania landfill as the national case study on how to reduce GHG emissions from landfills. While the commenter recognizes and appreciates that the emission data in table 3.8.1 of the draft 2015 Update correctly identifies Pennsylvania's landfills as overall carbon emission offset, this is a fact that the commenter believes should be more clearly and explicitly noted in the discussion section of Chapter 3.[79] (14)

Response: The Department appreciates the comment, is pleased to be a national model and feels the contributions of landfills in greenhouse gas emission reduction have been clearly noted in the Update, particularly in section 3.8 of Chapter three in the Update.

128. Comment: The *Increased Recycling Initiative* Workplan ("Recycling Workplan") is the perfect example as to the importance of the draft 2015 Update re-affirming the importance and continued validity of the other workplans that were included in the 2013 Update. The Recycling Workplan scored very high with the CCAC members for feasibility and emission reductions, and was seriously considered for further analysis as part of the draft 2015 Update. However, the Recycling Workplan already included detailed implementation steps—the specific activity that was to occur in preparation for the draft 2015 Update, so the CCAC removed it from the list of workplans recommended for more detailed development. (14)

Response: The Department acknowledges the comment and feels the process for selecting the work plans to be included in the 2015 Update is described in the 2015 Climate Change Action Plan Update. All workplans included in the 2013 Climate Change Action Plan Update continue to have the support of the Department.

129. Comment: Over the last several years, recycling operations have been subject to unprecedented economic pressures. The primary cause of this economic pressure is low commodity prices due to decreased demand for feedstocks, including recycled materials, caused by the global economic slowdown. Many recycled materials are selling for 50% or

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[79] The 2013 Update included a detailed discussion of the GHG emission performance of Pennsylvania's landfills, and PWIA believes the 2013 Update's Appendix, pages 46-53, would be a valuable resource in preparation of the additional discussion we are recommending.

less of their prices just 5 years ago. This trend has been discussed extensively in the popular press, including recent articles in the New York Times,[80] Washington Post,[81] CNBC,[82] and CBS.[83] This topic was discussed extensively at the January 21, 2016 Department's Solid Waste Advisory Committee meeting, including a detailed presentation from Robert E. Anderson, ReCommunity Regional Business Development Manager, entitled, *The Perfect Storm – Economic Impact in the Recycling Industry*.[84]

Recycling reduces GHG emissions. The Recycling Work plan documents several million tons of GHG emission reductions that can be easily achieved through a combination of discrete, specific implementation steps outlined in the work plan. These reductions can be achieved in a cost-effective manner; the work plan documents that the reductions would have a net "negative cost" (i.e. a net savings) because the economic savings exceed the economic costs. Similarly, the macroeconomic analysis included in Chapter 5 of the 2013 Update calculated a net economic benefit of $90 million (net value, 2013 dollars) to the citizens and businesses of the Commonwealth from implementation of this work plan. (14)

Response: The Department appreciates the comment and the information provided on the Recycling work plan from the 2013 Update. All the work plans included in the 2013 Climate Change Action Plan Update continue to have the support of the Department.

130. Comment: Collectively, the implementation steps included in the workplan address all of the various barriers to increasing the recycling rate, including economics, consumer behaviors, existing structural/regulatory impediments, and expansion of recycling availability to underserved areas such as public gathering places. (14)

Response: The Department appreciates the comment and the information provided on the Recycling workplan from the 2013 Update. All the work plans included in the 2013 Climate Change Action Plan Update continue to have the support of the Department.

131. Comment: The commenter urges the Department to:

- Restate its support for the Recycling Workplan in the draft 2015 Update;
- Take affirmative steps, as set forth in the workplan, to begin its implementation forthwith; and

[80] David Gelles, *Skid in Oil Prices Pulls the Recycling Industry Down With It*, N.Y. TIMES (Feb. 12, 2016), www.nytimes.com/2016/02/13/business/energy-environment/skid-in-oil-prices-pulls-the-recycling-industry-down-with-it.html?_r=0.
[81] Aaron C. Davis, *American recycling is stalling, and the big blue bin is one reason why*, WASHINGTON POST (Jun. 20, 2015), https://www.washingtonpost.com/local/dc-politics/american-recyling-is-stalling-and-the-big-blue-bin-is-one-reason-why/2015/06/20/914735e4-1610-11e5-9ddc-e3353542100c_story.html.
[82] Jeff Daniels, *Why recycling business is feeling so discarded these days*, CNBC (Mar. 9, 2016), www.cnbc.com/2016/03/09/why-recycling-business-is-feeling-so-discarded-these-days.html.
[83] Jonathan Berr, *Why recycling economics are in the trash bin*, CBS NEWS MONEYWATCH (Apr. 7, 2015), www.cbsnews.com/news/why-recycling-economics-are-in-the-trash-bin/.
[84] Robert E. Anderson, *The Perfect Storm – Economic Impact in the Recycling Industry* (Jan. 21, 2016) http://files.dep.state.pa.us/PublicParticipation/Advisory%20Committees/AdvCommPortalFiles/SWAC/Pefect%20Storm.pdf.

- Communicate directly with other state agencies, legislators, the Governor's Office and other relevant stakeholders regarding specific actions each group can take to implement this workplan. (14)

Response: The Department acknowledges the comment and feels the process for selecting the work plans to be included is described in the 2015 Climate Change Action Plan Update. All work plans included in the 2013 Climate Change Action Plan Update continue to have the support of the Department.

132. Comment: Municipal waste is a resource which can be used to generate renewable energy. Landfill gas is generated from the biodegradation of waste in landfills, collected, and can be used to produce electricity, processed into a renewable substitute for natural gas, processed into a compressed natural gas substitute for use as a renewable vehicle fuel, or used as a medium-BTU renewable fuel in boilers and similar devices. As discussed as part of our Comment #2 and referenced in the draft 2015 Update, the Commonwealth's landfills are an overall carbon emission sink due to the high utilization rate for beneficial use of landfill gas. (14)

Response: The Department acknowledges that converting landfill gas to energy helps reduce greenhouse gas emissions. There are a number of landfill gas to energy facility that are currently operating in Pennsylvania, helping to reduce greenhouse gas emissions.

133. Comment: The Beneficial Use of Municipal Solid Waste workplan ("Beneficial Use Workplan") contained in the 2013 Update documented seven existing barriers to increasing the utilization rate of landfill gas. The Beneficial Use Workplan also recommended specific actions and detailed implementation steps to increase the utilization rate of landfill gas. Unfortunately, none of these recommended actions or implementation steps have occurred in the intervening years, and Pennsylvania's national ranking in the number of operating beneficial use projects for landfill gas has slipped. (14)

Response: The Department appreciates the comment and continues to support the Beneficial Use of Municipal Solid Waste workplan and all other work plans from the 2013 Climate Change Action Plan Update.

134. Comment: The commenter urges the Department to:

- Restate its support for the Beneficial Use Workplan in the draft 2015 Update;
- Take affirmative steps, as set forth in the workplan, to begin its implementation forthwith; and
- Communicate directly with other state agencies, legislators, the Governor's Office and other relevant stakeholders regarding specific actions each group can take to implement this workplan. (14)

Response: The Department appreciates the comment and continues to support the Beneficial Use of Municipal Solid Waste workplan and all other work plans from the 2013 Climate Change Action Plan Update.

Macroeconomic Analysis

135. Comment: The results of the Center for Climate Strategies' macroeconomic analysis dispel the myth that climate protection is at odds with economic goals. While not all actions are ranked equally, most recommendations result in increased household and individual welfare. (5)

Response: The Department appreciates the comment and agrees that economic growth and greenhouse gas emission reductions can occur simultaneously. The Department values the positive results obtained during the macroeconomic analysis.

Climate Change Mitigation Needs

136. Comment: We should not rely on Carbon Capture and Sequestration ("CCS") and must focus on renewable sources. We are concerned about the reliability and environmental impacts of the methods the Plan supports for CCS. For example, the Plan states that "[o]ne established market for Carbon Dioxide is enhanced oil recovery ("EOR"), which involves flooding oil reservoirs with injected CO2 to displace oil contained within." Plan at 139. There needs to be further studies of the environmental impacts of this method before it is seriously considered as a viable, feasible option for Pennsylvania. The amount of CO2 leakage caused by CO2 escaping during the injection process should also be considered more comprehensively. Additionally, there is no guarantee that the CO2 will remain sequestered permanently. A study conducted by researchers at the Massachusetts Institute of Technology and partly funded by the U.S. Department of Energy found that most of the CO2 injected into the Earth escapes back into the atmosphere.[85] EOR is also an expensive technique and EOR projects have been cancelled in the past because the "associated costs and low returns...are unable to offset the extra costs."[86] (4)

Response: The Department acknowledges the comment on the use of CCS and EOR technology in Pennsylvania. The concept of producing far less carbon from combusting fossil fuels is by far the better solution. However, the transition to complete renewable sources of electricity cannot be accomplished for possibly a couple of decades. In that interim period technology such as CCS and EOR need to be explored to reduce the amount of carbon released into the atmosphere as a result of combusting fossil fuels for electricity generation until Pennsylvania's electricity needs can be met by complete renewable sources.

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[85] Jennifer Chu, *MIT study challenges the feasibility of carbon capture and storage*, PennEnergy (Jan. 30, 2015), http://www.pennenergy.com/articles/pennenergy/2015/01/mit-study-challengesfeasibility-of-carbon-capture-and-storage.html.

[86] Emily Rochon ET AL., *False Hope: Why Carbon Capture and Storage Won't Save the Climate*, Greenpeace International 28 (2008), www.greenpeace.org/international/Global/international/planet-2/report/2008/5/false-hope.pdf.

137. Comment: Another CCS method the Plan discusses is enhanced coal bed methane recovery. Plan at 141. We are apprehensive about this approach considering its potential to affect mine land remediation projects and result in large accidental releases of methane. The future environmental impacts of this method are unknown; more studies must be conducted to determine the geologic, hydrologic, and ecological consequences of this method. The Plan only cites to one study that was conducted in New Mexico, which is vastly different in terms of geology, hydrology, and ecology from Pennsylvania. It is incorrect to assume that the results of this method in New Mexico will be the same as the results if the method is used in Pennsylvania. Furthermore, this method could result in methane leakage to the surface. (4)

Response: The Department acknowledges the comment on the use of coal bed methane recovery technology in Pennsylvania. The study cited in the 2015 Update is not intended to project the results of what this technology will do in Pennsylvania, but rather as an example of technologies that are available to mitigate carbon emissions.

138. Comment: We cannot rely on CCS techniques as a permanent solution. The Plan even expresses doubt about the reliability of these techniques stating, "[c]arbon capture refers to the separation and capture of CO2 from emissions point sources or the atmosphere and the recovery of a concentrated stream of that CO2 that can be feasibly stored, sequestered or converted in such a way as to mitigate its impact as a greenhouse gas. This means stripping the carbon out of the fuel either before or after it is burnt, *and burying it in the hope that it will stay where it's put...*" Plan at 136 (emphasis added). There is no guarantee that these CSS techniques will be a permanent solution and we should not continue producing massive amounts of CO2 with the hope of relying on these techniques to sequester it. Instead, we should invest in renewable energy technology and storage so we produce far less CO2 emissions in the first place. (4)

Response: The Department acknowledges the comment on the use of Carbon Capture and Sequestration (CCS) technology in Pennsylvania. The concept of producing far less carbon from fossil fuels is by far the better solution. However, the transition to complete renewable sources of electricity cannot be accomplished for possibly a couple of decades. In that interim period technology such as CCS needs to be explored to reduce the amount of carbon released into the atmosphere as a result of combusting fossil fuels for electricity generation.

139. Comment: While efforts to develop CCS should not draw attention away from a long-term goal of developing less carbon-intensive electricity sources, by most accounts we will need to utilize coal and natural gas for at least the next two decades to meet a portion of our electricity needs. Capturing the carbon from the burning of these fuels is imperative. CCS should be seen as a bridge to achieving a renewable energy future. We encourage the state to tap into the research and expertise at Pennsylvania based institutions such as Carnegie Mellon University and the National Energy Technology Lab in southwestern Pennsylvania to determine how CCS best fits into an overall fuel mix. (5)

Response: The Department agrees with the commenter on the importance of taping into new research and technology to develop less carbon intensive electricity sources and the use of CCS technology and others as a bridge to achieving a renewable energy future.

Legislative Recommendations

140. Comment: We support all of the legislative recommendations in the Plan. In particular, we support the following legislative recommendations: (1) Explore Increasing the Alternative Energy Portfolio Standard; (2) Reinvest in Rooftop Solar; (3) Improve the Act 129 Program; (4) Create a Demand Side Management of Natural Gas Program; (5) Adopt the Latest Energy Codes; (6) Require Change of Ownership Energy Use Disclosure; (7) Continue to Invest in Programs such as "Keystone Help"; (8) Adopt the International Green Code Consortium; (9) Provide Additional Resources for Manufacturing Energy Technical Assistance; (10) Create a Pennsylvania PACE Program and; (11) Expand Funding for TreeVitalize. (4)

Response: Thank you for your support and comments. The Legislative Recommendations of the CCAP (Climate Change Action Plan) have been crafted to work hand-in-hand with existing legislation, recommended action plans and all sectors to provide Pennsylvania with a comprehensive set of actions to reduce the commonwealth's climate impacts and improve our environmental, economic and physical health.

141. Comment: Finally, we strongly support the adoption of community solar enabling legislation to allow for full development of our state's solar resources. This legislation would align well with existing solarize campaigns and the recommendation to create a solar exchange. (5)

Response: Thank you for your support and comments. The Legislative Recommendations of the CCAP (Climate Change Action Plan) have been crafted to work hand-in-hand with existing legislation, recommended action plans and all sectors to provide Pennsylvania with a comprehensive set of actions to reduce the commonwealth's climate impacts and improve our environmental, economic and physical health.

142. Comment: The commenter has serious concerns with the legislative recommendations proposed by DEP to expand the Tier 1 mandates of the Pennsylvania Alternative Energy Portfolio Standards Act, as well as funneling additional taxpayer dollars to the PA Sunshine program. We encourage the Commonwealth to let market conditions dictate the energy portfolio of the Commonwealth, which is in the interest of not only Pennsylvania ratepayers but also the long-term success of the energy generation industry. We support governmental policies that encourage an even playing field among Pennsylvania's diverse and abundant energy resources. (7)

Response: The Department acknowledges the comment and believes that increasing the amount of electrical energy provided through Tier 1 Alternative Energy Portfolio sources is a key component of reducing Pennsylvania's climate impacts.

143. Comment: The commenter understands that the General Assembly is considering several bills that could restore net metering to sources of biologically derived methane gas, including farm digesters and landfills. The commenter recommends that DEP review and evaluate those bills to determine if it should recommend passage of them in the Climate Plan's

Legislation section. The commenter further recommends that the DEP alert senior policy personnel in Governor Wolf's administration to this issue and the importance of combatting climate change. (8)

Response: The Department appreciates these comments and will continue to review and evaluate pending legislation regarding potential climate impacts and respond accordingly.

144. **Comment:** The Plan makes a legislative recommendation associated with energy use disclosure at time of property sale. We believe that this recommendation is a positive step in promoting energy efficiency. However, we suggest that the Committee also consider building a programmatic approach and work plan to supplement the policy recommendation and encourage the recognition of energy efficient features in property values. (12)

Response: The Department appreciates the comment and will strive to continue improving upon the work of each successive Climate Change Action Plan.

145. **Comment:** Pennsylvania has many real estate Multi-Listing Services (MLS), each serving either a regional or local real estate market. These listing services are the conduits by which property features are assessed and assigned a value based on comparable sales. For instance, a new property listing in a neighborhood is valued based on a comparable property in the same neighborhood with similar features. Some MLS organizations in Pennsylvania have taken the step of "greening" their service to include information on energy consumption, energy efficient features, and other "green" attributes. Comprehensive efforts sponsored by the National Association of Realtors (NAR) are underway to increase adoption of this practice.[87] We suggest including in the plan a recommendation to convene stakeholders involved in this effort and encourage MLS updates that recognize energy efficiency. Colorado engaged in a similar activity in 2012 with great success. See documentation related to that effort here: https://www.naseo.org/Data/Sites/1/documents/committees/buildings/calls/2013-06-13-colorado.pdf. (12)

Response: The Department appreciates the comment and will review the provided documentation to evaluate potential applicability toward improving Pennsylvania's CCAP (Climate Change Action Plan).

146. **Comment:** Given the biodiesel greenhouse gas reduction promise of ultra-low sulfur heating oil blended with biodiesel, there is no climate change policy reason for switching from heating oil to natural gas. (13)

Response: The Department acknowledges the comment. The vast majority (over 96%) of CO2 reductions attributable to CCAC Work Plan 5: Heating Oil Conservation and Fuel Switching are attributable to building envelope conservation and equipment efficiency measures, which are fuel-type agnostic.

[87] http://www.greenthemls.org/

147. Comment: Incentivizing fuel switching from oil to natural gas does not appear to be consumer friendly, economical, or environmentally cleaner and will clearly erode the business strength of over 700 retail operations, and eliminate many of the more than 4,700 jobs in the state's oil heating bioheating industry. (13)

Response: The Department acknowledges the comment. CCAC Work Plan 5: Heating Oil Conservation and Fuel Switching does not purport to eliminate oil heating or the bioheating industry. The work plan advocates improving building performance, equipment efficiency and, where the infrastructure exists and economically viable, switching to a lower impact source fuel.

148. Comment: There appears to be no good public policy reason (consumer economics, future energy price, GHG emissions or criteria pollutant emissions) for the Commonwealth of Pennsylvania to promote fuel switching from heating oil to natural gas. (13)

Response: The Department acknowledges the comment. Both the CCAC workplan evaluation and the macro-economic analysis of CCAC Work Plan 5: Heating Oil Conservation and Fuel Switching indicate environmental and economic benefits arising from implementing the conservation, efficiency and alternative fuel use measures as outlined in the work plan.

149. Comment: However, public policies that encourage upgrading older, inefficient oil-fired and natural gas boilers and furnaces, as well as encouraging the use of ULS HO and biodiesels will save energy, reduce cost, reduce pollution and increase jobs. (13)

Response: The Department appreciates the comment and concurs that upgrading older, inefficient combustion heating appliances (such as boilers, furnaces and hot water heaters) with modern, more efficient equipment in conjunction with improving building envelope performance (by air-sealing and insulating), reducing standby losses (such as using instantaneous, demand-type domestic hot water heaters), and using lower-emission and less environmentally impactful source energy or fuels will save energy, reduce cost, reduce pollution and increase jobs in Pennsylvania.

150. Comment: It is the commenter's understanding that several bills have been introduced in the General Assembly that would restore the ability of sources using biologically derived methane gas, including farm digesters and landfills, to participate in the net metering program at the levels established in the AEPS Act if final promulgation of the PUC rulemaking referenced in our comment #6 actually occurs. The commenter encourages the Department to review and evaluate those bills to determine if the Department should be recommending their passage in the draft 2015 Update's Legislation section. (14)

Response: The Department appreciates the comment and will continue to review, evaluate and respond accordingly to pending AEPS legislation and associated climate impacts.

151. Comment: The commenter also recommends that the Department, in consultation with the CCAC, evaluate the first eight years of implementation of Act 70 itself and make recommendations for legislative changes specific to that Act. (14)

Response: The Department appreciates the comment and will suggest the CCAC review opportunities for revising Act 70 to improve Pennsylvania's CCAP and potential implementation.

Work Plans

152. Comment: We support capturing methane from coal mines. The Climate Change Advisory Committee created a work plan that "encourages owners/operators of current longwall mines, and of any new gassy underground coal mines that are mined by any method to capture 10% of the estimated total coal mine methane that is released into the atmosphere before, during, and immediately after mining operations." Plan at 51. However, we believe that owners and/or operators of longwall mines and underground coal mines should be required to capture coal mine methane, not simply encouraged to do so. Capturing only 10% of the methane is a fraction of the emissions these operations are responsible for, considering that there was a total of 9.10 MMTCO2e emissions from "underground and surface coal mining, coal processing, and abandoned underground mines" in 2012. Plan at 26. Mine operators should be required to capture at least half of the estimated methane released by their activities, particularly since coal itself also produces more GHG emissions than other sources while generating proportionally less electricity. For example, the Plan states that in 2012, "coal produced over 79% of the GHG emissions while producing 39.0% of the electricity and natural gas produced 20.6% of the GHG emissions while producing 23.75% of the electricity." Plan at 30. DEP should launch a program creating methane regulations for coal mines like the regulations they are developing for oil and gas sites, which require a certain amount of methane capture to offset the incredible methane emissions from these operations.[88] (4)

Response: The Department appreciates the comment and will explore the feasibility of increasing the Methane capture rate at longwall mines. Safety concerns must be addressed when considering increasing the capture rate.

153. Comment: We encourage the state to focus on those measures that have the least cost and greatest certainty of reducing emissions. The Act 129 Energy Efficiency and Conservation Program has been very successful, resulting in a return on investment of $2.40 for every dollar invested. We support the plan's recommendations to expand to a 4th and 5th phase, to remove the 2% spending cap, and to expand to natural gas utilities. Natural gas accounts for 51% of home heating and is currently not addressed by Act 129. (5)

[88] Hess, *supra* note 14.

Response: The Department appreciates the comment and agrees with the success of the Act 129 program. The Department will continue to evaluate the effect of the spending cap and the possibility of expanding the program to Natural gas.

154. Comment: We strongly support the recommendation to adopt and use the most up-to-date building code, as well as an emphasis on combined heat and power and multi-family properties. Several recommendations relate to providing consumers with better information, such as providing information on energy usage compared to neighbors, or instituting an energy disclosure for change in property ownership. (5)

Response: The Department appreciates the support of the commenter and agrees with the commenter on the importance of the various avenues for achieving greenhouse gas reductions, including improved building codes, combined heat and power, and increased access to energy information for property owners.

155. Comment: Finally, while the proposed Re-Light Pennsylvania program has potential to result in short- term electricity savings, we caution program developers to ensure it does not have the unintended effect of reducing potential overall savings. Because lighting typically has the shortest payback of all building efficiency projects, bundling lighting projects with retrofits that may have longer payback periods, such as HVAC replacements or improvements to the building envelope, can improve the overall economics of the building project and lead to a more efficient building, as compared to picking out the lowest-hanging fruit first. For the so- called MUSH sector (municipal, university, schools, and hospital), the existing PennSEF program offers an excellent opportunity to complete comprehensive projects using performance-contracting. (5)

Response: The Department appreciates the comment and agrees that all building efficiency improvements must be considered over the life-time of a building. Several of the energy efficiency financing options provided in the Update will allow building owners to undergo more long term projects beyond lighting.

156. Comment: We support the plan's recommendations to expand to a 4th and 5th phase of Act 129, to continue driving energy efficiency improvements across all customer classes. The Act 129 Energy Efficiency and Conservation Program has been very successful, resulting in a return on investment of $2.97 for every dollar invested over the first phase of the program. That is a conservative figure that does not account for associated water and natural gas savings, nor does it include environmental and public health benefits. (6)

Response: The Department appreciates the comment and agrees with the success of the Act 129 program. The Department will continue to evaluate and explore methods to improve the Act 129 program in the future.

157. Comment: Further, we support the recommendation to remove the 2% spending limit for energy efficiency and conservation programs as it is a barrier for increased consumer engagement. The 2% spending cap is in reality a declining cap because it is based on 2006 numbers and does not take inflation into consideration. It is also quite restrictive and prevents the Electric Distribution Companies (EDCs) from achieving deeper energy efficiency savings through comprehensive measures. Considering that consumers are already tripling their investment, it does not make good business sense to keep such a restrictive spending cap. (6)

Response: The Department appreciates the comment and the information provided on the effect of the 2% spending cap. The Department will continue to examine and evaluate the effect of the spending cap on the Act 129 program.

158. **Comment:** Finally, we very much agree that the program should be expanded to include natural gas utilities. Natural gas accounts for 51% of home heating and is currently not addressed by Act 129. That results in a large amount of energy savings potential that we are failing to capture. By including natural gas, consumers will be able to cut down their heating bills while simultaneously reducing GHG emissions. In the most recent Northeast Energy Efficiency Partnership (NEEP) 2016 Regional Roundup of Energy Efficiency Policy, Pennsylvania is one of two states noted as "lagging," and is the only state in the region to not have an energy efficiency program covering natural gas distribution utilities. (6)

Response: The Department appreciates the comment and the information provided on the most recent Northeast Energy Efficiency Partnership. We will continue to evaluate Act 129 and the potential need to expand it to cover natural gas.

159. **Comment:** We strongly support the recommendation to adopt and use the most up-to-date building code. Up-to-date building codes save Pennsylvanians money through improved energy efficiency. In fact, according to the U.S. Department of Energy, the 2015 Universal Construction Code (UCC) would save consumers between $4,000-$24,000 over the course of a 30-year mortgage (as compared to the 2009 UCC), all while reducing air pollution and greenhouse gas emissions.

By failing to adopt the updated codes during the past two cycles, we have failed to achieve greater energy savings, increase the safety of our citizens, and missed out on GHG emission reductions. If we continue on this road, we are trapping Pennsylvania with outdated infrastructure for many years to come. (6)

Response: The Department appreciates the support of the commenter and the information provided on the potential savings available to a homeowner. The Department agrees with the commenter on the financial savings potential available by adopting up-to-date building codes and that the Commonwealth could achieve greater energy savings and safety to our citizens by updating building codes.

160. **Comment:** While energy efficiency improvements can result in significant monetary savings, the upfront cost can be an insurmountable barrier for many projects. We are greatly encouraged by recommended actions in the plan, including:

- Reinvest in the Keystone HELP program to make it ultimately self-sustaining;
- Incentivize the greater use of energy efficient mortgages;
- Allow for on-bill repayment

- Support enabling legislation and programs for residential property assessed clean energy (PACE)
- Permit residential and small commercial energy savings performance contracting
  We urge the state to consider efforts specifically to market these programs to "middle-income" homeowners, those individuals and families who do not qualify for low-income programs but do not have access to capital or financing to make improvements on their own. (6)

Response: The Department appreciates the comment and agrees that a variety of financing options will help accelerate the number of energy efficiency improvements, especially those that require a larger initial investment.

161. **Comment:** The DEP developed the Recycling Work Plan documenting cost-effective steps to achieving significant GHG reductions through recycling. In essence, these reductions would actually save money. According to Chapter 5 of the 2013 update of the Climate Change Action Plan, if the steps outlined in this work plan were implemented, a net economic benefit to of $90 million would accrue to the citizens and businesses of the Commonwealth.

However, recycling operations around Pennsylvania, just like those across the nation, are struggling under severe economic pressures, mainly due to low commodity prices. This is the result of several factors including decreased demand for feedstocks, strong dollar and low oil prices. As a whole, recycled materials are selling for half what they were selling for just 5 years ago. Pennsylvania's recyclers have not been immune to these factors.

If the Climate Plan included the implementation of the Recycling Work Plan, many of the problems experienced by the recycling industry could be addressed. In addition, the recycling rate would increase, economics would improve, consumer behaviors would support recycling, existing structural/regulatory impediments could be overcome, and recycling availability would expand to underserved areas such as public gathering places.

The commenter urges the DEP to restate its support for the Recycling Work Plan in the Climate Plan and immediately begin implementing the plan. We suggest that DEP also communicate directly with other state agencies, legislators, the Governor's Office and other relevant stakeholders regarding specific actions each group can take to implement this work plan. (8)

Response: The Department appreciates the comment and continues to support the implementation of the Recycling work plan.

162. **Comment:** Landfill gas derived from municipal solid waste is a source of renewable energy. It is generated from the biodegradation of organic fraction of the waste. When collected, it can be used to produce electricity, processed into a renewable substitute for natural gas, processed into a compressed natural gas substitute for use as a renewable vehicle fuel, or used as a medium-BTU renewable fuel in boilers and similar devices.

The 2013 update of the Climate Plan contained a Beneficial Use of Municipal Solid Waste Work Plan that documented seven barriers to increasing the utilization rate of landfill gas. This work plan suggested specific actions and detailed implementation steps to increase beneficial use of landfill gas. To date, these recommendations have not been implemented, stalling its use. To get back on track, the commenter urges the DEP to support this work plan in the Climate Plan and to immediately begin implementing the recommendations. (8)

Response: There are currently several facilities within the Commonwealth that convert landfill gas to energy. The Department appreciates the comment and the information on uses for landfill gases and continues to support the Beneficial Use of Municipal Solid Waste work plan that appeared in the 2013 Climate Change Action Plan Update.

163. Comment: The commenter supports the continuation and expansion of the Act 129 Energy Efficiency Program. Data from Phase I of the plan has shown it returns between two and three dollars in benefits for every dollar spent. This calculation used a very restrictive total resource cost (TRC) test that does not consider health and environmental benefits and, prior to Phase III, does not consider savings in natural gas or water that result from the installation of efficiency measures. We would like to recommend and the Act supports that DEP encourage the Public Utility Commission (PUC) to expand the TRC test to include non-energy benefits such as health, safety, and welfare savings and the social cost of carbon. (10)

Response: The Department appreciates the comment and the information on the non-energy benefits associated with Act 129. The Department has not quantified non-energy savings in any of the work plans included in the 2015 Climate Change Action Plan Update. While many of the work plans do offer other benefits than energy savings, in order to remain consistent within the work plans those benefits are not quantified.

164. Comment: Currently, Act 129 is far from achieving all of the cost-effective energy efficiency measures available. This is, for the most part, the result of an investment cap that limits spending on efficiency to two percent of 2006 utility sales. Because of inflation, this is effectively a declining cap. Act 129 should either be modified to remove this cap, or Pennsylvania should develop additional programs to incentivize efficiency measures beyond Act 129. Further, the cap prevents the Electric Distribution Companies (EDCs) from achieving deeper energy efficiency savings through comprehensive measures which we have advocated for throughout the comment process. Considering that consumers are already tripling their investment, it does not make good business sense to keep such a restrictive spending cap. (10)

Response: The Department appreciates the comment and the information on the effect of the 2% spending cap. The Department will continue to examine and evaluate the effect of the spending cap on the greenhouse gas emission reduction achieved in the Act 129 program.

165. Comment: Finally, we thank DEP for approving of our recommendation that the Act 129 program be expanded to include natural gas utilities. Natural gas accounts for 51% of home heating and the Plan recommends increased fuel switching from oil to natural gas. There is a large amount of energy savings potential that we are failing to capture and the natural gas utilities even noted that during the PUC's alternative ratemaking process. By including natural gas, consumers will be able to cut down their heating bills while simultaneously reducing GHG emissions. In the most recent Northeast Energy Efficiency Partnership (NEEP) 2016 Regional Roundup of Energy Efficiency Policy, Pennsylvania is one of two states noted as "lagging," and is the *only* state in the region to not have an energy efficiency program covering natural gas distribution utilities. (10)

Response: The Department appreciates the comment and the information provided on the most recent Northeast Energy Efficiency Partnership. We will continue to evaluate Act 129 and the potential need to expand it to cover natural gas.

166. Comment: We also strongly support the recommendation to adopt and use the most up-to-date Building code. Up-to-date building codes save Pennsylvanians money through improved energy efficiency. In fact, according to the U.S. Department of Energy, the 2015 Universal Construction Code (UCC) would save consumers between $4,000 - $24,000 over the course of a 30 year mortgage (as compared to the 2009 UCC), all while reducing air pollution and greenhouse gas emissions.

By failing to adopt the updated codes during the past two cycles, we have failed to achieve greater energy savings, increase the safety of our citizens, and missed out on GHG emission reductions. If we continue on this road, we are trapping Pennsylvania with outdated infrastructure for many years to come. (10)

Response: The Department appreciates the support of the commenter and the information provided on the potential savings available to a homeowner. The Department agrees with the commenter on the financial savings potential available by adopting up-to-date building codes and that the Commonwealth could achieve greater energy savings by updating building codes.

167. Comment: We support the recommendations related to providing consumers with better access to energy savings information. While energy disclosure requirements at the time of sale are one option, voluntary opportunities also exist, such as including "green" and energy related fields in the Commonwealth's twenty-some multi-listing services (MLS). It is important to note that home inspectors are not legally certified to tell their clients whether or not elements of their home are compliant with the building codes. (10)

Response: The Department appreciates the support of the commenter and the information concerning energy disclosure requirements. The Department will consider programs to improve the accessibility of energy information during building ownership transfer in the 2018 Climate Change Action Plan Update.

168. Comment: Having improved information allows actors in real estate transactions to make more informed decisions. It also provides an avenue for appraisers to identify comparable properties on which to justify the increased value of a home or building resulting from energy improvements, which today are not recognized in many MLS databases. At its 2015 annual conference, the Council of MLS announced that over half of its members now offer fields including energy-related information, yet this type of information is not yet available statewide in Pennsylvania. Only one MLS (Lehigh Valley) has energy data fields. (10)

Response: The Department appreciates the comment and the information concerning energy-related information being available on MLS. The Department will consider programs to improve the accessibility of energy information during building ownership transfer in the 2018 Climate Change Action Plan Update.

169. Comment: The commenter supports the use of the Home Energy Score (HES), a rating developed by the Department of Energy to serve a similar purpose to the miles-per-gallon rating for a new vehicle, allowing purchasers to make informed decisions about the long-term costs of owning a home. HES uses an easy to interpret 110 scale that weighs the energy efficiency features of a home and would "keep it simple" as DEP recommends. (10)

Response: The Department appreciates the comment and the information provided on the Home Energy Score. The Department will consider including a work plan involving the Home Energy Score when it develops the 2018 Climate Change Action Plan Update.

170. Comment: Similarly, BPI2101 Standard Requirements for a Certificate of Completion for Residential Energy Efficiency Upgrades (published September 2013) provides another way of documenting home energy upgrade improvements in a home. This is a Building Performance Institute standard that is supported by the U.S. DOE's Home Performance with ENERGY STAR program. (10)

Response: The Department appreciates the comment and the information provided for the Building Performance Institute standard. The Department will consider the BPI2101 program will developing the 2018 Climate Change Action Plan Update.

171. Comment: The HES, BPI2101 certificate, and/or other energy-related information about a home can feed into the regional multi-list service (MLS). These measures are important steps to recognizing the value of energy efficiency in the market. As compared to a mandated energy standard, which may be politically unpalatable, these certifications and greening the MLS provide home buyers and sellers with the necessary information to make rational market decisions. (10)

Response: The Department appreciates the comment and agrees that more energy related information available will allow home buyers to make better decisions.

172. Comment: Finally, in 2016, the Northeast Energy Efficiency Partnership (NEEP) led the creation of a database that will enable the automatic population of green data fields in multiple listing services in the northeast when information from rating programs like DOE's Home Energy Score is available. This database is called the Home Energy Labeling Information eXchange (HELIX). Although Pennsylvania is not a participating state in the project, it is worthwhile to monitor this project since its outcomes can be game changing for the industry. (10)

Response: The Department appreciates the comment and the information HELIX database. The Department will continue to monitor the Northeast Energy Efficiency Partnership program and evaluate becoming a participating state.

173. Comment: The urban tree workplan emphasizes energy savings and does not provide adequate attention to the value of well-placed urban trees for clean water benefits and reduced treatment costs. With roughly 80K miles of streams in PA, riparian trees are the connectivity key between urban canopy growth and forest fragmentation control. (11)

Response: The Department appreciates the comment. The other benefits of urban tree growth were discussed by the CCAC and a decision was made to not quantify any other impact than the energy saving potential for the trees.

174. Comment: On the implementation level, we recommend that the CCAC consider taking steps to engage a broader cross-section of topic-appropriate stakeholders in refining and implementing action plans. (12)

Response: The Department appreciates the comment and plans to attempt reaching a broader cross-section of stakeholders going forward when attempting to write and put into action implementation steps for each work plan.

175. Comment: The Advisory Committee has identified a variety of work plans and recommended actions associated with carbon reduction goals. These plans cover a wide breadth of topics from coal-bed methane recovery to energy efficiency finance. Our primary concern associated with these plans is how best to make them actionable. We suggest the DEP and the Advisory Committee target and engage stakeholders already working on these issues who are likely well positioned to follow up on implementation steps by refining and deploying the recommended strategies. (12)

Response: The Department appreciates the comment and is committed to the plans becoming actionable. The Department will continue to engage stakeholders and monitor the progress of the implementation of the initiatives suggested in each work plan.

176. Comment: For example, for Work Plan 7: High-Performance Buildings, there is a set of Pennsylvania-based organizations that are currently executing activities, or have missions directly relevant to this work plan. These organizations include, but are not limited to, the following:

- The Green Building alliance and their associated Pittsburgh and Oakland “2030 District” efforts
- Delaware Valley Green Building Council
- United States Green Building Council of Central Pennsylvania
- Carnegie Mellon University (12)

Response: The Department appreciates the comment and the identification of organizations within the Commonwealth with an interest in the High-Performance Building work plan.

177. Comment: For Work Plan 11: Semi-Truck Freight Transportation, stakeholders who are likely to respond to opportunities for direct engagement include those associated with the Department of Energy's Clean Cities programs in Pennsylvania, including but not limited to:

- Eastern Pennsylvania Alliance for Clean Transportation (EP-ACT)
- Pittsburgh Region Clean Cities
- Pennsylvania Motor Truck Association (PMTA)

This approach may also facilitate opportunities to expand capacity and identify additional work plans. (12)

Response: The Department appreciates the comment and the identification of organizations within the Commonwealth with an interest in the Semi-Truck Freight Transportation work plan.

178. Comment: We recommend that the DEP and CCAC consider a separate work plan focused on the deployment of solar energy, and include strategies for engagement with solar energy industry representatives as well as other knowledgeable stakeholders. (12)

Response: The Department supports the deployment of solar energy and will consider that as a potential workplan for the 2018 update. In the interim, DEP has applied to the U.S. Department of Energy, along with its Project Team members, Citizen's for Pennsylvania's Future (PennFuture) and the Vermont Energy Investment Corporation (VEIC) — for funding to coordinate and conduct a scenario-based stakeholder engagement process to create a cogent statewide Solar Deployment Plan for Pennsylvania, reaching out five years and ten years to facilitate achievement of solar representing 10% of Pennsylvania's electricity sales by 2030. Among the stakeholders are solar energy market actors, consumer and environmental advocates, legislators, utility representatives, the regional transmission organization, academic experts, and regulators.

179. Comment: We commend the DEP for its recent announcement of steps to implement a methane reduction strategy for Pennsylvania. We would challenge the DEP and the CCAC to develop additional methane-related work plans that help Pennsylvania address leaks from oil and gas operations and natural gas transmission and distribution, as well as legacy issues associated with abandoned oil, gas, and coal development sites. (12)

Response: The Department appreciates the comment and is continually evaluating ways to address Methane emissions in all sectors. Recent regulations within the Commonwealth have addressed Methane emissions in the Natural gas collection and transmission sector.

180. Comment: We support inclusion in the Action Plan of forest-related content and a work plan associated with encouraging urban tree-cover through the deployment of DCNR's TreeVitalize program. As the Action Plan correctly identifies, forests play an important role in mitigating the impacts of climate change. However, the Plan may overlook additional opportunities to develop beneficial policies and actions to encourage the cost-effective sequestration of greater amounts of carbon through healthy forests. The Committee should consider building a work plan to address this opportunity and assess the costs and benefits of additional forest related strategies. (12)

Response: The Department appreciates the support of the commenter and will consider additional forest related strategies when developing the 2018 Climate Change Action Plan Update.

181. **Comment:** The recommendations in the Update on switching from heating oil to natural gas do not take into account that many petroleum product distributors and homeowners are now using 5 percent biodiesel/#2 oil blend and some are receiving 20 percent and higher blends. The Update only refers to standard heating oil in its analysis. (13)

Response: The Department acknowledges the comment and agrees that only standard heating oil was used in the analysis for the fuel switching work plan.

182. **Comment:** Current emission information shows a biodiesel blend of less than 20 percent is equivalent to natural gas with respect to carbon dioxide emissions. (13)

Response: The Department acknowledges the comment and was not able to verify this claim.

183. **Comment:** The Update makes its comparison of cost and greenhouse gas emission reductions based on just the fuel emissions alone. When the lifecycle costs and emissions are included, current data shows biofuel blends actually have carbon dioxide emissions lower than natural gas. (13)

Response: The Department acknowledges this comment and was not able to verify this claim.

184. **Comment:** The Update should compare the lifecycle costs to convert home heating oil systems to natural gas, including service lines and a new furnace at a minimum, and compare them to the cost of converting home heating units to use bio blend fuels-- zero cost to homeowners for the same or better greenhouse gas reduction benefits. (13)

Response: The Department acknowledges this comment. As stated previously, the fuel switching work plan compared regular home heating oil and natural gas.

185. **Comment:** The analysis of fuel switching in the Update should also include methane and other greenhouse gas emissions from natural gas production and distribution in its economic analysis. (13)

Response: The Department acknowledges this comment. The economic analysis performed in the fuel switching work plan is consistent with the economic analysis performed in each of the other work plans.

Appendix A – Attached Sources

Sustainable Energy Options

Excerpted from the writings of Mark Z. Jacobson

Rather than debating whether hydraulic fracturing for natural gas development can ever be made safe, we should instead be focusing on how to convert to a truly safe and sustainable energy system, including an unqualified commitment to energy efficiencies and conservation measures. Such a system would be comprised of wind, water, and solar (WWS) power, and would be cheaper than our current fossil fuel system over the long term.

Mark Z. Jacobson, a professor of Civil and Environmental Engineering at Stanford University, has extensively studied the ability to convert to a sustainable, renewable energy system. Excerpts and conclusions from his publications are set out in this paper.

Converting to Sustainable Energy Options Can Power and Benefit Our Nation

Jacobson has developed plans for conversion for individual states, the entire United States, and the world. In his research, Jacobson found that the greatest barriers to this conversion are not "technical or even economic" but are instead "social and political."[1]

> The plans contemplate all new energy powered with WWS by 2020, about 80-85% of existing energy replaced by 2030, and 100% replaced by 2050. Electrification plus modest efficiency measures would reduce each state's end-use power demand by a mean of 37.6% with ~85% of this due to electrification and ~15% due to end-use energy efficiency improvements. Remaining 2050 all-purpose end-use U.S. power demand would be met with ~31% onshore wind, ~19% offshore wind, ~29.6% utility-scale photovoltaics (PV), ~8.6% rooftop PV, ~7.5% concentrated solar power (CSP), ~1.3% geothermal power, ~0.37% wave power, ~0.13% tidal power, and ~2.5% hydroelectric power. Over the U.S. as a whole, converting would provide ~5 million 40-year construction jobs and ~2.4 million 40-year operation jobs for the energy facilities alone, the combination of which would outweigh the ~3.9 million jobs lost. Converting would also eliminate ~62,000 (19,000-116,000) of today's U.S. air pollution premature mortalities/year and avoid ~$510 (158-1,155) billion/year in today's U.S. health costs, equivalent to ~3.15 (0.98-7.13) percent of the 2012 U.S. gross domestic product. Converting would further eliminate ~$730 billion/year in 2050 global warming costs due to U.S. emissions. The health cost savings to the U.S. plus the climate cost savings to the world due to U.S. emission reductions would equal the cost of installing a 100% WWS U.S. system within ~11.0 (7.3-15.4) years.[2]

Conversion to a 100% WWS energy infrastructure would eliminate energy-related air pollution mortality and morbidity, and the associated health costs. For example, a world conversion to a WWS system would eliminate "2.5-3 million annual air pollution deaths."[3]

> The conversion to WWS should stabilize energy prices since fuel costs would be zero. On the other hand, because the fuel costs of fossil fuels rise over time, a WWS infrastructure in 2050 would save the average U.S. consumer $4,500/person/year compared with the 2050 energy cost of fossil fuels to perform the same work. Health and climate cost savings due to WWS would be another $3,100/person/year benefit, giving a total cost savings in 2050 of $7,600/person/year due to WWS.
>
> The new footprint over land required for converting the U.S. to WWS for all purposes is equivalent to ~0.44% of the U.S. land area, mostly in deserts and barren land, before accounting for land gained from eliminating the current energy infrastructure. The spacing area between wind turbines, which can be used for multiple purposes, including farmland, ranchland, grazing land, or open space, is equivalent to 1.7% of U.S. land area. Grid reliability can be maintained in multiple ways. The greatest barriers to a conversion are neither technical nor economic. They are social and political. Thus, effective polices are needed to ensure a

1 Delucchi and Jacobson, 2011. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies, Energy Policy 39, 1170.

2 Jacobson et al., 2014. 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plans for the 50 United States, July 17, 2014 *Draft*, 1.

3 Jacobson, 2012. Why Natural Gas Warms the Earth More but Causes Less Health Damage Than Coal, so is not a Bridge Fuel nor a Benefit to Climate Change, October 31, 2012 *Draft*, 1.

rapid transition."[4]

Jacobson's roadmaps for states to convert to WWS detail anticipated infrastructure changes.

> In brief, [conversion] requires or results in the following changes:
>
> (1) Replace fossil-fuel electric power generators with wind tur- bines, solar photovoltaic (PV) plants and rooftop systems, concentrated solar power (CSP) plants, solar hot water heater systems, geothermal power plants, a few additional hydro-electric power plants, and a small number of wave and tidal devices.
>
> (2) Replace all fossil-fuel combustion for transportation, heating and cooling, and industrial processes with electricity, hydrogen fuel cells, and a limited amount of hydrogen combustion. Battery-electric vehicles (BEVs), hydrogen fuel cell vehicles (HFCVs), and BEV–HFCV hybrids…will replace all combustion-based passenger vehicles, trucks, buses, non-road machines, and locomotives sold...Long-distance trucks will be primarily BEV-HFCV hybrids and HFCVs. Ships…will similarly run on hydrogen fuel cells and electricity. Today, hydrogen-fuel-cell ships, tractors, forklifts, buses, passenger vehicles, and trucks already exist, and electric vehicles, ferries, and non-road machinery also exist. Electricity-powered air- and ground-source heat pumps, heat exchangers, and backup electric resistance heaters will replace natural gas and oil for home heating and air conditioning. Air- and ground-source heat pump water heaters powered by electricity and solar hot water preheaters will provide hot water for homes. High-temperatures for industrial processes will be obtained with electricity and hydrogen combustion. Petroleum products may still be used for lubrication and plastics as necessary, but such products will be produced using WWS power for process energy.
>
> (3) Reduce energy demand beyond the reductions described under (2) through energy efficiency measures. Such measures include retrofitting residential, commercial, institutional, and government buildings with better insulation, improving the energy-out/energy-in efficiency of end uses with more efficient lighting and the use of heat-exchange and filtration systems; increasing public transit and telecommuting, designing future city infrastructure to facilitate greater use of clean-energy transport; and designing new buildings to use solar energy with more daylighting, solar hot water heating, seasonal energy storage, and improved passive solar heating in winter and cooling in summer.
>
> (4) Boost economic activity by implementing the measures above. Increase jobs in the manufacturing and installation industries and in the development of new and more efficient technologies. Reduce social costs by reducing health-related mortality and morbidity and reducing environmental damage to lakes, streams, rivers, forests, buildings, and statues resulting from air and water pollution. Reduce social costs by slowing the increase in global warming and its impacts on coastlines, agriculture, fishing, heat stress, severe weather, and air pollution (which otherwise increases with increasing temperatures). Reduce long-term macroeconomic costs by eliminating exposure to future rises in fossil fuel prices.
>
> (5) The plan anticipates that the fraction of new electric power generators as WWS will increase starting today such that, by 2020, all new generators will be WWS generators. Existing conventional generators will be phased out over time, but by no later than 2050. Similarly, BEVs and HFCVs should be nearly the only new vehicles…sold…by 2020. The growth of electric vehicles will be accompanied by a growth of electric charging stations in residences, commercial parking spaces, service stations, and highway rest stops.
>
> (6) All new heating and cooling technologies installed by 2020 should be WWS technologies and existing technologies should be replaced over time, but by no later than 2050.
>
> (7) To ensure reliability of the electric power grids, several methods should be used to match renewable energy supply with demand and to smooth out the variability of WWS resources. These include (A) combining geographically-dispersed WWS resources as a bundled set of resources rather than as separate resources and using hydroelectric power to fill remaining gaps; (B) using demand-response grid management to shift times of demand to match better with the timing of WWS power supply; (C)

4 Jacobson et al., 2014. 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plans for the 50 United States, July 17, 2014 *Draft*, 1-2.

over- sizing WWS peak generation capacity to minimize the times when available WWS power is less than demand and to provide power to produce heat for air and water and hydrogen for transportation and heating when WWS power exceeds demand; (D) integrating weather forecasts into system operation to reduce reserve requirements; (E) storing energy in thermal storage media, batteries or other storage media at the site of generation or use; and (F) storing energy in electric-vehicle batteries for later extraction (vehicle-to-grid)."[5]

Why Wind, Water and Solar Are the Best Technology Options to Fuel Our Healthy Future

Jacobson's state roadmaps rely on technologies that will reduce air and water pollution and global warming impacts.

> The WWS energy technologies chosen…exist and were ranked the highest among several proposed energy options for addressing pollution and public health, global warming, and energy security (Jacobson, 2009). That analysis used a combination of 11 criteria (carbon dioxide equivalent emissions, air-pollution mortality and morbidity, resource abundance, footprint on the ground, spacing required, water consumption, effects on wildlife, thermal pollution, water, chemical pollution/radioactive waste, energy supply disruption, and normal operating reliability) to evaluate each technology. Mined natural gas and liquid biofuels are excluded from the…plan for the reasons given below.[6]

Natural gas was excluded from Jacobson's analysis

> for several reasons. The mining, transport, and use of conventional natural gas for electric power results in at least 60–80 times more carbon-equivalent emissions and air pollution mortality per unit electric power generated than does wind energy over a 100-year time frame. Over the 10–30 year time frame, natural gas is a greater warming agent relative to all WWS technologies and a danger to the Arctic sea ice due to its leaked methane and black carbon-flaring emissions…Natural gas mining, transport, and use also produce carbon monoxide, ammonia, nitrogen oxides, and organic gases. Although natural gas emits less carbon dioxide per unit electric power than coal, two factors cause natural gas to increase global warming relative to coal: higher methane emissions and less sulfur dioxide emissions per unit energy than coal…[N]atural gas is not a near-term 'low' greenhouse-gas alternative, in absolute terms or relative to coal. Moreover, it does not provide a unique or special path to renewable energy, and as a result, it is not bridge fuel and is not a useful component of a sustainable energy plan.
>
> Rather than use natural gas in the short term, [Jacobson et al.,] propose[s] to move to a WWS-power system immediately, on a worldwide scale, because the Arctic sea ice may disappear in 20–30 years unless global warming is abated (e.g., Pappas, 2012). Reducing sea ice uncovers the low-albedo Arctic Ocean surface, accelerating global warming in a positive feedback. Above a certain temperature, a tipping point is expected to occur, accelerating the loss to complete elimination (Winton, 2006). Once the ice is gone, regenerating it may be difficult because the Arctic Ocean will reach a new stable equilibrium (Winton, 2006). The only potential method of saving the Arctic sea ice is to eliminate emissions of short-lived global warming agents, including methane (from natural gas leakage and anaerobic respiration) and particulate black carbon (from natural gas flaring and diesel, jet fuel, kerosene burning, and biofuel burning)."[7]

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Jacobson, M.Z., 2009. Review of solutions to global warming, air pollution, and energy security. Energy and Environmental Science 2, 148–173, http://dx.doi.org/ 10.1039/b809990c.

Pappas, S., 2012. When Will Arctic Ice Completely Disappear, http://www. livescience.com/23362-arctic-summer-ice-disappearance.html (accessed 17.01.13).

Winton, M., 2006. Does the Arctic sea ice have a tipping point? Geophysical Research Letters 33, L23504, http://dx.doi.org/10.1029/2006GL028017.

Converting to Sustainable Energy Is Feasible

Jacobson has documented that we have the sustainable energy capacity necessary to power the United States.

5 Jacobson et al., 2013. Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight, Energy Policy 57, 586.

6 For reasons why nuclear power and coal with carbon capture are also excluded, see Jacobson and Delucchi (2011).

7 Jacobson et al., 2013. Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight, Energy Policy 57, 586-587.

The United States has more wind, solar, geothermal, and hydroelectric resources than is needed to supply the country's energy for all purposes in 2050. In this section, U.S. wind, solar, geothermal, hydroelectric, tidal, and wave resources are examined.

Wind

…Results suggest that the U.S. mean onshore capacity factor may be 30.5% and offshore, 37.3%. Locations of strong onshore wind resources include the Great Plains, northern parts of the northeast, and many areas in the west. Weak wind regimes include the southeast and the westernmost part of the west coast continent. Strong offshore wind resources occur off the east coast north of South Carolina and the Great Lakes. Very good offshore wind resources also occur offshore the west coast and offshore the southeast and gulf coasts…[T]he 2050 clean-energy plans require 1.7% of U.S. onshore land and 0.88% of U.S. onshore-equivalent land area sited offshore for wind-turbine spacing to power 50% of all-purpose 2050 U.S. energy. The mean capacity factor for onshore wind needed is 35.2% and that for offshore wind is 42.5%. Figure 1 suggests that much more land and ocean areas with these respective capacity factors or higher are available than are needed for the plans.

Solar

…The best solar resources in the U.S. are broadly in the Southwest, followed by the Southeast, the Northwest, then the Northeast. The land area in 2050 required for non-rooftop solar under the plan here is equivalent to ~0.41% of U.S. land area, which is a very small percent of area relative to the area of strong solar resources available in Figure 2 and in other solar resource analyses. As such, we do not believe there is a limitation in solar resources available for implementing the 50 state plans proposed …

Geothermal

The U.S. has significant traditional geothermal resources (volcanos, geysers, and hot springs) as well as heat stored in the ground due to heat conduction from the interior of the Earth and solar radiation absorbed by the ground. In terms of traditional geothermal, the U.S. has an identified resource of 9.057 GW[8] deliverable power distributed over 13 states, undiscovered resources of 30.033 GW deliverable power, and enhanced recovery resources of 517.8 GW deliverable power (USGS, 2008). As of April, 2013, 3.386 GW of geothermal capacity had been installed in the U.S. and another 5.15-5.523 GW was under development (GES, 2013).

States with identified geothermal resources (and the percent of resource available in each state) include Colorado (0.33%), Hawaii (2.0%), Idaho (3.68%), Montana (0.65%), Nevada (15.36%), New Mexico (1.88%), Oregon (5.96%), Utah (2.03%), Washington State (0.25%), Wyoming (0.43%), Alaska (7.47%), Arizona (0.29%), and California (59.67%). All states have the ability to extract heat from the ground for heat pumps. However, such energy would not be used to generate electricity; instead it would be used directly for heat, thereby reducing electric power demand for heat although electricity would still be needed to run heat pumps…

Hydroelectric

Under the plan proposed here, conventional hydro will supply 47.26 GW of delivered power, or 2.46% (Table 1) of U.S. 2050 total end-use power demand for all purposes. Thus, 2010 U.S. plus Canadian delivered hydropower (34.8 GW) already provides 73.6% of the U.S. 2050 delivered hydropower power goal. The plan here calls for very few new hydroelectric dams. Thus, the additional 12.5 GW of delivered hydro would be obtained by increasing the capacity factor of existing dams to an average of 53.1%. Existing dams currently provide less than their maximum capacity due to an oversupply of energy available from other sources and multiple priorities affecting water use…

Tidal

Tidal (or ocean current) is proposed to comprise about 0.13% of U.S. total power in 2050 (Table 1). The U.S. currently has the potential to generate 50.8 GW (445 TWh/yr)[9] of delivered power from tidal streams (Georgia Tech Research Corporation, 2011). States with the great-

8 GW or gigawatt. One GW is equal to one billion watts or 1,000 megawatts (MW).

9 TWh, or terawatt hour. One TW is equal to one trillion watts.

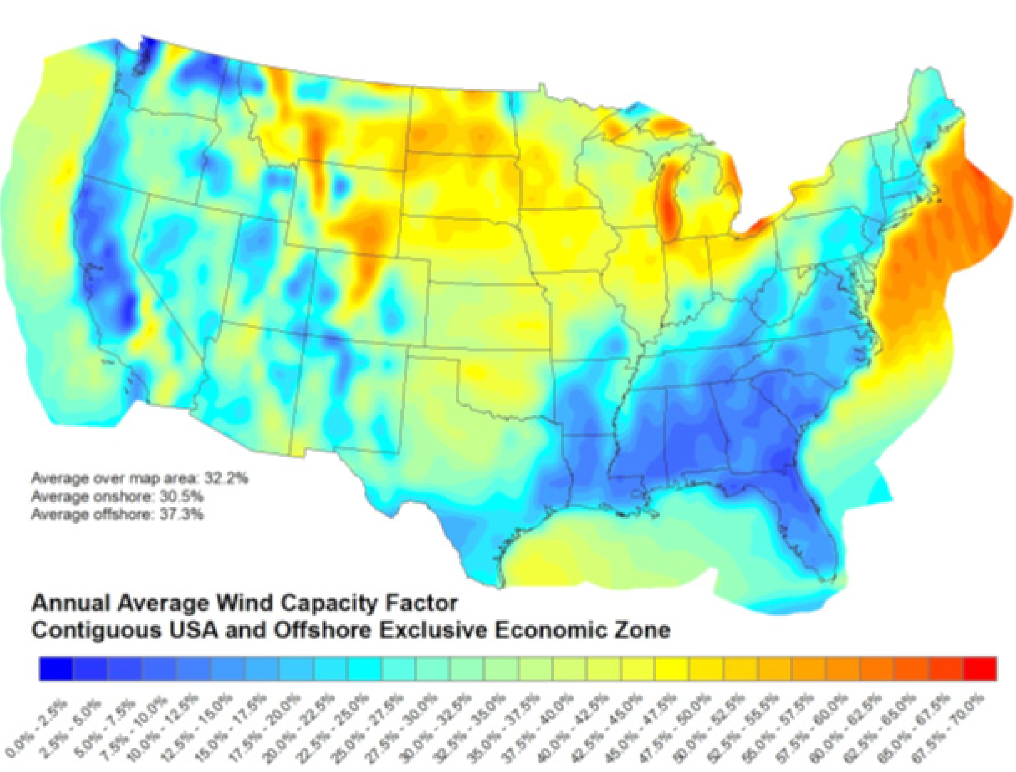

Figure 1. Modeled 2006 annually averaged capacity factor for 5 MW RePower wind turbines (126-m diameter rotor) at 100-m hub height above the topographical surface in the contiguous United States. The model used was GATOR-GCMOM (Jacobson et al., 2007; Jacobson, 2010), which was nested for one year from the global to regional scale with resolution on the regional scale of 0.6 degrees W-E x 0.5 degrees S-N.

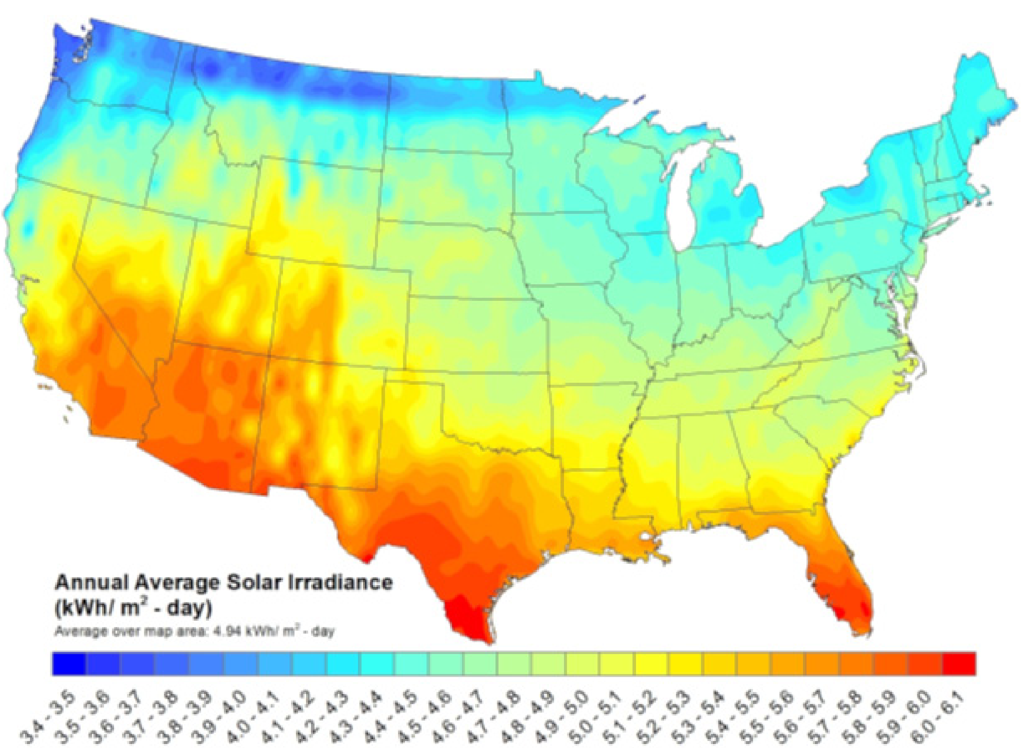

Figure 2. Modeled 2013 annual downward direct plus diffuse solar radiation at the surface (kWh/m$_2$/day) available to photovoltaics in the contiguous United States. The model used was GATOR-GCMOM (Jacobson et al., 2007; Jacobson, 2010), which simulates clouds, aerosols gases, weather, radiation fields, and variations in surface albedo over time. The model was nested from the global to regional scale with resolution on the regional scale relatively coarse (0.6 deg W-E x 0.5 deg S-N).

Energy Technology	Rated power of one plant or device (MW)	Percent of 2050 power Demand met by plant/device	Nameplate capacity of existing plus new plants or devices (MW)	Percent of nameplate capacity already installed 2013	Number of new plants or devices needed for U.S.	Percent of U.S. land area for footprint of new plants / devices[A]	Percent of U.S. land area for spacing of new plants / devices
Onshore wind	5	30.98	1,818,769	3.36	351,547	0.00005	1.7057
Offshore wind	5	18.99	904,726	0.00	180,945	0.00002	0.8779
Wave device	0.75	0.37	33,657	0.00	44,876	0.00026	0.0122
Geothermal plant	100	1.29	28,935	8.32	265	0.00099	0.0000
Hydroelectric plant	1300	2.46	92,816	95.92	4	0.02701	0.0000
Tidal turbine	1	0.13	10,687	0.00	10,687	0.00003	0.0004
Res. roof PV	0.005	4.73	641,416	0.55	127,573,149	0.05208	0.0000
Com/gov roof PV	0.1	3.89	495,593	0.36	4,938,184	0.04032	0.0000
Solar PV plant[B]	50	29.62	2,923,981	0.06	58,444	0.23859	0.0000
Utility CSP plant	100	7.54	833,012	0.00	8,330	0.17275	0.0000
Total		100.00	7,783,592	2.05	0	0.53	2.60
Total new land[C]						0.44	1.71

A Total land area for each state is given in Jacobson, M.Z., G. Bazouin, and M.A. Delucchi, 2014a. Spreadsheets of calculations for this study. http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html.

B The solar PV panels used for this calculation are Sun Power E20 panels. The capacity factors used for residential and commercial/ government rooftop solar production estimates are given in Jacobson et al. (2014a) for each state. For utility solar PV plants, nominal "spacing" between panels is included in the plant footprint area. The capacity factors assumed for utility PV are given in Jacobson et al. (2014a).

C The footprint area requiring new land is equal to the footprint area for new onshore wind, geothermal, hydroelectric, and utility solar PV. Offshore wind, wave and tidal are in water, and so do not require new land. The footprint area for rooftop solar PV does not entail new land because the rooftops already exist and are not used for other purposes (that might be displaced by rooftop PV). Only onshore wind entails new land for spacing area. The other energy sources either are in water or on rooftops, or do not use additional land for spacing. Note that the spacing area for onshore wind can be used for multiple purposes, such as open space, agriculture, grazing, etc.

Table 1. Number, capacity, footprint area, and spacing area of WWS power plants or devices needed to provide the U.S. total annually-averaged end-use power demand for all purposes in 2050, accounting for transmission, distribution, and array losses. Individual tables for each state and their derivation are given in Jacobson et al. (2014a).

…Short- and moderate distance transmission and distribution losses for offshore wind and all other energy sources treated here were assumed to be 5-10%. Since each state's plan is self-contained, extra-long distance transmission was assumed not necessary. However, If it were needed, losses from it would be 1.4-6% per 1000 km plus 1.3-1.8% in the station equipment (Delucchi and Jacobson, 2011).

est potential offshore tidal power include Alaska (47.4 GW), Washington State (683 MW), Maine (675 MW), South Carolina (388 MW), New York (280 MW), Georgia (219 MW), California (204 MW), New Jersey (192 MW), Florida (166 MW), Delaware (165 MW), Virginia (133 MW), Massachusetts (66 MW), North Carolina (66 MW), Oregon (48 MW), Maryland (35 MW), Rhode Island (16 MW), Alabama (7 MW), Texas (6 MW), Louisiana (2 MW). The available power in Maine, for example, is distributed over 15 tidal streams. The present state plans call for extracting just 2.5 GW of delivered power, which would require an installed capacity of 10.7 GW of tidal turbines.

Wave

Wave power is also proposed to comprise 0.37%, or about 7.1 GW, of the U.S. total end-use power demand in 2050 (Table 1). The U.S. has a recoverable delivered power potential (after accounting for array losses) of 135.8 GW (1,190 TWh) along its continental shelf edge (EPRA, 2011). This includes 28.5 GW of recoverable power along the West Coast, 18.3 GW along the East Coast, 6.8 GW along the Gulf of Mexico, 70.8 GW along Alaska's coast, 9.1 GW along Hawaii's coast, and 2.3 GW along Puerto Rico's coast. Thus, all states border the oceans have wave power potential. The available supply is almost 20 times the delivered power needed under this plan."

…Short- and moderate distance transmission and distribution losses for offshore wind and all other energy sources treated here were as-

sumed to be 5-10%. Since each state's plan is self-contained, extra-long distance transmission was assumed not necessary. However, If it were needed, losses from it would be 1.4-6% per 1000 km plus 1.3-1.8% in the station equipment (Delucchi and Jacobson, 2011).[10]

Jacobson's References

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Sustainable Energy is Reliable

Jacobson has determined that WWS can provide the power when and where it is needed.

> An important concern to address in a clean -energy economy is whether electric power demand can be met with WWS supply on a minutely, daily, and seasonal basis…Several studies have examined whether up to 100% penetrations of WWS resources could be used reliably to match power with demand (e.g., Jacobson and Delucchi, 2009; Mason et al., 2010; Hart and Jacobson, 2011, 2012; Connolly et al., 2011; Elliston et al., 2012; NREL (NationalRenewableEnergyLaboratory), 2012; Rasmussen et al., 2012; Budischak et al.,2013). Using hourly load and resource data and accounting for the intermittency of wind and solar, both Hart and Jacobson (2011) and Budischak et al. (2013) found that up to 99.8% of delivered electricity could be produced carbon-free with WWS resources over multiple years…Eliminating remaining carbon emission is challenging but can be accomplished in several ways. These include using demand response and demand management, which will be facilitated by the growth of electric vehicles; oversizing the grid and using the excess power generated to produce district heat through heat pumps and thermal stores and hydrogen for other sectors of the energy economy (e.g. heat for buildings, high-temperature processes, and fuel-cell vehicles); using concentrated solar power storage to provide solar power at night; and storing excess energy at the site of generation with pumped hydroelectric power, compressed air (e.g. in underground caverns or turbine nacelles), flywheels, battery storage packs, or batteries in electric vehicles (Kempton and Tomic, 2005). Oversizing the peak capacity of wind and solar installation to exceed peak inflexible power demand can reduce the time that available WWS power supply is below demand, thereby reducing the need for other measures to meet demand. The additional energy available when WWS generation exceeds demand can be used to produce hydrogen (a storage fuel) by electrolysis for heating processes and transportation and to provide district heating. Hydrogen must be produced in any case as part of the WWS solution. Oversizing and using excess energy for hydrogen and district heating would also eliminate the current practice of shutting down (curtailing) wind and solar resources when they produce more energy than the grid can accommodate. Denmark currently uses excess wind energy for district heating using heat pumps and thermal stores (e.g., Elsman, 2009).[11]

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10 Jacobson et al., 2014. 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plans for the 50 United States, July 17, 2014 *Draft*, 10-17.

11 Jacobson et al., 2013. Examining the feasibility of converting New York State's all-purpose energy infrastructure to one using wind, water, and sunlight, Energy Policy 57, 591.

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Sustainable Energy Is Cost Effecient

The cost of sustainable energy will continue to decrease over time. By comparison, conventional fuel costs are expected to rise over time, making sustainable energy the better near term and long term choice based on cost.

> With a 100% WWS market penetration proposed for 2050, significant cost reductions are expected not only due to anticipated technology improvements and the zero fuel cost of WWS resources, but also due to less expensive manufacturing and streamlined project deployment from increased economies of scale. On the other hand, private electricity costs of conventional fuels are expected to continue to rise.
>
> Costs of onshore wind and hydroelectric power are expected to remain low through 2030. The cost of wind-generated electricity has declined recently due to the rapid decline in turbine prices and improvements in technology leading to increased net capacity factors (e.g. increases in average hub height and rotor diameter). National costs of solar PV are expected to fall to 4.5-10 cents/kWh by 2030, with the low-end reduction for utility-scale solar and the high end for residential. With this expected price reduction, solar PV is expected to be competitive with other energy sources throughout the U.S. by significantly before 2030.
>
> Due to the nascent state of the wave and tidal industries (the first commercial power projects have just now been deployed in the United States), it is difficult to make accurate cost estimates. Roughly 50 different tidal devices are in the proof-of-concept or prototype development stage, but large-scale deployment costs have yet to be demonstrated. Although current wave power-generating technologies appear to be expensive, they might follow a learning curve similar to that of the wind power industry. Industry analyses point toward a target annualized cost of 4-11 U.S. ¢/kWh for wave and 5-7 ¢/kWh for tidal power (Asmus and Gauntlett, 2012), although a greater understanding of costs will become available once systems in the field have been in operation for a few years.
>
> …[M]any future wind and solar farms may be far from population centers, requiring long-distance transmission. For long-distance transmission, high-voltage direct-current (HVDC) lines are used because they result in lower transmission line losses per unit distance than alternating-current (AC) lines (Table 1, footnote). The cost of extra-long-distance HVDC transmission on land (1,200-2,000 km) ranges from 0.3-3 U.S. cents/kWh, with a median estimate of ~1 U.S. cent/kWh (Delucchi and Jacobson, 2011). A system with up to 25% undersea HVDC transmission would increase the additional long-distance transmission cost by less than 20%. Transmission needs and costs can be reduced by considering that decreasing transmission capacity among interconnected wind farms by 20% reduces aggregate power by only 1.6% (Archer and Jacobson, 2007).
>
> … [E]ven with extra-long-distance HVDC transmission, the costs of hydroelectric and wind power are already cost competitive with fossil electricity sources. In fact, a state by-state examination of fractional electricity generation by wind versus cost of electricity by state provides the following results. From January-July 2013, two states (South Dakota and Iowa) generated nearly 28% of their electric power from wind. Nine states generated more than 13% from wind (South Dakota, Iowa, Kansas, Minnesota, North Dakota, Oklahoma, Idaho, Colorado, and Oregon). The tenth state, Texas, generated 9.3% of its electricity from wind (EIA, 2013a). The average increase in residential electricity price from 2003-2013 in the 10 states with the highest fraction of their electricity from wind was 3 ¢/kWh. The price increase during the same period in all other 40 states was 4 ¢/kWh. The price increase in Hawaii during the same period

was 19.9 ¢/kWh. This result suggests that states that invested more in wind saw less of a price increase than states that invested less in wind, contrary to the perception that the addition of an intermittent renewable energy source causes an average increase in electricity price.[12]

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Sustainable Energy Options Avoid Expensive Air Pollution Costs and the Damage it Does to Our Health and Lives

Jacobson has also considered the considerable human health implications of converting to WWS.

The top-down approach to estimate air-pollution mortality in the U.S. The premature human mortality rate in the U.S. due to cardiovascular disease, respiratory disease, and complications from asthma due to air pollution has been estimated conservatively by several sources to be at least 50,000-100,000 per year. In Braga et al. (2000), the U.S. air pollution mortality rate was estimated at about 3% of all deaths. The all-cause death rate in the U.S. is about 833 deaths per 100,000 people and the U.S. population in 2012 was 313.9 million. This suggests a present-day air pollution mortality rate in the U.S. of ~78,000/year. Similarly, from Jacobson (2010), the U.S. death rate due to ozone and particulate matter was calculated with a three-dimensional air pollution-weather model to be 50,000-100,000 per year. These results are consistent with those of McCubbin and Delucchi (1999), who estimated 80,000 to 137,000 due to all anthropogenic air pollution in the U.S. in 1990, when air pollution levels were higher than today.

The bottom-up approach to estimate air-pollution mortality in the U.S. This approach involves combining measured countywide or regional concentrations of particulate matter ($PM_{2.5}$) and ozone (O_3) with a relative risk as a function of concentration and with population by county. From these three pieces of information, low, medium, and high estimates of mortality due to $PM_{2.5}$ and O_3 pollution are calculated with a health-effects equation (e.g., Jacobson, 2010)…The medium values for the U.S. for $PM_{2.5}$ were ~48,000 premature mortalities/yr…and for O_3 were ~14,000 premature mortalities/yr, with a range of 7,000-21,000/yr. Thus, overall, the bottom-up approach gives ~62,000 (19,000-116,000) premature mortalities/year for $PM_{2.5}$ plus O_3. The top-down estimate (50,000–100,000), from Jacobson (2010), falls within the bottom-up range.

…[T]he total social cost [of fossil fuel-based energy] due to air pollution mortality, morbidity, lost productivity, and visibility degradation in the U.S. today is conservatively estimated from the ~62,000 (19,000-116,000) premature mortalities/yr to be $510 (158-1,155) billion/yr (using an average of $8.2 million/mortality for the low and medium numbers of mortalities and $10 million/mortality for the high number). Eliminating these costs today represents a savings equivalent to ~3.15 (0.98-7.13)% of the 2012 U.S. gross domestic product.

Energy-related greenhouse gas emissions from the U.S. cause climate-related damage to the world… Ackerman et al. (2008) estimated global warming damage costs (in 2006 U.S. dollars) to the U.S. alone due to world emissions of greenhouse gases and warming aerosol particles of $271 billion/yr in 2025, $506 billion/yr in 2050, $961 billion/yr in 2075, and $1.9 trillion/yr in 2100. That analysis accounted for severe storm and hurricane damage, real estate loss, energy-sector costs, and water costs. The largest of these costs was water costs. It did not account for increases in mortality and illness due to increased heat stress, influenza, malaria, and air pollution or increases in forest-fire incidence, and as a result it probably underestimated the true cost.

…[C]onverting the U.S. to WWS would avoid $510 (158-1,155) billion/year in air pollution

12 Jacobson et al., 2014. 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plans for the 50 United States, July 17, 2014 *Draft*, 24-27.

health costs to the U.S. and ~$730 billion/yr in global-warming damage costs worldwide by 2050. The U.S.-mean installed capital cost of the electric power system proposed here, weighted by the proposed installed capacity of each generator, is approximately $1.8 million/MW. Thus, for new nameplate capacity, summed over all generators, of 7.63 TW (Table 1), the total capital cost of a U.S. WWS system is ~ $13.7 trillion. As such, the health-cost savings alone to the U.S. due to converting to WWS may equal the installation cost of WWS generators within 27 (12-87) years. The health-cost savings to the U.S. plus the climate-cost savings to the world may equal the generator cost within 11 (7.3-15.4) years.

…[M]odels predict the creation of ~4.95 million 40-year construction jobs and ~2.4 million 40-year operation and maintenance jobs for the WWS generators proposed. The shift to WWS will simultaneously result in the loss of ~3.88 million in the current fossil-based electricity generation, petroleum refining, and uranium production industries in the U.S. Thus, a net of ~3.48 million 40-year jobs will be created in the U.S. The direct and indirect earnings from WWS amount to $271 billion/year during the construction stage and $152 billion/yr for operation. The annual earnings lost from fossil-fuel industries total ~$233 billion/yr giving a net gain in annual earnings of ~$190 billion/yr. These numbers are not meant to be a precise forecast, but rather an indication of the economic effect WWS electricity generation may have on the U.S. The actual job and revenue impacts are subject to various uncertainties associated with progress in technology, projects scale and policies. Overall, the positive socio-economic impacts of WWS resource electricity implementation are expected to exceed significantly the negative impacts."[13]

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A Sustainable Energy Future is Achievable

Sustainable energy to fuel our future is within our grasp. To get the health, environment and economic benefits of sustainable energy and leave behind the damage of shale gas and continued use of fossil fuels, we just need to take the steps to make it happen.

> Manpower, materials, and energy resources do not constrain the development of WWS power; the obstacles to realizing this transformation are primarily social and political, not technological.[14] With clear direction in the form of broad-based policies and relatively small social changes "it may be possible for a 25% conversion in 10-15 years, 85% in 20-30 years, and 100% by 2050."[15]
>
> Least-cost energy system optimization studies and practical implementation considerations will determine the most efficient design and operation of the energy system… Several methods exist to match renewable energy supply with demand and to smooth out the variability of WWS resources" and to reduce costs associated with the transition.[16]

In the United States, approximately 40% of the total annual carbon dioxide emissions are associated with the generation of electricity.[17] Implementation of a WWS energy system will essentially "eliminate the costs related to these emissions such as energy-related global warming; air, soil, and water pollution; and energy insecurity.[18]

13 Jacobson et al., 2014. 100% Wind, Water, Sunlight (WWS) All-Sector Energy Plans for the 50 United States, July 17, 2014 *Draft*, 36.

14 Delucchi and Jacobson, 2011. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies, Energy Policy 39, 1170.

15 Delucchi and Jacobson, 2011. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies, Energy Policy 39, 1179.

16 Jacobson, et al., 2014. A 100% Wind, Water, Solar (WWS) All-Sector Energy Plan for Washington State, July 14, 2014 *Draft*, 44.

17 Hart and Jacobson, 2011, A Monte Carlo approach to generator portfolio planning and carbon emissions assessments of systems with large penetrations of variable renewables, Energy Policy 36, 2278, citing Energy Information Administration. Annual energy outlook 2009, table a18, http://www.eia.doe.gov/oiaf/aeo/pdf/appendixes.pdf; 2009.

18 Jacobson, et al., 2014. A 100% Wind, Water, Solar (WWS) All-Sector Energy Plan for Washington State, July 14, 2014 *Draft*, 46.

Cornell University

Statement of Robert W. Howarth, Ph.D.

House Democratic Policy Committee Hearing
"Should Pennsylvania Incentivize Natural Gas?"

March 21, 2016

Thank you for the opportunity to address you today. My name is Robert Howarth. I am an Earth systems scientist with a Ph.D. jointly from MIT and the Woods Hole Oceanographic Institution. I have been a tenured member of the faculty of Cornell University since 1985 and have held an endowed position as the *David R. Atkinson Professor of Ecology & Environmental Biology* at Cornell since 1993. I also serve as an Adjunct Senior Scientist at the Ecosystems Center in Woods Hole, MA. I am the Editor in Chief of the academic journal *Limnology & Oceanography* and previously served as Editor in Chief of the academic journal *Biogeochemistry* for over 20 years. I have published more than 200 peer-reviewed research articles and am the editor or author of 8 scholarly books.

I have conducted research and taught on several aspects of global change for over 35 years. In 2011, I published the first ever peer-reviewed analysis of the greenhouse gas footprint of shale gas. Since then, I have published an additional 6 peer-reviewed papers as well as a background report for the US Climate Change assessment on the topic of greenhouse gas emissions from the development and use of shale gas. I also have published 2 peer-reviewed articles laying out plans for the states of New York and California to become free of all fossil fuel use. I served as a delegate to the United Nations COP21 negotiations on climate change in Paris this past December, and while there participated in several discussions on the role of methane and shale gas in climate change. My most recent peer-reviewed publication on the role of methane emissions in the greenhouse gas footprint of shale gas (Howarth 2015), published in October of last year, is appended at the end of this testimony. The statements and conclusions I draw here are all well documented in that paper.

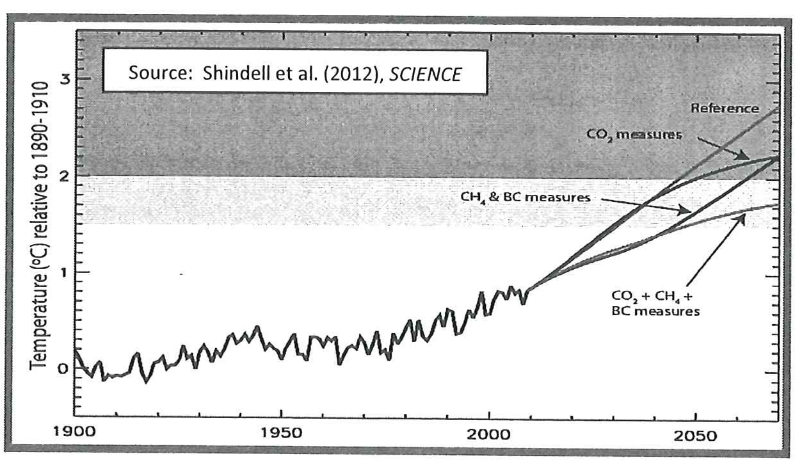
In the past, industry as well as many politicians promoted natural gas, including shale gas, as a "bridge fuel" that would allow society to continue to use fossil fuels for the next few decades while reducing carbon dioxide emissions. While less carbon dioxide is produced while burning natural gas than is true for coal for a given amount of energy, methane emissions from the use of natural gas are far higher than from coal. Methane is a potent greenhouse gas, one that is more than 100 times as effective as carbon dioxide in trapping heat in the atmosphere for the decade or so following emission

when both gases remain in the atmosphere. Using the best available evidence on rates of methane emissions, shale gas is seen to have a greenhouse gas footprint that is 2.5-fold greater than that of coal when compared over a 20-year averaged period following the burning of the two fuels. Conventional natural gas also has a larger footprint than does coal, although only slightly so.

Before the shale gas revolution began in earnest in 2009, the scientific literature ignored methane emissions from this fuel. We first suggested in our 2011 paper that methane emissions from shale gas may be far larger than from conventional natural gas. The available evidence at that time was limited, and so one of our major conclusions was to point for the need for better studies. Our suggestion of high methane emissions was hotly contested by industry and by some academics, but extensive subsequent research has indicated that indeed the methane emissions are far higher than for shale gas. This is particularly evident in the study by Schneising and colleagues published in 2014 that used satellite data, comparing methane levels in the atmosphere for a few years before the shale gas revolution (2006-2008) with levels in the first few years after heavy shale gas and oil development began (200-2011). During this time, the methane concentration in the atmosphere increased globally, and the satellite data indicate the shale gas and shale oil plays of the United States are the likely source of most if not all of this increased methane.

These methane emissions from shale gas have had a major impact on the greenhouse gas inventory of the United States. Beginning in 2007, carbon dioxide emissions from fossil fuel use in the US fell, in part due to recession but also due to some switching of natural gas for coal in electricity generation. However, as shale gas became an increasingly large percentage of natural gas production, methane emissions began to rise sharply. As a result, the total greenhouse gas inventory of the US has been rising rapidly since 2008, and in fact this has been the most rapid rate of increase in greenhouse gas emissions seen in many decades. Clearly natural gas is no bridge fuel.

Note that my analysis differs from the position of the US EPA in their inventory reporting, for two reasons: 1) the EPA continues to underestimate the extent of methane emissions, as noted by a growing number of critics including the inspector general of the US EPA; and 2) the EPA continues to use outdated science to compare the influence of methane and carbon dioxide, despite the guidance to the contrary given by the Inter-Governmental Panel on Climate Change in their most recent synthesis report from 2013. For more discussion on these problems with the EPA analysis, please refer to my 2015 paper, appended below.



I would like to provide one update on the importance of methane to global warming based on events since my most recent paper was published 6 months ago: in Paris 3 months ago, the 195 nations of the world came together and agreed to keep the temperature of the Earth well below 2° C compared to the pre-industrial

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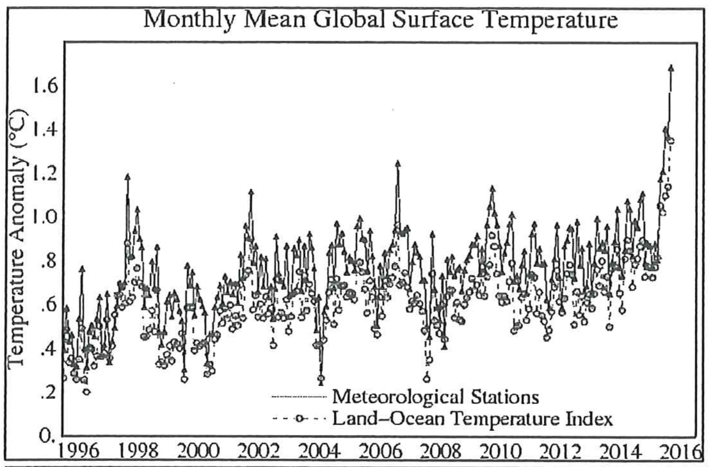

Global warming reaches all-time new high in February 2016. Source: NASA Goddard Space Sciences Institute, downloaded March 13, 2016.

Unfortunately, the very latest evidence shows that the planet is warming even more quickly than model predictions. Last month, the temperature of the Earth spiked above 1.6° C, according to data from the NASA Goddard Space Institute. The temperature increase from a year ago is the fastest ever observed. This high temperature for February 2016 is driven both by *el nino* and by human-caused global warming, and we can expect the temperature to decrease some over the coming months. Nonetheless, the accelerating upward general trend of global warming is alarming.

Given the role of methane in global warming, and the large emissions of unburned methane to the atmosphere as shale gas is developed, I strongly recommend that society more as quickly as possible away from using shale gas a fuel. We have alternatives: embrace wind, solar, and highly efficient 21st Century technologies for using electricity for transportation and for heating. I urge that the House Democratic Policy Committee show leadership and help move the Commonwealth of Pennsylvania to this alternative energy future.

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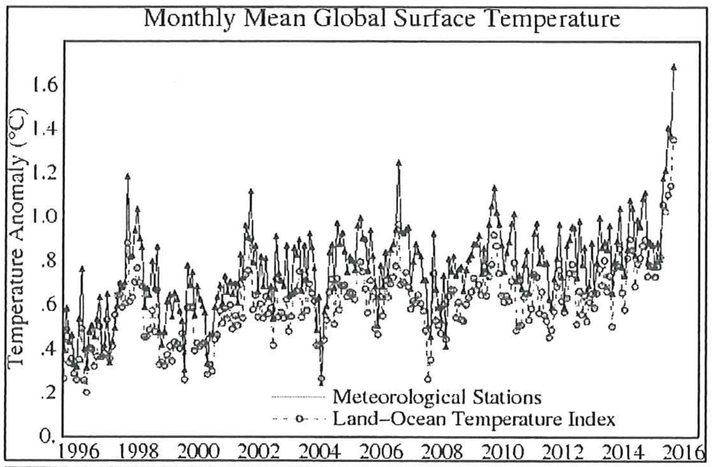

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REVIEW

Methane emissions and climatic warming risk from hydraulic fracturing and shale gas development: implications for policy

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Abstract: Over the past decade, shale gas production has increased from negligible to providing >40% of national gas and 14% of all fossil fuel energy in the USA in 2013. This shale gas is often promoted as a bridge fuel that allows society to continue to use fossil fuels while reducing carbon emissions since less carbon dioxide is emitted from natural gas (including shale gas) than from coal and oil per unit of heat energy. Indeed, carbon dioxide emissions from fossil fuel use in the USA declined to some extent between 2009 and 2013, mostly due to economic recession but in part due to replacement of coal by natural gas. However, significant quantities of methane are emitted into the atmosphere from shale gas development: an estimated 12% of total production considered over the full life cycle from well to delivery to consumers, based on recent satellite data. Methane is an incredibly powerful greenhouse gas that is >100-fold greater in absorbing heat than carbon dioxide, while both gases are in the atmosphere and 86-fold greater when averaged over a 20-year period following emission. When methane emissions are included, the greenhouse gas footprint of shale gas is significantly larger than that of conventional natural gas, coal, and oil. Because of the increase in shale gas development over recent years, the total greenhouse gas emissions from fossil fuel use in the USA rose between 2009 and 2013, despite the decrease in carbon dioxide emissions. Given the projections for continued expansion of shale gas production, this trend of increasing greenhouse gas emissions from fossil fuels is predicted to continue through 2040.

Keywords: shale gas, natural gas, methane, greenhouse gases, global warming, bridge fuel

Video abstract

Point your SmartPhone at the code above. If you have a QR code reader the video abstract will appear. Or use: http://youtu.be/0UjSk8EFzrw

Introduction

Shale gas is natural gas tightly held in shale formations, and as for conventional natural gas, shale gas is composed largely of methane. The difference between shale gas and conventional natural gas is the mode of extraction. Shale gas cannot be obtained commercially using conventional techniques and has entered the market only recently as industry has used two relatively new technologies to extract it: high-precision horizontal drilling with high-volume hydraulic fracturing. Over the past decade, shale gas development in the USA has increased rapidly, a trend that both the Energy Information Agency (EIA) of the US Department of Energy and the industry expect to continue[1–3] (Figure 1). To date, almost all shale gas production in the world has occurred in the USA, a condition likely to continue for at least another decade.[2] The EIA projections for future growth in shale gas development may well be too rosy because both the expense of developing shale gas and the pattern of production from a shale gas well have proven to differ dramatically from that seen in conventional gas wells, with very rapid declines over the first year or two.[4] An independent assessment concludes that

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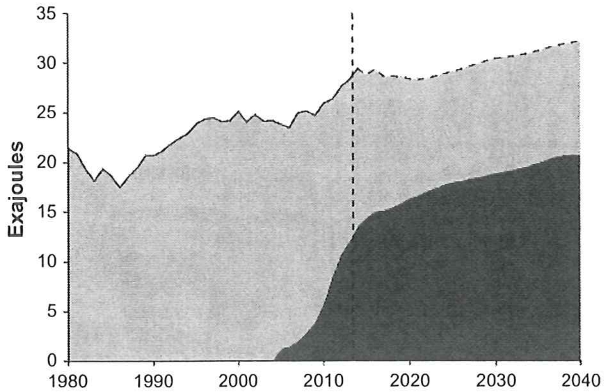

Figure 1 Natural gas production in the USA from 1980 to 2013 and future natural gas production until 2040 as predicted by the US Department of Energy in the *Annual Energy Outlook 2015*.[1] Conventional gas is indicated in yellow, shale gas in red.

shale gas production in the USA is likely to underperform the EIA estimates by almost 40% between now and 2040.[5] However, all these estimates are highly uncertain. If the EIA projections prove true, what might some of the environmental and public health consequences be?

Since shale gas development is a recent phenomenon, scientific investigations on its environmental and public health consequences are also quite new, with the first peer-reviewed studies published only in 2011.[6,7] Nonetheless, the literature has quickly grown, and evidence is accumulating of many adverse effects, including surface and groundwater contamination,[8] degraded air quality,[9,10] increased release of greenhouse gases,[11,12] increased frequency of earthquakes,[13] and evidence of harm to the health of humans and domestic animals, including farm livestock.[7,14–18]

The natural gas industry often points out that hydraulic fracturing has been in use for >60 years, implying that there is little new about shale gas development.[19] The scale of hydraulic fracturing used to develop shale gas, however, is far greater than the fracturing employed in previous decades for conventional gas, with two orders of magnitude increase in the volume of water and chemicals used from the hydraulic fracturing and even proportionally greater return of fracturing wastes to the surface.[6] Further, the use of high-volume hydraulic fracturing with high-precision directional drilling to develop shale gas leads to an intensity of development not generally seen with conventional natural gas and to the redevelopment of regions where conventional gas has largely played out, which may intensify some effects such as air emissions due to interactions with old wells and formations.[20] The appropriate focus when considering the environmental and public health effects of shale gas development is on the entire enterprise and use of the gas and not merely on the process of hydraulic fracturing.

This paper focuses on the role of methane emissions in determining the greenhouse gas footprint of shale gas. Natural gas, including shale gas, is often promoted as a bridge fuel that will allow society to continue to use fossil fuels over the coming decades while reducing carbon emissions. This was highlighted, for example, by President Obama in his State of the Union speech in January 2014.[21] For a given unit of energy consumed, the emissions of carbon dioxide from natural gas are substantially lower than from oil or coal,[11,22] which is the basis for the bridge fuel concept. However, natural gas is composed mostly of methane, a greenhouse gas that on a mass-to-mass basis is >100 times more powerful than carbon dioxide as an agent of global warming for the time when both gases persist in the atmosphere.[23] Consequently, even small releases of methane to the atmosphere from the development and use of shale gas can greatly influence the greenhouse gas footprint of shale gas.

How much methane is emitted?

My coauthors and I published the first peer-reviewed assessment of methane emissions from shale gas development in 2011.[11] We concluded that 3.8% (±2.2%) of the total lifetime production of methane from a conventional gas well is emitted into the atmosphere, considering the full life cycle from well to final consumer.[11] The data available for estimating emissions from shale gas were more scarce and more poorly documented at that time, but we estimated that the full life cycle emissions of shale gas were ~1.5-fold higher than that of conventional natural gas, or 5.8% (±2.2%).[11] We attributed the higher emissions to venting of gas during the flowback period following high-volume hydraulic fracturing, although a subsequent study identified other sources as well, such as drilling through strata previously developed for coal and conventional natural gas.[20] For both conventional gas and shale gas, we estimated the "downstream" emissions associated with storing gas and delivering it to market to be 2.5% (±1.1%), so our estimates for "upstream" emissions at the well site and from gas processing averaged 1.3% for conventional natural gas and 3.3% for shale gas.[11,12]

Through 2010, the US Environmental Protection Agency (EPA) continued to estimate emissions for conventional natural gas as 1.1%, with 0.9% of this from downstream emissions and 0.2% from upstream emissions, based on a joint EPA and industry study from 1996, as I discuss elsewhere.[12]

They did not separately consider shale gas emissions. Soon after our paper was published in 2011, the EPA released new estimates that were very similar to ours in terms of upstream emissions: 1.6% for conventional natural gas and 3.0% for shale gas.[12] They kept their downstream emission estimates at 0.9%, yielding full life cycle emissions of 2.5% and 3.9%, respectively, for conventional gas and shale gas. EPA subsequently reduced their estimates for upstream emissions, cutting them approximately in half, relying on a non-peer-reviewed industry report[24] asserting that the 2011 estimates had been too high.[12,25] This yielded a full life cycle emission estimate for all natural gas in the USA, considering the contributions from both conventional and shale gas as of 2009, of 1.8%.[12] The inspector general of the EPA has called for improvements in the agency's approach in estimating emissions,[26] at least in part because of the 2013 decision to lower emission estimates.[12,25]

In our original 2011 paper, we called for new and better studies of methane emissions from the natural gas industry,[11] and in fact, many studies have been published in the subsequent 4 years. In 2014, I published a review of the new studies that had come out through February 2014.[12] One of these studies evaluated a large set of data from monitoring stations across the USA for the period 2007–2008, before the large increase in shale gas production, and concluded that the EPA estimate of 1.8% emission was clearly too low by a factor of at least 2 and that full life cycle emissions from conventional natural gas must be ≥3.6% on average across the USA.[27] Other, shorter term studies evaluated upstream emissions from shale gas and other unconventional gas development (ie, tight sands), with two finding high emissions (4%–9%)[25,28] and one published by Allen et al finding low emissions (0.4%).[29] In a summary published in early 2014, Brandt et al concluded that emissions from the natural gas industry, including both conventional gas and shale gas, could best be characterized as averaging 5.4% (±1.8%) for the full life cycle from well to consumer.[30] I accepted that conclusion and presented it as the best value in my 2014 review.[12]

Further thought and subsequent studies published since February 2014 have led me to reconsider. I now believe that emissions from conventional natural gas are somewhat <5.4%, based on the ^{14}C content of atmospheric methane globally, and emissions from shale gas are likely substantially more, based on global trends observed from satellite data and new evidence that the 2013 report by Allen et al of only 0.4% emissions[29] is likely to be flawed.

^{14}C content of methane and emissions from conventional natural gas

The ^{14}C radiocarbon content of methane in the planet's atmosphere provides a constraint on the emission rate from conventional natural gas systems. On average during the years 2000–2005, 30% of atmospheric methane was ^{14}C "dead", indicating that it came from fossil sources.[31,32] During this time period, the total global flux of methane to the atmosphere was probably in the range of 548 (±22) Tg CH_4 per year.[33] Therefore, the flux from fossil sources, 30% of the total flux, would have been ~165 Tg CH_4 per year. These fossil sources include fluxes associated with coal, oil, and natural gas development as well as natural seeps. Using global production data for coal and oil[34] and well-accepted methane emission factors for these two fuels as described elsewhere,[11] I estimate the combined methane emissions from oil and coal as ~50 Tg CH_4 per year. Using the 5.4% emission rate and global natural gas production estimates[34] for the years 2000–2005 yields a methane emission of 130 Tg CH_4 per year from the natural gas industry or 180 Tg CH_4 per year from all fossil fuels. This is too high compared to the ^{14}C constraint, suggesting that an emission rate of 5.4% for conventional gas is too high, even if natural seeps are negligible, as assumed by the Intergovernmental Panel on Climate Change (IPCC) in 2007 in their fourth assessment report.[35] Flux estimates from natural seeps are poorly constrained, but these natural emissions may be as great as 50 Tg CH_4 per year or higher.[31] If we instead use the mean emission factor from our 2011 paper for conventional natural gas of 3.8%,[11] the global flux from natural gas emissions is estimated as 91 Tg CH_4 per year, giving an emission flux from all fossil fuels of ~140 Tg CH_4 per year and an estimate of emissions from natural seeps of 15 Tg CH_4 per year. This combination is plausible, if uncertain, and the 3.8% factor agrees well with the robust conclusion from Miller et al that emissions from conventional natural gas systems in the USA, from before the shale gas boom, must have been at least 3.6% of production.[27]

How high are methane emissions from shale gas?

A paper published by Schneising et al in the fall of 2014 used satellite data to assess global and regional trends in atmospheric methane between 2003 and 2012.[36] Methane concentrations rose dramatically in the northern hemisphere, particularly after 2008. In a detailed comparison across the

USA for the time periods 2006–2008 (before there was much shale gas or shale oil development) and 2009–2011 (after shale gas and oil production began in earnest), atmospheric methane concentrations rose dramatically in many of the major shale-producing regions. By evaluating trends in drilling and hydraulic fracturing activity, Schneising et al estimated methane emission rates of 9.5% (±7%) in terms of energy content during the 2009–2011 period for the two large shale regions – the Eagle Ford in Texas and the Bakken in North Dakota – where they felt most comfortable in estimating emissions.[36] They reported similar methane emissions for the Marcellus shale, but with much greater uncertainty in the analysis of the satellite data because of sparser spacing of wells, the mountainous terrain, and the proximity of the region to the Great Lakes. For the Bakken, shale oil production was far greater than gas production during this time period,[37] and the methane emissions may have been more associated with the oil production. However, natural gas was the dominant form of shale energy produced in the Eagle Ford formation between 2009 and 2011, contributing 75% of all shale energy with oil contributing 25%.[37] For the Marcellus shale, virtually all shale energy production through 2011 came from shale gas and not oil.[37] Therefore, it seems reasonable to attribute a methane emission rate of ~9.5% to shale gas development in the Eagle Ford and Marcellus formations.

The satellite methane emission estimate is largely for upstream emissions and does not fully account for downstream emissions during storage and delivery of gas to customers, which may on average add another 2.5% of methane emission.[11,12,22] The conclusion is that shale gas development during the 2009–2011 period, on a full life cycle basis including storage and delivery to consumers, may have on average emitted 12% of the methane produced. This is more than twice what we had estimated for shale gas in our 2011 analysis,[11] but the satellite-based estimate is based on more robust data and integrates across a period of 2 years. These shale gas emissions already may have a globally observable effect on methane in the atmosphere.[36]

The satellite-based estimate is ~20-fold greater than the estimate presented by Allen et al,[29] a study that worked closely with industry to measure emissions from various component processes of shale gas development. In my 2014 review, I suggested that the study by Allen et al may represent a best-case scenario for low emissions, given that measurements were made only at sites where industry allowed.[12] Since then, two papers published in 2015 have indicated that in fact the data in the Allen et al's paper may be flawed. Allen et al used a high-flow analyzer that employs two independent sensors, switching between a catalytic oxidation detector when methane levels are low and a thermal conductivity detector when methane concentrations are greater. Howard et al noted that the high-flow analyzer is prone to underestimating methane fluxes when switching between detectors.[38] A follow-up paper by Howard et al carefully evaluated the use of a high-flow analyzer by Allen et al and concluded that "the data reported by Allen et al. (2013) suggest their study was plagued by such sensor failure", and as a result "their study appears to have systematically underestimated emissions."[39] The sensor failure issue may well have affected other data reported by industry to the EPA and used by the EPA in their assessment of methane emissions, leading to serious underestimation.[38,39]

Several other recent studies have estimated upstream methane emissions from shale gas and other unconventional natural gas development (ie, from tight-sand formations) using more robust and more integrated measurement techniques such as airplane flyovers, but still with highly variable results. Estimates were ~30% greater than the satellite-derived data for one gas field,[40] were comparable in two other cases,[20,25] were only about half as much for two sets of measurements in another gas field,[28,41] and were substantially less in three other cases.[40] Peischl et al have suggested that higher emissions are associated with wet-gas fields and lower emissions with dry-gas fields.[40] Alternatively, the variation in emissions may simply reflect variance in space and/or in time: many of these studies were quite short in duration, for example, based on measurements made during airplane flyovers of just 1–2 days.[20,40] It is also important to note that these emission estimates are given as percentages of the gas production rates. The activity of the natural gas industry and rates of production in various gas fields are quite variable in time, and some of the differences in percentage emission rates may reflect this variability. For instance, Caulton et al reported high emission rates in the southwestern Pennsylvania portion of the Marcellus shale based on a June 2012 flyover,[20] while Peischl et al reported a very low percentage of emission rate in the northeastern Pennsylvania portion of the Marcellus shale from a July 2013 flyover.[40] Between these two flights, gas drilling activity for shale gas fell by 64% due to low prices for gas,[42] yet shale gas production remained high based on prior drilling and hydraulic fracturing.[1] If methane emission is more related to drilling and hydraulic fracturing activity than to production, these rapid changes in activity may explain at least part of the differences between the two estimates for Marcellus shale.

I therefore conclude that the satellite data[36] provide the most robust estimates for upstream methane emissions from shale gas operations to date.

Is natural gas a bridge fuel?

Natural gas is widely promoted as a bridge fuel, a source of energy that allows society to continue to use fossil fuels while reducing greenhouse gas emissions over the next 2 decades or so, until renewable energy sources can more fully come on line. Our 2011 paper challenged that view because of methane emissions from natural gas, although we tempered our conclusion because of the uncertainty in methane emissions from shale gas development.[11] We also observed that the time frame over which one compares the consequences of emissions of carbon dioxide and methane is important in determining the overall greenhouse gas footprint of natural gas. While many studies have made this comparison only by averaging the radiative forcing of the two gases over a time of 100 years following emission, we compared on a 20-year timescale as well, following the lead of Hayhoe et al[22] and Lelieveld et al.[43] Methane has a residence time in the atmosphere of only 12 years,[23,33] while the influence of carbon dioxide emissions persists in the atmosphere for many hundreds of years or longer.[23] While both gases are in the atmosphere, the greenhouse warming effects of methane are >100-fold greater than for carbon dioxide on a mass-to-mass basis.[23] When compared on a 100-year average time after emission, the emitted methane is largely absent from the atmosphere for almost 90% of that time, which greatly underplays the importance of methane while it is in the atmosphere.

Our 2011 paper was criticized for comparing the consequences of methane and carbon dioxide over a 20-year period in addition to the 100-year period, with some authors stating that only a 100-year period should be used under the guidance of the IPCC.[44,45] This was never the case, and in the fourth synthesis report in 2007, the IPCC presented analyses based on both 20- and 100-year time periods.[35] Further, in the fifth synthesis report in 2013, the IPCC explicitly weighed in on this controversy, stating that "there is no scientific argument for selecting 100 years compared with other choices", and "the choice of time horizon [...] depends on the relative weight assigned to the effects at different times".[23]

So what is the best choice of timescale? Given current emissions of greenhouse gases, the Earth is predicted to warm by 1.5°C above the preindustrial baseline within the next 15 years and by 2°C within the next 35 years.[46,47] Not only will the damage caused by global warming increase markedly but also at these temperatures, the risk of fundamentally altering the climate system of the planet becomes much greater.[48,49] Further, reducing emissions of carbon dioxide will do little if anything to slow the rate of global warming over these decadal time periods.[47] On the other hand, reducing emissions of methane has an immediate effect of slowing the rate of global warming.[47] For these reasons, comparing the global warming consequences of methane and carbon dioxide over relatively short time periods is critical. The use of a global warming potential (GWP) estimate for the 20-year time period from the IPCC fifth assessment report provides a convenient approach for doing so.[23] This GWP value of 86 is the relative radiative forcing for methane compared to that of carbon dioxide, averaged over 20 years, for two equal masses of the gases emitted into the atmosphere today.

Figure 2 compares the greenhouse gas footprint of shale gas with that of conventional natural gas, oil, and coal. Methane emissions of shale gas are derived from the satellite-based estimates of Schneising et al[36] with an additional 2.5% emission rate assumed from downstream transport, storage, and distribution systems.[11,12,22] Methane emissions for the other fuels are those used in our 2011 paper, which is 3.8% (±2.2%) for conventional natural gas.[11] Methane emissions are converted to carbon dioxide equivalents using the 20-year GWP value of 86 from the IPCC assessment.[23] While for a

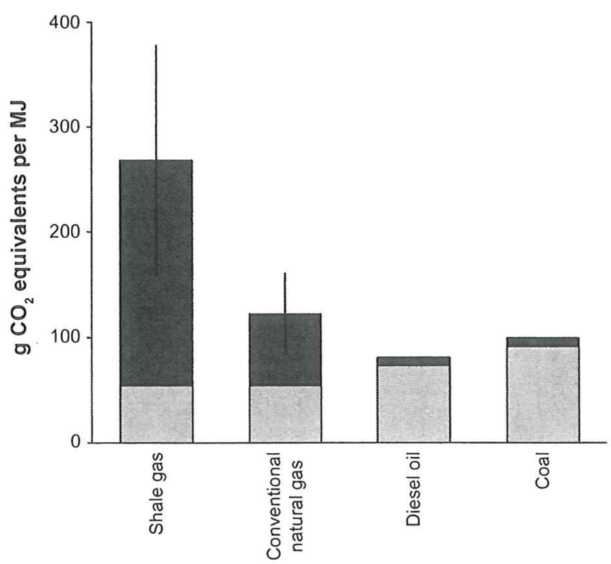

Figure 2 The greenhouse gas footprints of shale gas, conventional natural gas, oil, and coal expressed as g CO_2 equivalents per MJ of heat produced.
Notes: Yellow indicates direct and indirect emissions of carbon dioxide. Red indicates methane emissions expressed as CO_2 equivalents using a global warming potential of 86. Vertical lines for shale gas and conventional natural gas indicate the range of likely methane emissions. Emissions for carbon dioxide for all fuels and for methane from conventional natural gas, oil, and coal are as in Howarth et al.[11] Mean methane emission estimate of shale gas is taken as 12% based on Schneising et al[36] as discussed in the text.

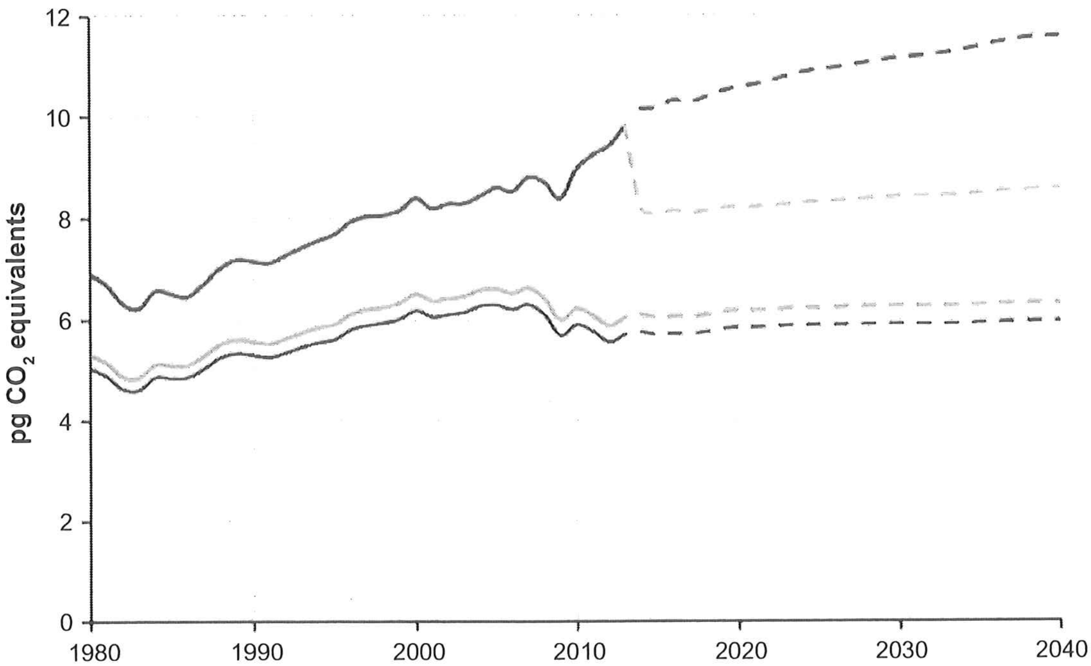

Figure 3 Trends in greenhouse gas emissions from fossil fuel use in the USA from 1980 to 2013 and future trends predicted until 2040 based on historical energy use and energy predictions in the *Annual Energy Outlook 2015*.[1] Shown are: emissions just for carbon dioxide (gray line); emissions for carbon dioxide and for methane using EPA assumptions, which undervalue the importance of methane (green line); emissions for carbon dioxide and methane based on emission factors for conventional natural gas, oil, and coal from Howarth et al,[11] mean methane emission estimates for shale gas of 12% based on Schneising et al[36] as discussed in the text, and a global warming potential for methane of 86 (red line); and future emissions for carbon dioxide and methane based on the same assumptions as for the red line, except assuming that shale gas emissions can be brought down to the level for conventional natural gas (blue line). Historical data are shown by solid lines; dashed lines represent future predictions.
Abbreviation: EPA, Environmental Protection Agency.

given unit of energy produced, carbon dioxide emissions are less for shale gas and conventional natural gas than those for oil and coal, the total greenhouse gas footprint of shale gas is substantially greater than that of the other fossil fuels when methane emissions are included (Figure 2). Note that this is true even for the low-end estimates of methane emissions from the Schneising et al study. The greenhouse gas footprint of conventional natural gas is also higher than that of conventional oil and coal for the mean estimate of methane emissions and still greater than or comparable to that of these other fuels even at the low-end estimate for methane emissions. Natural gas – and shale gas in particular – is not a bridge fuel when methane emissions are considered over an appropriate timescale.

Trends in greenhouse gas emissions from fossil fuels in the USA

Figure 3 shows the greenhouse gas emissions from all use of fossil fuels in the USA from 1980 to 2013 and projections for emissions through 2040, based on data for fossil fuel use and projections of future use from the EIA *Annual Energy Outlook 2015* report[1] and carbon dioxide emissions per unit of energy produced for each fuel.[11,22] Total carbon dioxide emissions fell in the early 1980s due to economic recession, but as the economy recovered, emissions rose steadily until the great recession of 2008. Carbon dioxide emissions continued to fall from 2008 to 2013 and are predicted to remain relatively flat through 2040.[1] President Obama and others have attributed the decrease in carbon dioxide emissions since 2008 to a switch from coal to shale gas,[21,50] although a recent analysis by Feng et al concludes that the sluggish economy was the more significant cause.[51]

When methane emissions are included in the analysis, we see some important differences in trends in national greenhouse gases. For the top line in Figure 3, methane emissions are included as carbon dioxide equivalents using the 20-year GWP of 86 from the IPCC fifth assessment[23] and methane emission factors from the 2011 study by Howarth et al[11] for coal, conventional oil, and conventional natural gas and a factor of 12% based on the satellite data discussed earlier for shale gas. In this analysis, methane contributes 28% of total fossil fuel emissions for the USA in 1980 and 42% in 2013 (Figure 3). The increasing trend in the relative importance of methane in the greenhouse gas emissions of the USA is due to an increasingly large portion of the nation's fuel mix coming from natural gas and particularly from shale gas for the time since 2009.[1] Shale gas production was negligible before 2005 (Figure 1) but rose to contribute 14% of all fossil fuel energy used in the USA in 2013.[1] Importantly, while carbon dioxide emissions fell between 2008 and 2013, total greenhouse gas emissions including methane fell only briefly in 2008 before beginning a rapid increase that lasted through 2013 and are projected to continue to rise through 2040.

The US EPA includes methane emissions in the natural gas inventory, but they do so in a manner that greatly undervalues their importance. This can be seen in Figure 3, where the green line that is just above and closely tracks the gray line for carbon dioxide emissions is based on EPA assumptions: a methane emissions rate of only 1.8% from natural gas and a GWP of 21 based on the 100-year time period from the second IPCC assessment from 1996.[52] Note that the EPA used this GWP value of 21 for many years, through 2013, before switching to the 100-year value of 25 in 2014 from the IPCC fourth assessment from 2007. The 2013 assessment of the IPCC gives a GWP value of 34 for the 100-year period but, as noted earlier, also states that the 100-year time frame is arbitrary. A shorter time frame, such as the 20-year GWP of 86 used in the top line in Figure 3, far better accounts for the importance of methane to global warming in the critical next few decades as the temperature is predicted to reach 1.5°C–2°C above the preindustrial baseline if methane emissions are not reduced.

Implications for policy on shale gas

As of January 2015, the US EPA has taken some steps to reduce emissions from shale gas, but how effective these will be in reducing methane emissions remains unclear. A draft regulation proposed in 2012 would have prevented the venting of methane during the flowback period following hydraulic fracturing, with some exceptions such as for wells in frontier regions not yet serviced by pipelines.[53] This would be important, since such venting can emit a large amount of methane.[11] However, the final regulation distinguishes between two phases of flowback, an "initial flowback stage" and a "separation flowback stage". Venting of methane and other gas is explicitly allowed during the initial stage, and recovery of the gas is only required during the separation stage.[53] The separation stage is supposed to commence as soon as it is technically feasible to use a flowback gas separator. At this stage, EPA requires that the gas be sold to market, reinjected into the ground, used as an onsite fuel, or, if none of these are possible, flared (ie, burned). No direct venting of gas is allowed during this separation flowback stage, "except when combustion creates a fire or safety hazard or can damage tundra, permafrost or waterways".[53] Much is left to operator judgment as to when the shift from the initial stage to the separation stage occurs and whether an exception is necessary, which would seem to make enforcement of these regulations difficult.

Further, EPA continues to ignore some methane emission sources, such as during the drilling phase. Caulton et al identified many wells that were emitting high levels of methane during this drilling phase, before the drillers had even reached the target shale, and long before hydraulic fracturing,[20] perhaps because drillers were encountering pockets of methane gas from abandoned conventional gas wells or abandoned coal mines. Our understanding of emission sources remains uncertain, with the study of shale gas methane emissions commencing only in the past few years.[6] Adequate regulation to reduce emissions requires better knowledge of sources, as well as better oversight and enforcement.

Nonetheless, methane emissions from shale gas can be reduced to some extent. I suggest that the best-case scenario would have these emissions reduced to the level for conventional natural gas, or ~3.8% for the full well-to-consumer life cycle. This best-case scenario is explored in Figure 3 (dashed blue line), where it is assumed that shale gas methane emissions are reduced from 12% to 3.8% as of 2014. Even still, methane accounts for 30% of total greenhouse gas emissions from fossil fuels in the USA throughout the period from 2014 to 2040 under this scenario, and total emissions continue to rise, albeit more slowly than without the aggressive reduction in shale gas methane emissions. This best-case scenario seems unlikely, and actual emissions from shale gas are likely to range between 3.8% and 12%, giving total greenhouse gas emissions for all fossil fuels that lie between the dashed red and blue lines in Figure 3.

Methane emissions severely undercut the idea that shale gas can serve as a bridge fuel over the coming decades, and we should reduce our dependence on natural gas as quickly as possible. One of the most cost-effective ways to do so is to replace in-building use of natural gas for domestic space and water heating with high-efficiency heat pumps. Even if the electricity that drives these heat pumps comes from coal, the greenhouse gas emissions are far less than from the direct use of natural gas.[12] Heating is the major use for natural gas in the USA, making this change of use imperative.

Concluding thoughts and a path forward

Should society continue to use coal rather than convert toward more electricity production from shale gas? Absolutely not. The carbon dioxide emissions from burning any fossil fuel will continue to influence the climate for hundreds of years into the future, and coal is the worst of the fossil fuels in terms of carbon dioxide emissions. Given the imperative of also reducing methane emissions to slow global warming over the coming few decades, though, the only path forward is to reduce the use of all fossil fuels as quickly as possible. There is no bridge fuel, and switching from coal to shale gas is accelerating rather than slowing global warming.

Fortunately, society does have a path forward: recent studies for the State of New York[54] and for the State of California[55] have demonstrated that we can move from a fossil fuel-driven economy to one driven totally by renewable energy sources (largely solar and wind) in a cost-effective way using only technologies that are commercially available today. The major part of the transition can be made within the next 15 years, largely negating the need for shale gas, with a complete transition possible by 2050. A critical part of these plans is to use modern, efficient technologies such as heat pumps and electric vehicles, which greatly reduce the overall use of energy. The cost of the transition is less than the cost currently paid for death and illness related to air pollution from using fossil fuels.[54] The costs of renewable energy today are equal to or lower than those from using fossil fuels, when the external costs to health and the climate are considered.

In June 2015, six of the largest oil and gas companies in Europe including BP and Shell called for a carbon tax as a way to slow global warming.[56] An editorial in the *New York Times* endorsed this idea,[56] and indeed, a carbon tax is perhaps the best way to equalize the playing field for renewable energy technologies. The International Monetary Fund estimates that subsidies to fossil fuels globally are in the range of $5 trillion per year, with much of this due to the effects of global warming and consequences on human health.[57] A carbon tax would help rectify these subsidies and help promote renewable energy. However, the editorial in the *Times* made a fundamental error by ignoring methane emissions when they wrote "this tax would reduce demand for high-carbon emission fuels and increase demand for lower emission fuels like natural gas".[56]

Any carbon tax should recognize the two faces of carbon: the two major greenhouse gases, carbon dioxide and methane, are both carbon gases. Both of these carbon gases are critically important, and the 2013 IPCC synthesis report tells us that the effects of global methane being emitted today matches the consequences of carbon dioxide emissions as drivers of global warming.[23] The modes of interaction with the planetary climate system are dramatically different, though. The climate is slow to respond to changes in carbon dioxide emissions, and so immediate reductions in emissions would take 30–40 years before having an influence on slowing warming, but the emissions have a warming effect on the climate that will persist for hundreds of years.[23,46,47] The climate responds quickly to changes in methane emissions, and reducing methane emissions is essential for slowing climate change over the coming 30–40 years; however, the methane remains in the atmosphere for little more than 1 decade, and methane emissions have no lasting influence on the Earth's climate systems in future centuries, unless global warming over the coming decades leads to fundamental thresholds and changes in the climate.[12,23,46,47]

A carbon tax that adequately addresses the immediacy of global climate change must include both carbon gases. Methane emissions should be taxed using the best available information on methane emissions. And the tax on methane should adequately reflect the importance of methane in current global warming and its influence in global warming over the critically important next few decades. Taxing methane emissions at 86 times the tax for carbon dioxide emissions, using the 20-year GWP from the most recent IPCC synthesis report,[23] would accomplish this.

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Disclosure

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Testimony of Mark Szybist
House Democratic Policy Committee
Harrisburg, March 21, 2016

Chairman Vitali, Honorable Members of the Committee: good morning, and thank you for the invitation to testify today on the question of natural gas incentives in Pennsylvania.

My name is Mark Szybist; I am an attorney by training, and I work as a Senior Program Advocate for the Natural Resources Defense Council. NRDC is a national environmental organization with more than 90,000 members and online activists in Pennsylvania, and offices in New York, Washington, D.C., Chicago, Santa Monica, San Francisco, Montana, and Beijing. I am based in NRDC's Washington, D.C. office, but my work focuses on Pennsylvania environmental issues, especially implementation of the Clean Power Plan.

The question of today's hearing is whether Pennsylvania should incentive natural gas. My testimony will address this question as it applies to the Clean Power Plan, the federal initiative to reduce carbon pollution from power plants. In terms of the Clean Power Plan, I would state the question as follows: whether the Commonwealth should incentivize new natural gas power plants by exempting those plants from its State Plan implementing the Clean Power Plan. My answer to this question is: no. Pennsylvania should not incentive new gas plants. Instead, it should cover those plants in its State Plan.

The Clean Power Plan is an example of a kind of lawmaking that lawyers call cooperative federalism, in which the federal government and state governments work together to address problems that are too complex for either to address alone. In the case of the Clean Power Plan, the EPA has established a series of carbon pollution reduction targets for the states. These targets will be phased in over time, and the states have an extraordinary range of tools to meet them – expanding consumer-side energy efficiency in homes, factories, and government buildings; generating more electricity from zero-emitting sources like the wind and the sun; utilizing the full capacity of existing but underutilized natural gas plants; burning coal more efficiently at coal plants; and so on.

Several coal companies and other parties, including 27 states, have sued the EPA over the Clean Power Plan. (Sixteen other states, and many generators, business groups, and environmental organizations, have also intervened on the side of the EPA; Pennsylvania is one of three states that is not participating in the lawsuit). The opponents' claims will be decided by the federal Court of Appeals for the District of Columbia after oral arguments in June. Meanwhile, last month the U.S. Supreme Court issued a "stay" order that prohibits the EPA from enforcing the Clean Power Plan until the litigation is over. During the stay, states can continue working on their state plans, and Governor Wolf's administration has wisely committed to doing so. As DEP Secretary Quigley pointed out to the House Appropriations Committee a couple weeks ago, continuing work on the State Plan is the prudent course for Pennsylvania. On the one hand, given the way that cheap, oversupplied natural gas and other factors are transforming its power sector, Pennsylvania needs to do this work anyway. On the other hand, failing to plan would leave the state flat-footed if the Clean Power Plan is ultimately upheld – and NRDC is confident that it will be.

For the purposes of the Clean Power Plan, a new gas power plant is a plant that started construction after January 8, 2014. One of the decisions that states have to make in implementing the Clean Power Plan is whether to include new plants in their State Plans – and thereby make them compete against existing plants on an equal footing – or to leave them out and thereby give them a competitive advantage. Inclusion and exclusion are both options for states because existing power plants and new power plants are covered under two different sections of the Clean Air Act.

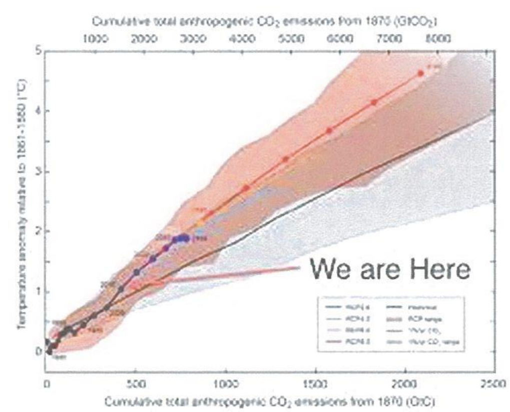
If Pennsylvania's State Plan covers new power plants, all fossil-fuel plants of 25 megawatts (MW) or more will be covered by a reasonable, growth-based cap on carbon pollution. This cap will not only cut carbon pollution; it will also cut emissions of harmful co-pollutants like sulfur dioxides and particulate matter; incentivize the use of energy efficiency to lower both emissions and electricity bills; and allow Pennsylvania's economy to prosper. Based on comments that generators and other stakeholders made during the DEP's listening sessions on the Clean Power Plan last fall, the Commonwealth is likely to choose is a mass-based compliance approach in which power plants have to buy carbon "allowances" to cover their pollution. In practical terms, covering new as well as existing power plants would mean that *all* coal and gas power plants have to buy allowances to cover the carbon pollution they emit, and all are subject to the growth-based cap. If this sounds like common sense, it is. It will ensure a level playing field for existing plants and new plants, and ensure that pollution reductions from existing plants are not compromised by huge pollution increases from new plants.

By contrast, if Pennsylvania leaves new gas power plants out of the state plan, so that only plants built before 2014 would have to stay under the cap and buy carbon allowances, it would create an incentive for new power plants. New plants could operate without carbon pollution limits and carbon pricing, and this would give them a built-in, competitive advantage over existing plants. In this kind of distorted market, we would likely see the premature closure of existing gas plants and the unnecessary construction of new plants, with the construction costs passed on to electricity ratepayers. We would see pollution "leak" to new plants from the existing plants that are covered by the state cap. The new plants would have to be supplied by new pipelines, and the extra gas they burned would be produced by more hydraulic fracturing. A greater number of coal plants would probably retire.

Right now, there are at least five new natural gas power plants in the Commonwealth that are either under construction or recently finished construction – in Jessup, Lackawanna County (1,500 MW); Shamokin Dam, Snyder County (1,224 MW); Clinton Township, Lycoming County (825 MW); Asylum Township, Bradford County (825 MW); and Salem Township, Luzerne County (1,029 MW). The combined planned capacity for these plants is more than 5,000 MW. In addition, Talen Energy has announced that it will convert its Brunner Island coal-fired power plant to fire gas as well as coal. Other new gas plants have been proposed in Clinton County and Lawrence County.

What the construction of these new power plants tells us is that Pennsylvania does not need incentives for new natural gas power plants. Those plants are being built because Pennsylvania is sitting on top of the most productive shale gas formations in the United States, natural gas is oversupplied and cheap (not to mention already heavily incentivized, on both the federal and the state level), and neither of these things will change any time soon. What Pennsylvania ought to incentivize is energy efficiency, our lowest-cost energy resource (for instance, by improving its building codes and removing the arbitrary limits on efficiency in Act 129) and zero-emitting renewable energy from the wind and the sun. Because of the potential health benefits, job benefits, and electricity bill benefits – as well as climate impacts – expanding clean energy now makes sense for the Commonwealth with or without the Clean Power Plan, and will help Pennsylvania meet its carbon reduction targets when the time comes to do so.

How to set National GHG Emissions Reduction Target After the 2015 Paris Climate Agreement



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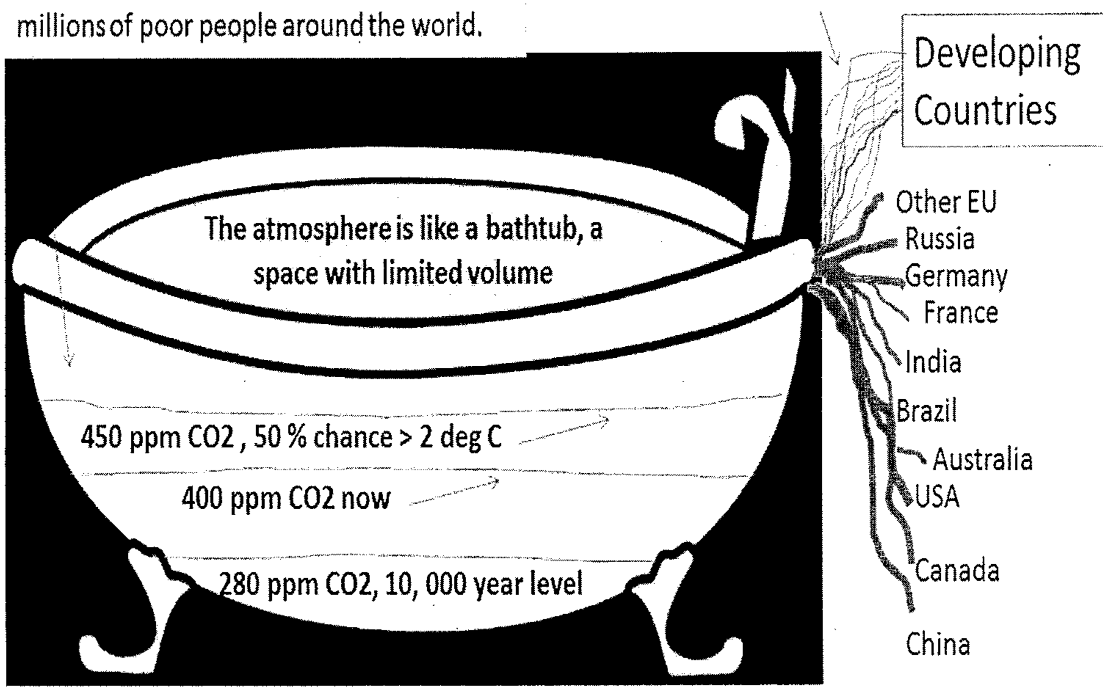
Major Positive Developments in Paris

- 186 nations made commitments to reduce ghg emissions, far short of 2° C goal
- Nations agreed to limit the increase in global average temperatures to "well below 2° C" and to "pursue efforts" to limit temperature increase to 1.5 ° C.
- The Paris Agreement, **GHG emissions must be no greater than sinks by the second half of this century**

The Justice Question: What levels of GHGs will be permitted in the bathtub given that the higher the levels-- the greater the harms to those countries and millions of poor people that have done little to fill the bathtub and given some levels of warming are an existential threat to millions of poor people around the world.

The Equity Question: Who gets to fill the rest of the atmospheric bathtub given limited remaining space to limit atmospheric GHG concentrations to safe levels, different historical and per capita emissions that have filled the bathtub to current levels, and the needs of poor countries to grow economically.



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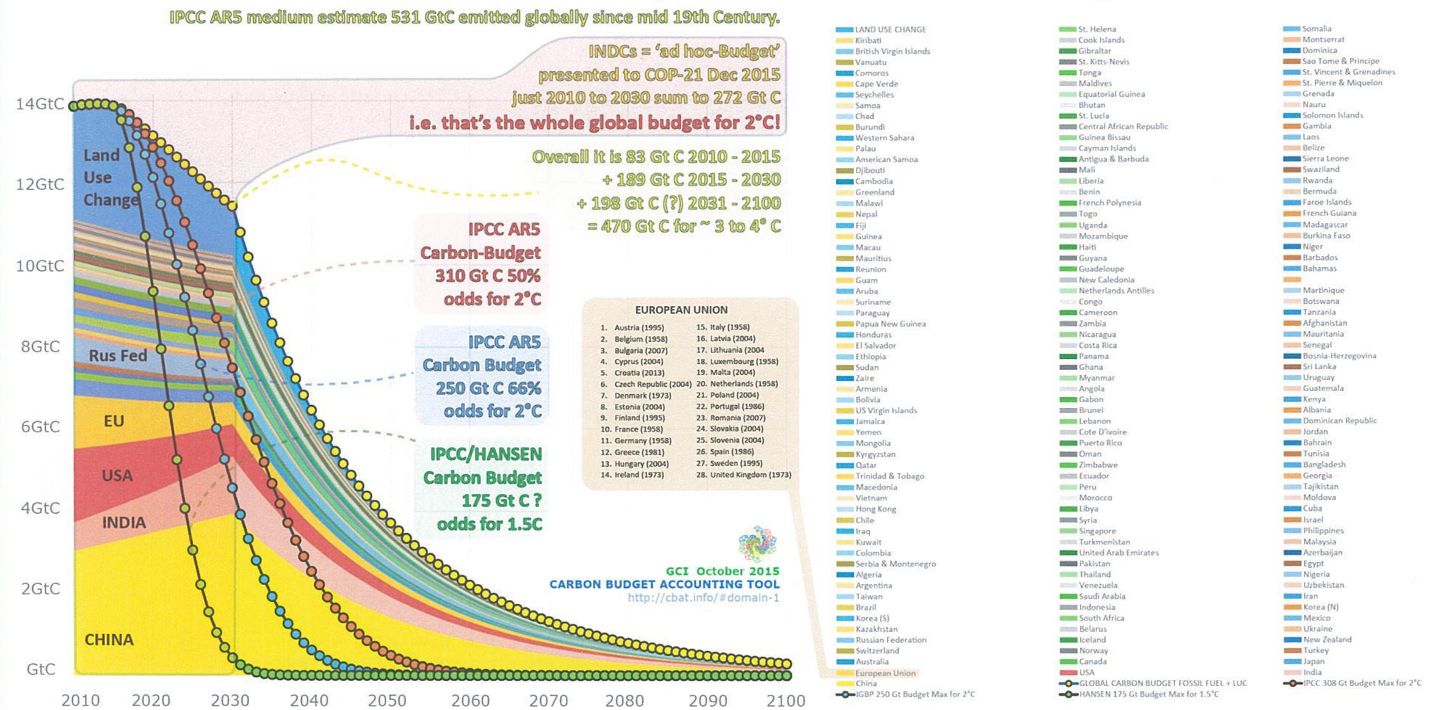
COP-21 International INDCs 20 2030, compared with Global Carbon Budgets for 1.5° & 2.0°C



Pg 28 2015 UNEP EMMISSIONS Gap Report

Box 2.1: The global carbon dioxide (CO_2) budget, non-CO_2 GHGs and the link to global warming

Limiting warming to any desired level requires a cap on total, cumulative anthropogenic CO_2 emissions. Working Group I of the IPCC (IPCC, 2013) showed that global mean temperature increases are almost directly proportional to cumulative carbon dioxide emissions since the pre-industrial period. This leads to the important conclusion that there is a maximum amount of carbon dioxide emissions, or a CO_2 budget, that can be discharged to the atmosphere over time if society wishes to stay within a 2°C or other global warming limit. The IPCC indicated that to limit warming to below 2°C with a 'likely chance' (that is >66% chance) by the end of the century, about 1 000 $GtCO_2$ of CO_2 emissions remained 'in the budget' from 2011 onward* (IPCC, 2014b; Knutti and Rogelj, 2015). To keep CO_2 emissions within such a budget allowance, annual global CO_2 emissions have to become zero at some point during the 21st century. This is a geophysical requirement that applies regardless of the budget level chosen. For non-CO_2 GHGs with a shorter lifetime in the atmosphere, such as methane, the levels of emissions that are emitted per year are more important than the cumulative amount**. Reducing their annual emissions is also important to limit global mean temperature increase to low levels. Table 2.1 indicates the year of global annual emissions becoming net zero for each of the pathways considered.

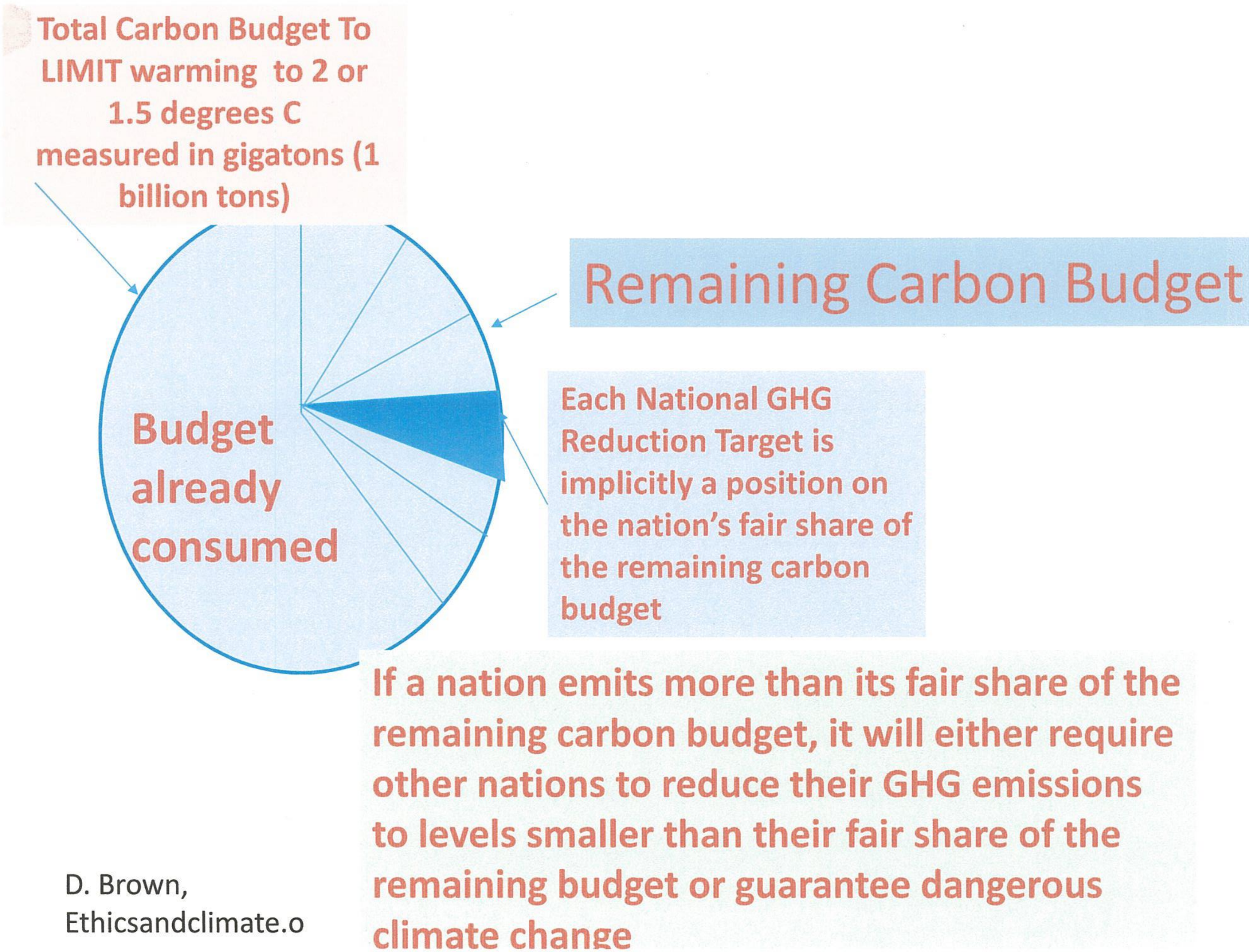
* This number is accompanied by an uncertainty range, which depends on the concurrent mitigation of non-CO_2 GHGs.
** This is approximately true, as for non-CO_2 GHGs that stay in the atmosphere for quite a while (for example, N_2O has an atmospheric lifetime of 121 years) there is also a more limited cumulative effect. See, for example, Smith *et al.* (2012).

Table 2.1: Overview of pathway characteristics of 1.5°C and 2°C scenarios based on a re-analysis of the IPCC AR5 Scenario Database and a recent study on 1.5°C scenarios[15].
All scenarios have prescribed 2020 emissions consistent with the GHG pledges made by Parties in Cancun in 2010, and hence do not represent least-cost emission levels until then. All available scenarios with limited action until 2020 rely on net negative CO_2 emissions from energy and industry during the 21st century. Most scenarios with such specifications were contributed to the IPCC AR5 Scenario Database by the LIMITS intercomparison project[16]. Note that this table provides data for limiting warming below 1.5°C and 2°C in 2100. Further information is provided in the Tables of Annex A (available online)

Limiting warming in 2100 (allowing for overshoot)					
1.5°C (>50% in 2100)	Pathways limiting warming to below 1.5°C by 2100 with >50% chance Limited action until 2020 and least-cost mitigation afterwards				
Number of available scenarios: 6; Number of contributing modelling frameworks: ~~2~~ Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **(2060-2080)**; total CO_2 (including LULUCF): **(2045-2050)**; CO_2 from energy and industry: **(2045-2055)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e$/yr]				
Year	2020	2025	2030	2050	2100
median*	**56**	**47**	**39**	**8**	**-5**
range and spread**	53(-/-)56	46(-/-)48	37(-/-)40	4(-/-)14	-5(-/-)-3
2°C (>66% in 2100)	Pathways limiting warming to below 2°C by 2100 with >66% chance Limited action until 2020 and least-cost mitigation afterwards				
Number of available scenarios: 10; Number of contributing modelling frameworks: ~~4~~ Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **2085 (2080-2090)**; total CO_2 (including LULUCF): **2070 (2060-2075)**; CO_2 from energy and industry: **2070 (2060-2075)**					
	Annual emissions of global total greenhouse gases [GtCO2e/yr]				
Year	2020	2025	2030	2050	2100
median*	**52**	**48**	**42**	**23**	**-3**
range and spread**	49(49/53)55	44(46/50)53	29(31/44)44	17(18/27)29	-11(-9/-1)0
2°C (50-66% in 2100)	Pathways limiting warming to below 2°C by 2100 with 50-66% chance Limited action until 2020 and least-cost mitigation afterwards				
Number of available scenarios: 4; Number of contributing modelling frameworks: 2 Year of global annual emissions becoming net zero† for: Kyoto-GHGs: **(2095-2095)**; total CO_2 (including LULUCF): **(2065-2070)**; CO_2 emissions from energy and industry: **(2070-2080)**					
	Annual emissions of global total greenhouse gases [$GtCO_2e$/yr]				
Year	2020	2025	2030	2050	2100
median*	**53**	**50**	**47**	**28**	**-1**
range and spread**	50(-/-)55	49(-/-)51	46(-/-)48	27(-/-)29	-2(-/-)-1

† Rounded to nearest 5 years. Explanation of format: 'median (20th percentile – 80th percentile)' – for example, '2085 (2080-2090)'; no median is provided if fewer than 10 scenarios are available '(minimum–maximum)' – for example, '(2060-2080)'.
* Rounded to the nearest 1 $GtCO_2e$/yr.
** Rounded to the nearest 1 $GtCO_2e$/yr. Explanation of format: 'minimum value (20th percentile/80th percentile) maximum value' – for example, '44(46/50)53'. No percentiles are provided if fewer than 10 scenarios are available – for example, '46(-/-)48'.

15 See Rogelj *et al.* (2015a)



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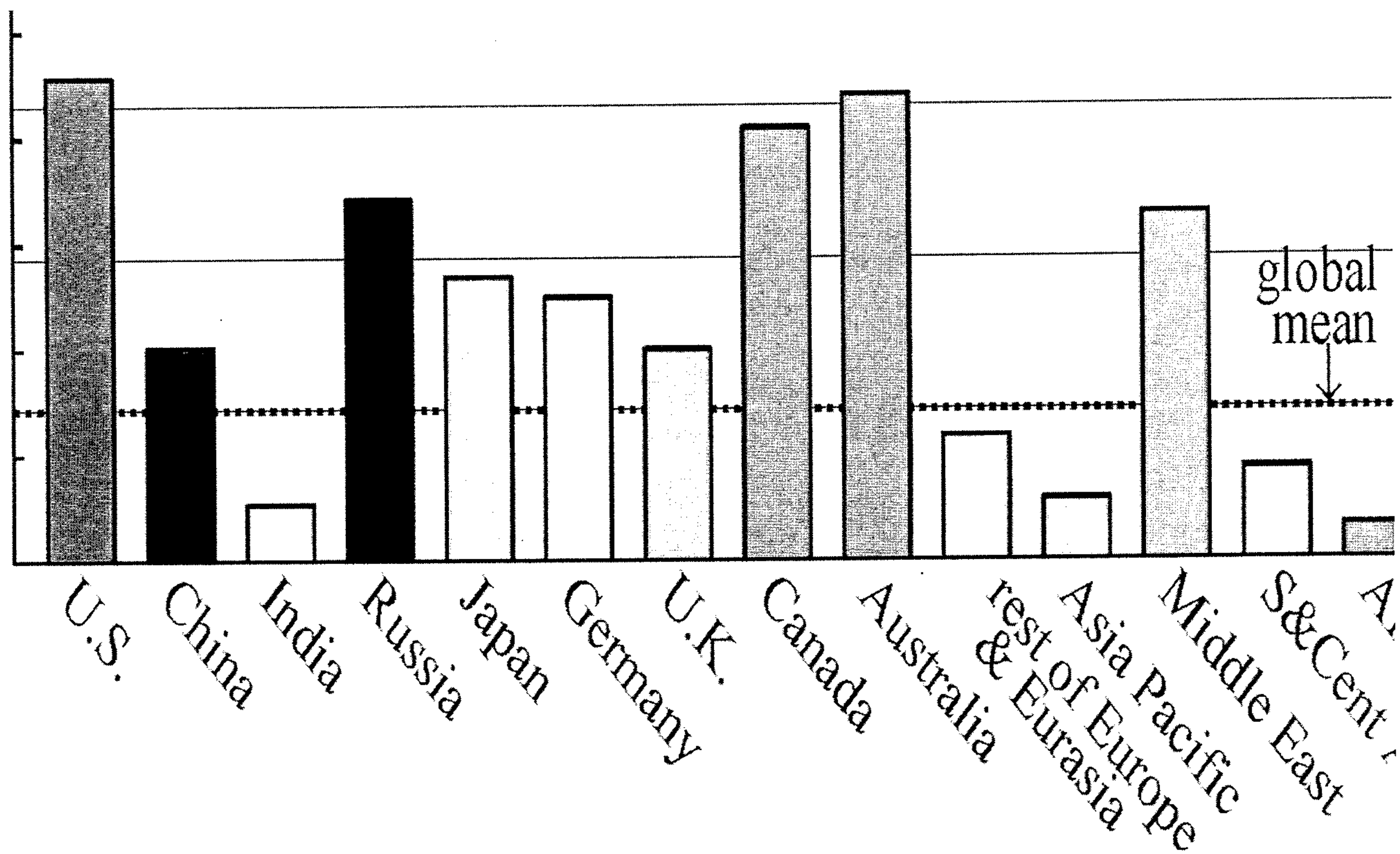
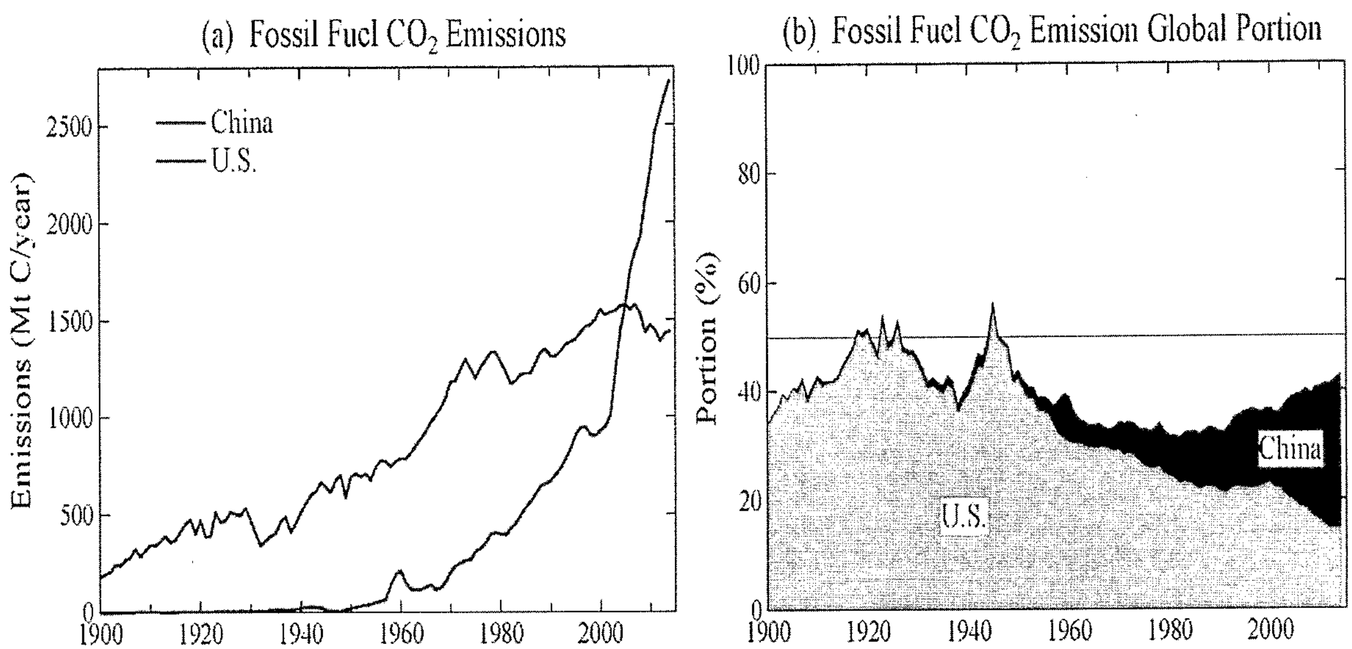
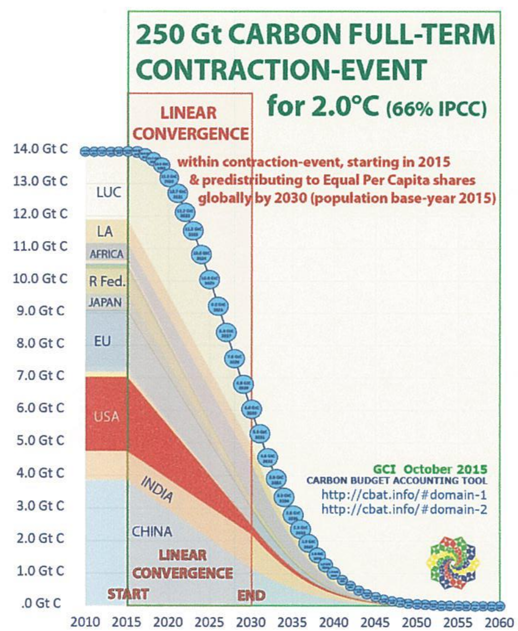
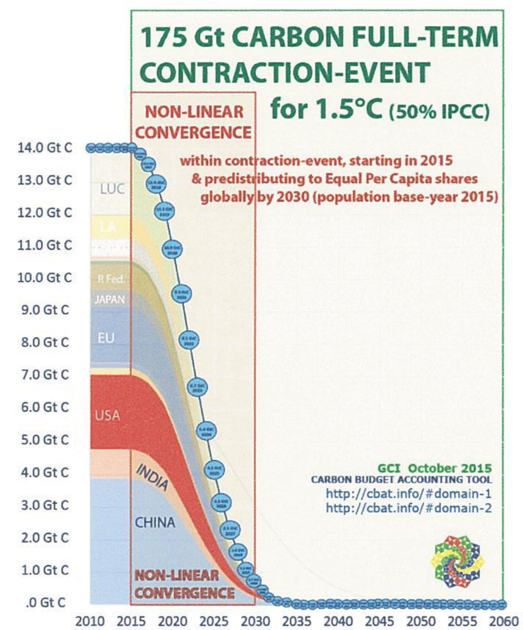

global
mean
U.S.
China
India
Russia
Japan
Germany
U.K.
Canada
Australia
rest of Europe
& Eurasia
Asia Pacific
Middle East


(a) Fossil Fuel CO_2 Emissions
Emissions (Mt C/year)
China
U.S.
0
500
1000
1500
2000
2500
1900
1920
1940
1960
1980
2000
(b) Fossil Fuel CO_2 Emission Global Portion
Portion (%)
0
20
40
60
80
100
U.S.
China
1900
1920
1940
1960
1980
2000

Emissions Reductions with contraction to equal per capita emissions in 2030



250 GtC Global	
YEAR	US
2010	2.3 Gt C
2011	2.3 Gt C
2012	2.3 Gt C
2013	2.3 Gt C
2014	2.3 Gt C
2015	2.3 Gt C
2016	2.1 Gt C
2017	2.0 Gt C
2018	1.9 Gt C
2019	1.7 Gt C
2020	1.6 Gt C
2021	1.5 Gt C
2022	1.3 Gt C
2023	1.2 Gt C
2024	1.1 Gt C
2025	.9 Gt C
2026	.8 Gt C
2027	.7 Gt C
2028	.5 Gt C
2029	.4 Gt C
2030	.3 Gt C
2031	.2 Gt C
2032	.2 Gt C
2033	.2 Gt C
2034	.1 Gt C
2035	.1 Gt C
2036	.1 Gt C
2037	.1 Gt C
2038	.1 Gt C
2039	.1 Gt C
2040	.0 Gt C
2041	.0 Gt C
2042	.0 Gt C
2043	.0 Gt C
2044	.0 Gt C
2045	.0 Gt C
2046	.0 Gt C
2047	.0 Gt C
2048	.0 Gt C
2049	.0 Gt C
2050	.0 Gt C
2051	.0 Gt C
2052	.0 Gt C
2053	.0 Gt C
2054	.0 Gt C
2055	.0 Gt C
2056	.0 Gt C
2057	.0 Gt C
2058	.0 Gt C
2059	.0 Gt C
2060	.0 Gt C
TOTAL	33.1 Gt C



175 GtC Global	
YEAR	US
2010	2.3 Gt C
2011	2.3 Gt C
2012	2.3 Gt C
2013	2.3 Gt C
2014	2.3 Gt C
2015	2.3 Gt C
2016	2.2 Gt C
2017	2.2 Gt C
2018	2.1 Gt C
2019	2.0 Gt C
2020	1.8 Gt C
2021	1.5 Gt C
2022	1.3 Gt C
2023	1.1 Gt C
2024	.9 Gt C
2025	.7 Gt C
2026	.5 Gt C
2027	.4 Gt C
2028	.3 Gt C
2029	.2 Gt C
2030	.1 Gt C
2031	.1 Gt C
2032	.0 Gt C
2033	.0 Gt C
2034	.0 Gt C
2035	.0 Gt C
2036	.0 Gt C
2037	.0 Gt C
2038	.0 Gt C
2039	.0 Gt C
2040	.0 Gt C
2041	.0 Gt C
2042	.0 Gt C
2043	.0 Gt C
2044	.0 Gt C
2045	.0 Gt C
2046	.0 Gt C
2047	.0 Gt C
2048	.0 Gt C
2049	.0 Gt C
2050	.0 Gt C
2051	.0 Gt C
2052	.0 Gt C
2053	.0 Gt C
2054	.0 Gt C
2055	.0 Gt C
2056	.0 Gt C
2057	.0 Gt C
2058	.0 Gt C
2059	.0 Gt C
2060	.0 Gt C
TOTAL	31.0 Gt C

What Should The US and Pa GHG Emissions ReductionTarget Be?

Carbon Neutral As Soon As Possible But No Later Than 2040.

This is based on converging on equal per capita shares after 2030 and achieving global reductions necessary to limit warming to 1.5 degrees. According to UNEP, the electricity and energy sector for the entire world must be carbon neutral between 2045 and 2050.

What questions should be asked of proponents of continued use of natural gas on the record.

1. How is the United States and Pennsylvania going to assure that carbon emissions are no greater than carbon sinks by no later then 2040 if governments continue to rely on natural gas?
2. Do proponents of natural gas agree that the US and Pennsylvania must as quickly as possible replace fossil fuel with non-fossil fuel to limit warming to non-dangerous levels?
3. Will proponents of continued increase use of natural gas work with the State to replace fossil fuel with non-fossil fuel as quickly as possible?

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The '2°C capital stock' for electricity generation: Committed cumulative carbon emissions from the electricity generation sector and the transition to a green economy

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HIGHLIGHTS

- Defines '2°C capital stock' as infrastructure that gives a 50% chance of 2°C warming.
- The '2°C capital stock' for electricity generation will be reached by 2017 on current trends.
- New electricity generation assets globally must then be zero carbon to avoid stranding, CCS or CDR.
- Risk of stranded assets is relevant to investors and policy makers.

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Carbon budget
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Net zero emissions
Committed cumulative carbon emissions

ABSTRACT

This paper defines the '2°C capital stock' as the global stock of infrastructure which, if operated to the end of its normal economic life, implies global mean temperature increases of 2°C or more (with 50% probability). Using IPCC carbon budgets and the IPCC's AR5 scenario database, and assuming future emissions from other sectors are compatible with a 2°C pathway, we calculate that the 2°C capital stock for electricity will be reached by 2017 based on current trends. In other words, even under the very optimistic assumption that other sectors reduce emissions in line with a 2°C target, no new emitting electricity infrastructure can be built after 2017 for this target to be met, unless other electricity infrastructure is retired early or retrofitted with carbon capture technologies. Policymakers and investors should question the economics of new long-lived energy infrastructure involving positive net emissions.

1. Introduction

The human population has grown over 4-fold from 1.65 billion in 1900 to over 7 billion today [1,2]. Over a similar period, world average per capita output has increased almost 6-fold from ~$1300 in 1900 to ~$7600 in 2008 real GDP in 1990 US dollars [3]. This remarkable achievement has been accompanied by significant increases in pressure on the natural environment, and it is accordingly suggested that the current geological era be termed the 'Anthropocene' [4]. Humans may now be confronting 'planetary boundaries' [5]. Environmental concerns have been presented in the past, coupled with calls to arrest economic growth [6–8]. So far, price signals have triggered demand efficiencies, substitution, new supplies and new technologies that have moderated concerns about resource scarcity [9]. However, accurate price signals are absent for climate change and other natural capital such as biodiversity and fisheries. The trends are highly adverse, particularly on climate change [10,11]. Electricity generation (and heating) currently contributes approximately 25% of global anthropogenic greenhouse gas emissions, the main driver of observed climate change [12]. A global transition to clean electricity generation is therefore anticipated [13] and necessary to curtail future climate impacts. How rapid does this transition need to be for reasonable odds of limiting temperature increases to safe levels?

There are two critical inertias associated with addressing climate change that create two stock problems. First, built infrastructure in the energy sector is characterised by long lifetimes. In the EU, for example, approximately 29% of thermal power plant

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capacity is over 30 years old and 61% over 20 years old [14]; today's energy infrastructure even includes assets constructed over 50 years ago.[1] Energy sector investments made today are likely to be operating and emitting carbon dioxide (CO_2) for decades into the future. Building on Davis et al. [15], Davis and Socolow [16] [DS] advance a methodology for estimating these future emissions from energy sector assets, which we refer to as 'committed cumulative carbon emissions' (CCCE). An implication of this inertia for policy-makers is that greater focus should be upon investments in long-lived infrastructure, such as coal mines, oil and gas fields and power plants, than upon the operation of existing assets.

Second, the climate system has its own inertia. CO_2 emissions remain resident in the atmosphere for centuries and it is the *stock* of atmospheric CO_2 that affects temperatures, rather than the *flow* of emissions in any given year [17]. Many of the expected economic damages from climate change depend on peak warming, and peak warming is a function of cumulative carbon emissions ('CCE') (e.g. [18,19]). In recent years some policy makers have acknowledged the existence and implications of carbon budgets (e.g. [20]). Nevertheless, it remains common practice for policy-makers to focus on annual CO_2 emission reduction targets – such as reducing emissions by 40% by 2030 [21] – which are only indirectly relevant to the core objective of limiting the cumulative stock of carbon in the atmosphere.

This paper introduces the concept of a '2°C capital stock' for the electricity sector by combining DS's concept of CCCE with Allen et al.'s concept of a cumulative carbon budget. We define the '2°C capital stock' as the stock of infrastructure that implies future emissions consistent with a 50% probability of a peak global mean temperature increase of 2°C or less. By making use of integrated assessment model (IAM) scenarios of energy system transitions, we calculate the date at which the installed electricity infrastructure reaches the 2°C capital stock.

The implications for energy policy of this concept are significant. Once the 2°C capital stock for the electricity sector has been reached, all new additions to the stock of generating infrastructure need to be net zero emissions to meet the 2°C target with 50% probability, without subsequent large-scale deployment of carbon capture technologies[2] or without the premature stranding of energy sector assets.

Our core result is that for a 50% probability of limiting warming to 2°C, assuming other sectors play their part, *no new investment in fossil electricity infrastructure (without carbon capture) is feasible from 2017 at the latest*, unless energy policy leads to early stranding of polluting assets or large scale carbon capture deployment. If other sectors remain on business as usual rather than a 2°C consistent pathway, even a stranding (i.e. premature retirement) of the entire global fossil fuel electricity generating capital stock today would not be sufficient to provide a 50% probability of limiting increases to 2°C. The paper highlights a set of choices for policy-makers: they can either (a) ensure that all new electricity generation investment is zero carbon from 2017, or (b) make major investments in retrofitting carbon capture technologies, which is at present expensive and uncertain to deliver at cost and at scale, (c) be prepared to strand substantial parts of the built fossil energy infrastructure, (d) invest heavily in negative emissions technologies, or (e) abandon the 2°C stabilisation goal and accept the substantial risks of dangerous climate change and the knock-on impacts [11].

This paper builds upon earlier research on committed emissions. Davis et al. [15] calculated committed cumulative emissions from combustion of fossil fuels by existing infrastructure between 2010 and 2060 and find that the capital stock in 2010 entailed a commitment to a warming around 1.3°C above the pre-industrial era. Guivarch and Hallegatte [23] build upon these results by including non-CO_2 greenhouse gases and inertia in transportation infrastructure to conclude that future climate policies need to consider existing polluting infrastructure if the 2°C stabilisation goal is to be met. Lecocq and Shalizi [24] conclude that mitigation policy should be targeted towards countries where long-lived infrastructure is being built at a rapid rate. Bertram et al. [25] find that under less stringent near-term policies, most of the near-term emissions come from additional coal-powered generation capacity and conclude that significant coal capacity would have to be retired in the future to meet warming targets. Johnson et al. [26] find that the timing and rate of the complete phase-out of coal-based electricity generation without CCS will depend mostly on the strength of near-term climate policies. They conclude that an effective strategy for reducing stranded capacity is to minimize new construction of coal capacity (without CCS) in the first place. Finally and perhaps most notably, the International Energy Agency reports in its 2012 World Energy Outlook that "…infrastructure in existence in 2017 and expected to continue to operate through to 2035 would emit all the cumulative emissions allowed in the 450 Scenario" ([27]; p. 265). This paper goes beyond the IEA in that we not only use the full variety of models and scenarios from the Intergovernmental Panel on Climate Change (IPCC), we also extend the analysis to 2100, present results for 1.5°C and 3°C carbon budgets, and further test the sensitivity of the results for the 2°C capital stock to a range of different assumptions and scenarios. Results of the analysis in this paper reinforce these previous findings.

The problems created by 'committed' emissions are also related to the concept of 'carbon lock-in', which is defined as "the tendency for certain carbon-intensive technological systems to persist over time, 'locking out' lower-carbon alternatives" [28]. For example, Unruh [29] explored how the barriers to the scale-up of low carbon alternatives created path-dependent increasing returns to scale in the fossil energy sector. Kalkuhl et al. [30] show that market imperfections may trigger lasting dominance of one technology over another for several decades, even if that other technology is more efficient.

Our paper adds to the existing body of literature and extends the existing research by adding future emissions from all sectors as projected in the IPCC 5th Assessment Report [IPCC AR5] scenarios. Focusing on long-lived committed CO_2 emissions, we calculate not only the remaining carbon budgets in 2014 for the polluting electricity generating capital stock but also the year in which the remaining budget will be exhausted. This paper assesses the impact of different levels of mitigation ambition in other sectors across the economy and the simplicity of our approach allows us to identify some of the key features that matter for the lock-in of polluting electricity generating infrastructure.

The paper is structured as follows. Section 2 sets out the data sources employed in the analysis and the methodologies used to analyse the data. Section 3 discusses the results and sensitivities of our analysis. Finally, Section 4 examines the policy choices and the implications for policymakers and investors.

2. Methods

To assess when the capital stock consistent with a 50% chance of limiting global warming to 2°C is reached, three elements are

[1] E.g. the 'Alpena Huron 07' subcritical coal generator in Alpena, MI (online since 1955 – 60 years) or the 'Anan 1' subcritical oil generator in Anan City, Japan (online since 1963 – 52 years) which are both still in operation according to the June 2015 version of the Platts WEPP database.

[2] Carbon capture technology in this context could include new or retrofitted electricity sector carbon-capture-and-storage (CCS) as well as technologies that remove CO_2 from the ambient air, commonly referred to as carbon dioxide removal (CDR) technologies [22].

required: (1) total cumulative carbon budgets consistent with the latest climate science for multiple peak warming thresholds and at different probabilities; (2) historical and projected committed future cumulative emissions from electricity generation and (3) projections for future emissions from all sectors.

The following subsections detail our methods in each of these areas. Section 2.1 details estimates of the carbon budget for different peak warming and probability threshold combinations. Section 2.2 describes assumptions for the evolution of the committed cumulative emissions from the electricity generation capital stock. Section 2.3 describes scenarios for the future realised emissions from different sectors.

2.1. Remaining carbon budget and treatment of short-lived climate pollutants

The analysis in the current paper is solely focused on long-lived CO_2 emissions. While the emissions of short-lived climate pollutants (SLCPs), notably methane and black carbon, also provide a radiative forcing on the climate system, long-term temperature stabilization (over the timescale of centuries) is largely a function of the cumulative stock of long-lived greenhouse gases (GHGs), predominantly CO_2, when global net emissions of long-lived gases fall to zero [17]. The contribution of SLCPs to peak warming is a function of their rate of emission at the time when net emissions of long-lived GHGs reach zero [31]. If emissions of SLCPs were then stopped completely, their contribution to long-term irreversible warming would eventually decay to zero, unlike CO_2, from which warming persists for centuries. Due to the essentially irreversible impact of CO_2 emissions on the climate system, we focus our analysis on the risk of locking in irreversible temperature change via committed future cumulative emissions of CO_2 from infrastructure being built over the next few decades. When thinking about temperature changes at specific times over the 21st century, SLCP-induced warming will have an important role to play and the impact of different SLCP mitigation choices needs to be fully considered alongside CO_2 [32].

Estimates of cumulative CO_2 emission budgets depend on the magnitude of peak warming and probability of restricting warming to beneath this value (due to uncertainty in the physical climate response) being considered. We take estimates for multiple peak warming thresholds at multiple probabilities from Table 2.2 of the IPCC 5th Assessment Synthesis Report [33], summarised in Table 1. These carbon budgets assume a contribution to peak warming from SLCPs consistent with the RCP8.5 high emissions scenario [34]. The probability thresholds given here correspond to percentiles of the CMIP5 Earth System Model distribution and are not equivalent to the calibrated likelihood statements of IPCC Working Group 1 [35] as those calibrated likelihood statements also assess uncertainty not captured by the models. To calculate historical emissions, we use 2011 cumulative emissions from IPCC AR5 WG1 (515GtC) updated with emissions data for 2011–2013 from the Global Carbon Budget 2014 [36].

For our analysis we focus mainly on a budget to achieve $\leqslant 2$°C peak warming with a 50% probability. For peak warming of 2°C the remaining budget is 322GtC (1184GtCO_2). The budget varies between 77GtC (284GtCO_2) for <1.5°C (66% probability) and 853GtC (3134GtCO_2) for <3°C (33% probability).

Table 1
2011 and 2014 remaining cumulative carbon budgets for different peak warming and probability thresholds. Data and information are taken from Table 2.2 of [33] with cumulative emissions between 2011 and 2013 calculated from Le Quéré et al. [36].

	Warming[b]	Likelihood[c] (%)	Budget (CCE)[d] in 2011	Emitted (CCE) 2011–2013	Budget (CCE)[d] in 2014
[GtCO_2]	<1.5°	66	400	116	284
		50	550	116	434
		33	850	116	734
	<2.0°	66	1000	116	884
		50	1300	116	1184
		33	1500	116	1384
	<3.0°	66	2400	116	2284
		50	2800	116	2684
		33	3250	116	3134
[GtC][a]	<1.5°	66	109	32	77
		50	150	32	118
		33	231	32	200
	<2.0°	66	272	32	241
		50	354	32	322
		33	408	32	377
	<3.0°	66	653	32	622
		50	762	32	731
		33	885	32	853

[a] Conversion factor: 1GtC = 3.664GtCO_2.
[b] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[c] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[d] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios. Values are rounded to the nearest 50.

2.2. The CCCE of electricity infrastructure

Using emission intensity and generation data from 2009 (CARMA database; see www.carma.org), DS analyse the currently existing polluting electricity infrastructure and find that *new* fossil fuel power plants (i.e. oil, coal, and gas) built in 2012 will alone cumulatively emit approximately 5.2GtC if their average lifetime is 40 years. The corresponding estimate of 'committed' emissions from *all* fossil fuel power plants operating in 2012 is 84GtC.[3]

DS not only analyse the currently existing capital stock of polluting electricity infrastructure, but also how this capital stock has developed in the past. New coal-fired power plants continue to be built, and "more have been built in the past decade than in any previous decade."[4] According to their calculations, "worldwide, an average of 89 gigawatts per year (GWyr^{-1}) of new coal generating capacity was added between 2010 and 2012, 23GWyr^{-1} more than in the 2000–2009 time period and 56GWyr^{-1} more than in the 1990–1999 time period."[5] Overall they conclude that the world's committed emissions from electricity infrastructure have grown by approximately 4% p.a. over the last decade.

Much of that accelerated growth over the past decade comes from the renaissance of coal (described e.g. by Steckel et al. [37]) and given the current pipeline of planned coal-fired power stations, our central scenario assumes a continuation of 4% p.a. growth in committed cumulative emissions from the electricity capital stock in the coming decades. We examine sensitivities to this growth rate in the range 0–7% p.a. An exponential growth pathway of committed cumulative emissions is likely to be unrealistic in the long run. However, given planned investments over the next decade and the limited time remaining until the 2°C capital

[3] According to DS and depending on the assumed average lifetime of energy infrastructure, committed emissions in 2012 vary from 26.8GtC (20 years lifetime) up to 157.5GtC (60 years lifetime).
[4] Davis and Socolow [16], p.1.
[5] Ibid.

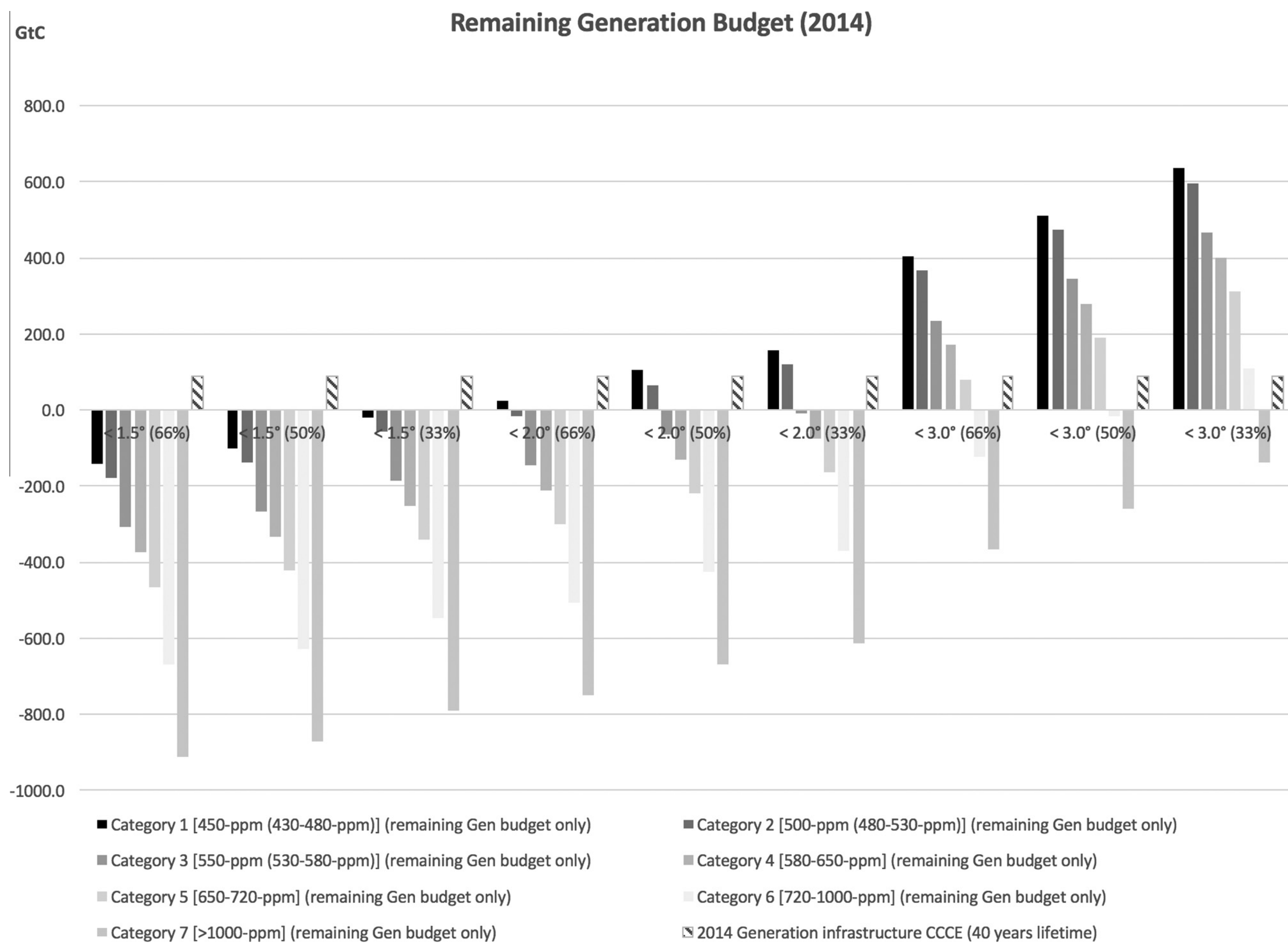

Fig. 1. Remaining 2014 carbon budget for electricity generation, for different peak warming magnitudes and probabilities, decomposed by groupings of emissions pathways (denoted by scenario 2100 concentrations). The 2014 CCCE from electricity generation infrastructure (40 years lifetime) is shown by the hatched bar for each case.

stock is reached, these growth assumptions remain broadly plausible in the relatively short timeframes under consideration.

2.3. Future realised emissions

The electricity sector is not the only source of CO_2 emissions within the economy. Industry, land-use, transport and other non-electricity sectors also contribute to global emissions. Given an overall cumulative emissions budget, cumulative emissions across the century from other sectors reduce the cumulative emissions that can be emitted from the electricity sector.

For ranges of possible scenarios of cumulative emissions from other sectors, we use the IAM database compiled for IPCC AR5 WG3.[6] IAM scenarios aim to find a cost-optimal energy system transition to meet a goal for CO_2-equivalent (incorporating the impacts of some non-CO_2 climate forcing agents) atmospheric concentrations in 2100, given certain constraints on policy action and technological availability [38]. IAMs are highly idealised and often assume globally coordinated policy action that can start immediately. These emission scenarios are not harmonised – in other words, different scenarios have different assumed histories over 2005–2015 that can be different to the actual historical emissions. However, the spread of different scenarios gives a range of futures for 21st century cumulative emissions from sectors other than electricity generation under varying degrees of climate policy ambition.

In these scenarios, the emission pathways in the different sectors are highly connected to each other. Thus, in any given scenario, the budget remaining for electricity generation emissions (after accounting for emissions from the other sectors) is itself a function of the electricity generation emissions assumed in that scenario. The endogenous nature of the power sector increases the complexity of comparative scenario analysis. In order to explore the year in which the 2°C electricity generation capital stock is reached under different assumptions, we consider different (exogenous) rates of growth in future emissions from the electricity generation, holding other features of the scenarios constant. Results are reported below in our sensitivity analyses. It is also notable that in many scenarios, emissions from non-electricity sectors have not reached zero in 2100, our cut-off year. As we do not account for post-2100 emissions from these sectors, our calculations for the remaining emissions budget for electricity generation is likely to be an overestimate.

Scenarios can be grouped by their 2100 CO_2-eq atmospheric concentration [41]. Scenarios with 2100 concentrations in the range 430–480-ppm correspond to an IPCC assessed *likely* (>66%) probability of warming in the 21st century remaining beneath 2°C, when assessed under representative climate response uncertainty [12]. 480–530-ppm scenarios correspond to >50% probability (when concentrations do not overshoot 530-ppm) and to <50% probability when overshoots do occur. All other scenario groupings for higher 2100 concentrations are consistent with successively less likely probabilities of limiting warming to beneath 2°C.

We use these scenarios for estimates of emissions from sectors other than electricity generation across the century but also for estimates of *realised* electricity generation emissions over time. In the near-term, there are very small differences between

[6] Found at https://tntcat.iiasa.ac.at/AR5DB/dsd?Action=htmlpage&page=about.

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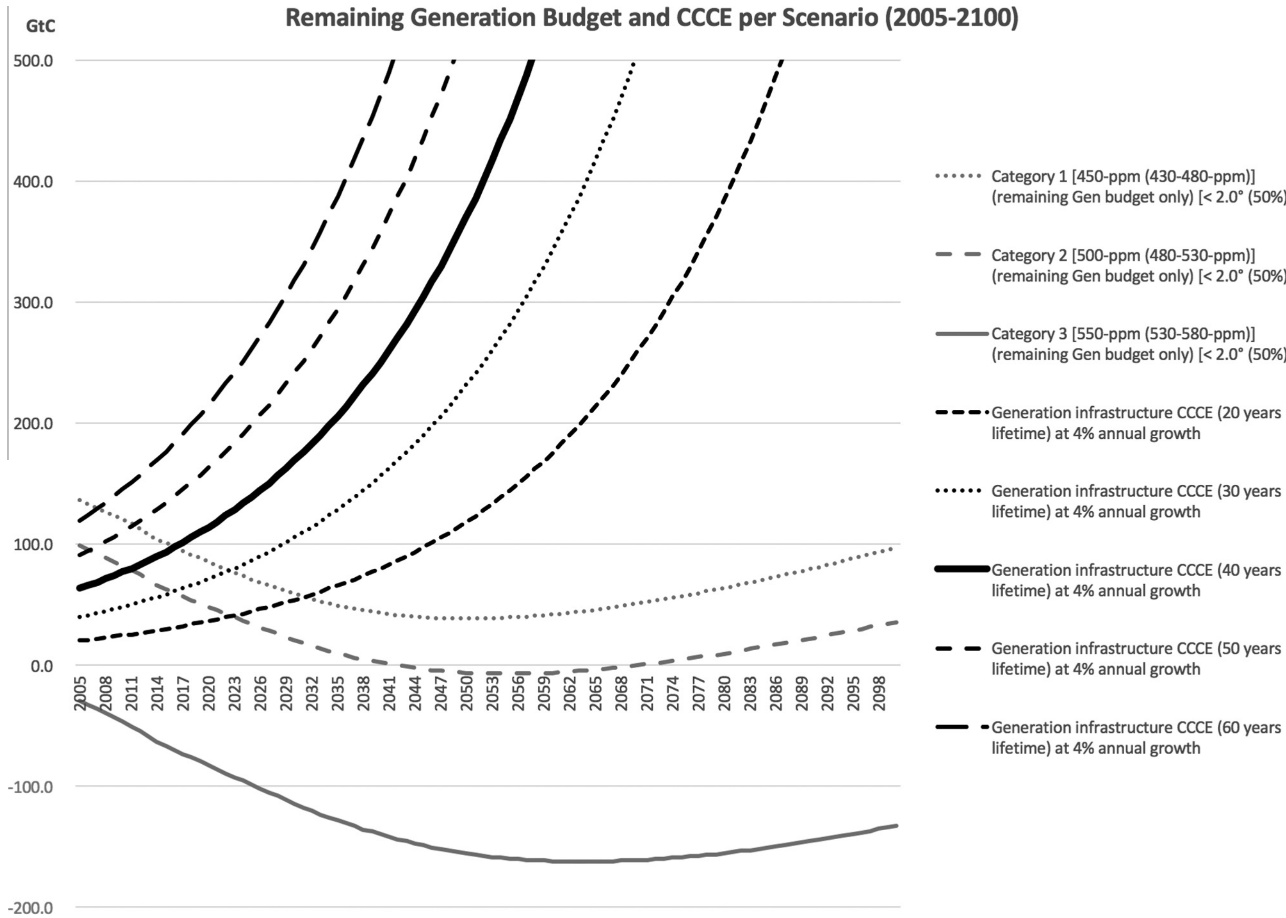

Fig. 2. Future development of CCCE from electricity infrastructure (assuming different lifetimes and a 4% growth p.a.) and remaining generation budget for 430–580-ppm pathways, 2005–2100, assuming a ⩽2°C (50% probability) overall budget.

scenarios in the degree to which realised emissions reduce the size of the remaining carbon budget. This is despite likely significant differences in electricity sector investments and partially reflects the inertia of realised emissions to previously locked-in emissions. However, a useful area for further work would be to enable the committed cumulative emissions to be calculated directly from the reported IAM output for a given emission scenario, in order to more precisely capture the relationship between growth in committed and realised emissions in electricity generation and other sectors.

3. Results

3.1. Remaining electricity sector cumulative emissions budget in 2014

Using the scenarios described in Section 2.3, it is possible to assess the present-day (2014) remaining carbon budgets for electricity generation, dependent on the level of ambition of future mitigation in non-electricity sectors. As shown in Fig. 1, if future emissions from all sectors follow the mean of the 430–480-ppm scenarios, and today's electricity infrastructure has an average lifetime of 40 years, by 2014 we were already committed to 87% (or 136% for 480–530-ppm non-electricity pathways) of the remaining 2014–2100 electricity generation budget for a 2°C peak warming target with 50% probability through existing infrastructure. For a ⩽2°C goal (33% probability), more than half (57%) (or 75% for 480–530-ppm) of the remaining electricity generation budget has already been committed. Mean transition pathways in the non-electricity sectors that are less ambitious than the 430–480 ppm and 480–530 ppm groupings are likely to entail that the 2°C electricity capital stock has already been reached. Too much carbon emitting electricity capital stock has already been installed to be consistent with a peak warming goal more ambitious than 2°C with 66% probability, irrespective of the non-electricity emissions pathway.

3.2. Commitment year for 2°C (50% probability) electricity infrastructure capital stock

Assuming committed cumulative emissions from the electricity sector continue to increase at 4% p.a. (following DS and Tidball et al. [40]) the date at which the electricity sector 2°C capital stock can be calculated, dependent on the alternative futures of realised emissions. As shown by the solid black line in Fig. 2, if all other emissions follow a mean scenario consistent with overall 2100 430–480-ppm concentrations, we will have built the electricity generating capital stock consistent with a ⩽2°C (50% probability) budget, by 2017. Such a scenario implies very significant mitigation action in all sectors, and even if this could be realised, all new electricity capital would have be to zero carbon by 2017, or rely on future carbon capture technology in order to remain consistent with an overall ⩽2°C (50% probability) budget.

If emissions from other sectors are only slightly higher, following a 480–530-ppm path instead of a 430–480-ppm path, the 2°C electricity capital stock was installed in 2011. If realised emissions in all sectors follow pathways consistent with concentrations above 530-ppm, new electricity generating assets needed to be

Table 2
Year in which generation budget is committed (assuming 40 years lifetime and 4% growth p.a.) for mean realised emissions scenario groupings and peak warming budgets (bold years are future years, after 2015).

Lifetime of capital stock 40 years at 4% annual growth				Year of budget commitment (2006–2100)[e]						
Warming[a]	Likelihood[b] (%)	Budget (CCE)[c] in 2014	Committed CCE[d] in 2014	Cat. 1 450-ppm (430–480-ppm)	Cat. 2 500-ppm (480–530-ppm)	Cat. 3 550-ppm (530–580-ppm)	Cat. 4 580–650-ppm	Cat. 5 650–720-ppm	Cat. 6 720–1000-ppm	Cat. 7 >1000-ppm
[GtC]										
<1.5°	66	77	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
	50	118	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
	33	200	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
<2.0°	66	241	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
	50	322	90	**2017**	2011	<2006	<2006	<2006	<2006	<2006
	33	377	90	**2024**	**2019**	<2006	<2006	<2006	<2006	<2006
<3.0°	66	622	90	**2048**	**2045**	**2032**	**2025**	2013	<2006	<2006
	50	731	90	**2055**	**2053**	**2042**	**2036**	**2027**	<2006	<2006
	33	853	90	**2062**	**2059**	**2051**	**2045**	**2038**	**2017**	<2006

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[b] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[c] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios.
[d] Only electricity generation capital stock based on Davis and Socolov [3]: CCCE of 307GtCO_2 (84GtC) in 2012 growing by 4% p.a. (assuming a 40 year lifetime).
[e] Year of budget commitment is the year in which enough electricity generation capital stock is built to consume remaining budget for only electricity generation.

zero carbon long ago to meet the 2°C (50% probability) target (see Table 2). These findings are largely consistent with existing integrated assessment literature (reviewed e.g. in Krey [39]) examining the question of delayed action on climate change mitigation. If electricity sector mitigation is delayed, the 2°C target will be hard to achieve due to the locked in emissions from the existing energy infrastructure.

As shown in Table 2, even in the most stringent IPCC scenarios we have already committed to more electricity generation emissions with today's infrastructure than any scenario contains which would give us a realistic chance to 1.5°C global warming. Meeting a 1.5°C target without CCS or asset stranding would have required that all additions to the electricity sector were zero carbon from 2006 onwards, at the latest.

3.3. Sensitivity of results

The year at which the 2°C electricity capital stock is reached depends on a number of assumptions. The assumptions for future cumulative carbon emissions from non-electricity sectors have a significant effect on the remaining budget for electricity, and hence upon the point in time at which committed emissions from the electricity sector imply temperature increases of 2°C. While we use the different IPCC scenarios and models to cover a wide range of possible non-electricity sector emissions in our approach, this section tests the sensitivity of our results towards other relevant assumptions. In particular, we test the sensitivity of our results towards: (1) the assumed lifetime of polluting electricity-generating infrastructure; (2) the annual growth rate of CCCE; (3) the influence of CCS in later decades of this century on the remaining carbon budgets; and (4) the variance of emissions pathways within a certain IPCC ppm range.

3.3.1. Lifetime of polluting capital stock

Fig. 2 shows the development of CCCE from the electricity sector under different assumed plant lifetimes. For all realised emissions pathways a reduction (or increase) of the mean lifetime of power plants has significant impact on the commitment year.

If, for example, the average economic lifetime of existing and future fossil-fuelled power plants could be reduced from 40 to 30 years, the commitment year for the 2°C (50% probability) capital stock would be between 2016 (480–530-ppm pathways) and 2023 (430–480-ppm pathways) instead of 2011–2017. Table 3 shows an overview of commitment years under the 30 years lifetime assumption for all budgets and scenarios. Given that historically the average economically useful life of electricity generating infrastructure is 40 years [40,16], this would imply stranding assets 10 years before the end of their useful life.

When generating capacity is prematurely retired, the type of replacement plant is highly relevant. Coal to gas substitution may not, for instance, reduce CCCE. As discussed further below, if coal-fired generation capacity is replaced immediately by new CCGTs with 40-year lifetimes, CCCE may actually be higher than if the coal-fired plant were instead replaced later, at the end of its economic life, with zero carbon generation.

3.3.2. Different growth rates of polluting capital stock

Fig. 3 shows the development of CCCE of generation capital stock under different growth assumptions. Given the short time until the expected commitment year, only dramatic reductions of the annual growth rate of CCCE can have a meaningful impact. In the analysed scenarios of 430–530-ppm pathways, a small reduction in the growth rate has an insignificant impact on the commitment year. If, for example, the annual growth rate of existing and future generation CCCE could be reduced from 4% to 3% p.a., the relevant years for the 2°C (50% probability) capital stock remain

Table 3
As for Table 2 but assuming a 30 year mean lifetime of existing electricity sector generation stock (bold years are future years, after 2015).

Lifetime of capital stock 30 years at 4% annual growth					Year of budget commitment (2006–2100)[e]						
	Warming[a]	Likelihood[b] (%)	Budget (CCE)[c] in 2014	Committed CCE[d] in 2014	Cat. 1 450-ppm (430–480-ppm)	Cat. 2 500-ppm (480–530-ppm)	Cat. 3 550-ppm (530–580-ppm)	Cat. 4 580–650-ppm	Cat. 5 650–720-ppm	Cat. 6 720–1000-ppm	Cat. 7 >1000-ppm
[GtC]	<1.5°	66	77	56	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	118	56	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		33	200	56	<2006	<2006	<2006	<2006	<2006	<2006	<2006
	<2.0°	66	241	56	2009	<2006	<2006	<2006	<2006	<2006	<2006
		50	322	56	**2023**	**2016**	<2006	<2006	<2006	<2006	<2006
		33	377	56	**2032**	**2026**	<2006	<2006	<2006	<2006	<2006
	<3.0°	66	622	56	**2060**	**2056**	**2041**	**2032**	**2019**	<2006	<2006
		50	731	56	**2068**	**2065**	**2053**	**2045**	**2034**	<2006	<2006
		33	853	56	**2074**	**2072**	**2062**	**2056**	**2046**	**2023**	<2006

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[b] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[c] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios.
[d] Only electricity generation capital stock based on Davis and Socolov [16]: CCCE of 307GtCO_2 (84GtC) in 2012 growing by 4% p.a. (assuming a 30 year lifetime).
[e] Year of budget commitment is the year in which enough electricity generation capital stock is built to consume remaining budget for only electricity generation.

as before, namely between 2011 (480–530-ppm pathways) and 2017 (430–480-ppm pathways). Table 4 shows an overview of commitment years under the 3% p.a. growth assumption for all budgets and scenarios.

This insensitivity is due to the large already existing commitments from the energy sector compared to the ⩽2°C (50% probability) budget (87%, see Fig. 1). Even a significant structural change in future investments in this capital stock would, without a premature shut-down of polluting capacity, only marginally affect the relevant 'cut-off' year. For instance, under the assumption of a 7% p.a. growth rate, the commitment year is only slightly earlier. Under the assumption of 0% annual growth of CCCE (i.e. new investment in polluting generation capacity only replaces retiring capacity), the remaining generation budget is still used up in the early 2020s (see Table 8).

3.3.3. Sensitivity to carbon capture technology assumptions

Assuming realised emissions from all sectors consistent with 430–480 ppm scenarios, new generating infrastructure has to be net zero carbon by 2017. This finding does not imply that no new fossil generation investment is possible from 2017 onwards. It implies that any new committed fossil emissions from 2017 must be eliminated by incorporating carbon capture, offset by retrofitting carbon capture for existing infrastructure or by carbon dioxide removal (CDR) technologies to remove the same amount of cumulative carbon from the atmosphere as the newly built infrastructure will emit over its lifetime.

IPCC scenarios that assume more carbon capture tend to involve greater near-term emissions (precisely because the capture technologies operate in the future). This implies a *lower* available near-term budget for electricity generation, which moves the date of the 2°C capital stock (with assumed CCS in the future) earlier in time. Carbon capture deployment is particular prevalent in the 430–530-ppm groupings.

Table 5 shows the calculations under the assumption that CCS has no significant impact to 2100. In scenarios in which no CCS is deployed new power plants must be net zero several years later (2019–2029). This is explained by the fact that a 430–530-ppm consistent pathway without CCS (which primarily affects the electricity sector) requires stronger and faster decarbonisation in sectors other than electricity generation. As a consequence, there is a larger share of cumulative carbon budget available for electricity generation, which hence has more time before reaching the 2°C capital stock.

Similarly, in scenarios in which significant CCS is deployed, we find that the 'cut-off' date moves closer to the present (Table 6). Assuming that CCS will capture most of the emissions from generating infrastructure in future decades of this century would require committed emissions to stop growing by 2010 (480–530-ppm pathways) and by 2016 (430–480-ppm). Scenarios that assume that most of the electricity sector emissions will be captured in later decades of the century allow for a slower decarbonisation of other sectors and hence leave less generation budget to the electricity sector today.

In nearly all 430–530-ppm scenarios, CCS plays an important role. Only 7 scenarios from the 430 to 480-ppm pathways assume no CCS between 2005 and 2100 (108 scenarios assume CCS) and only 21 scenarios assume no CCS in the 480–530-ppm pathways (254 scenarios assume CCS), raising the question about the plausibility of reaching a ⩽2°C (50% probability) goal without significant CCS deployment.

3.3.4. Sensitivity to non-electricity emission pathways

In our approach, we use simple averages of the emissions of all IPCC scenario-model combinations within a certain ppm range (e.g. 430–480-ppm). However, within this range the emission pathways

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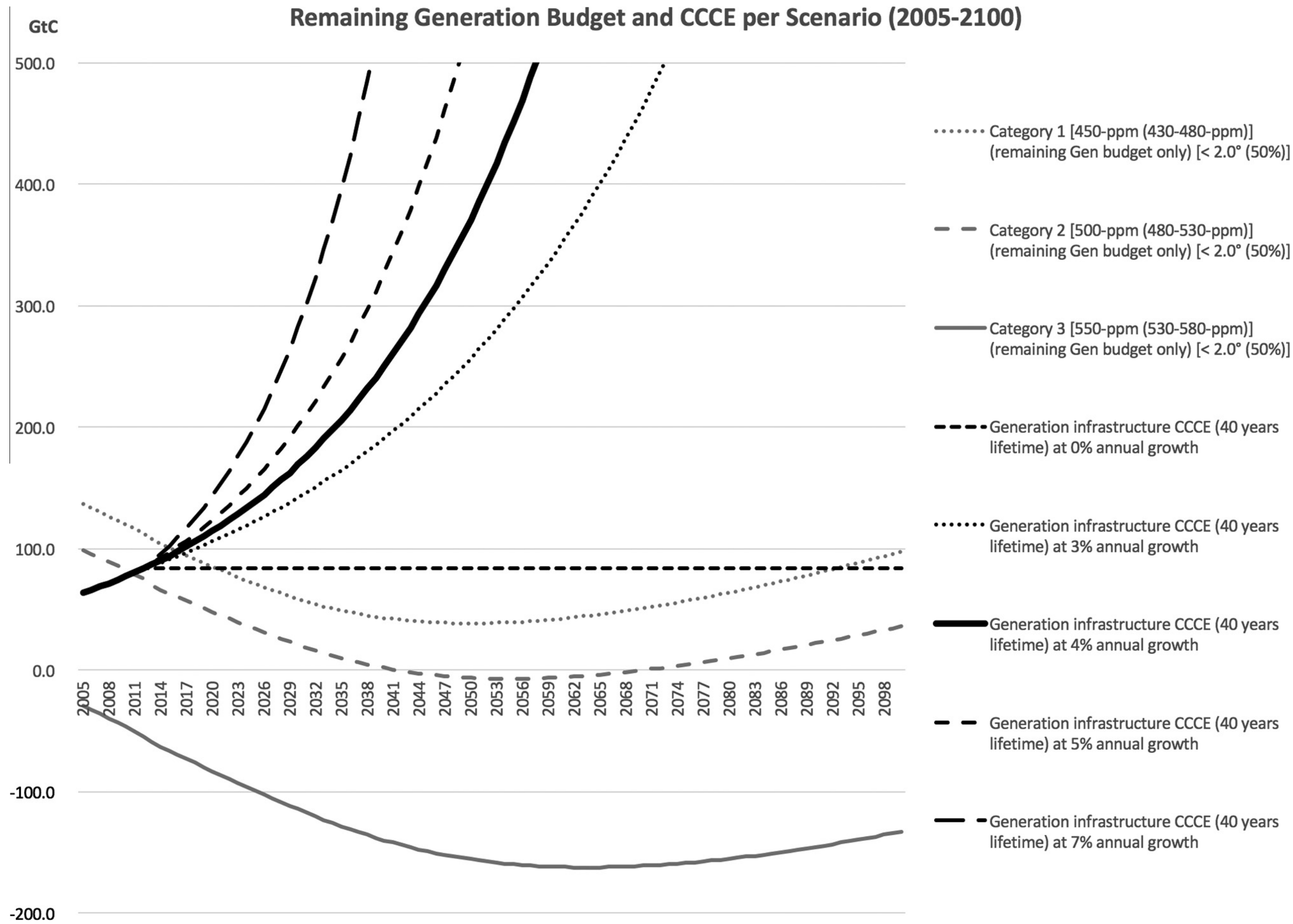

Fig. 3. As for Fig. 2 but for different post-2012 rates of increase in committed cumulative emissions (CCCE) for the electricity sector.

of the combinations can be significantly different from each other. We also test the sensitivity of our results to different emission pathways within the 430–480-ppm and the 480–530-ppm ranges.

For each ppm range, we report the average and median values of each relevant set of scenarios along with the scenario with the maximum and minimum *cumulative 2005–2100 carbon emissions* from the electricity sector. The "max" scenario hence assumes the emissions trajectory of the model-scenario-combination with the highest possible electricity-sector emissions within the respective ppm range[7] (relatively lower non-electricity-sector emissions) and the "min" scenario the trajectory of the combination with the lowest electricity-sector emissions[8] (relatively higher non-electricity-sector emissions).

Table 7 shows that the differences between the "max" and "min" values. Assuming, for example, that non-electricity sector emissions follow a pathway with relatively steep decarbonisation over the next decades ("max" scenario) would leave until 2024 (430–480-ppm scenarios) or 2023 (480–530-ppm scenarios) to completely decarbonise new electricity sector investments (for the 2°C (50% probability) target). Assuming that non-electricity sector emissions follow a pathway with relatively high emissions ("min" scenario) would imply that we already reached the date from which on new electricity sector investments would have been required to be net zero in 2006 or before to stay within the 2°C (50% probability) budget.

3.3.5. Combined sensitivities to emission pathways and CCCE growth rates

We also briefly consider sensitivities to combinations of the assumed CCCE growth rate and the variance in emission pathways. Specifically, we test the sensitivity of the year in which we will have committed to 2°C (50% probability) warming given annual CCCE growth rates of 0–7% in combination with different possible pathways ("min", "max", "median", "average") within the 430–480-ppm and the 480–530-ppm categories.

We find that, assuming extremely low growth rates of CCCE (0–2% p.a.) and emission pathways for non-electricity sectors at the low boundary of possible pathways, the commitment year can be pushed to the late 2020s or even early 2030s. Assuming more likely growth rates of CCCE close to the average growth rates over the past decade of 3–6%, and the same very optimistic non-electricity sector emission pathways the commitment year comes closer to today (2021–2025). Assuming non-electricity sector emissions at the upper boundary of possible 430–480-ppm and 480–530-ppm pathways the annual growth rate of CCCE does not matter as we would have already committed to 2°C in 2006 or before.

4. Discussion

4.1. Policy choices

Nation states affirmed the target to limit warming to below 2°C in 2011 at COP 17 in Durban, and again in 2015 at COP 21 in Paris. The main finding of this paper, however, is that the '2°C capital

[7] MERGE-ETL_2011 + AMPERE2-450-LimSW-HST for the 430–480-ppm range and GCAM 3.0 + EMF27-550-EERE for the 480–530-ppm range.

[8] MERGE_EMF27 + EMF27-450-FullTech for the 430–480-ppm rage and IMACLIM v1.1 + AMPERE2-450-NucOff-LST for the 480–530-ppm range.

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Table 4
As for Table 4 but assuming a 3% p.a. growth rate of CCCE from 2012 on (bold years are future years, after 2015).

Lifetime of capital stock 40 years at 3% annual growth					Year of budget commitment (2006–2100)[e]						
	Warming[a]	Likelihood[b] (%)	Budget (CCE)[c] in 2014	Committed CCE[d] in 2014	Cat. 1 450-ppm (430–480-ppm)	Cat. 2 500-ppm (480–530-ppm)	Cat. 3 550-ppm (530–580-ppm)	Cat. 4 580–650-ppm	Cat. 5 650–720-ppm	Cat. 6 720–1000-ppm	Cat. 7 >1000-ppm
[GtC]	<1.5°	66	77	89	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	118	89	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		33	200	89	<2006	<2006	<2006	<2006	<2006	<2006	<2006
	<2.0°	66	241	89	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	322	89	**2017**	2011	<2006	<2006	<2006	<2006	<2006
		33	377	89	**2026**	**2020**	<2006	<2006	<2006	<2006	<2006
	<3.0°	66	622	89	**2060**	**2055**	**2036**	**2027**	2013	<2006	<2006
		50	731	89	**2070**	**2066**	**2050**	**2041**	**2029**	<2006	<2006
		33	853	89	**2079**	**2075**	**2063**	**2054**	**2043**	**2017**	<2006

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[b] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[c] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios.
[d] Only electricity generation capital stock based on Davis and Socolov [16]: CCCE of 307GtCO_2 (84GtC) in 2012 growing by 3% p.a. after 2012. (assuming a 40 year lifetime).
[e] Year of budget commitment is the year in which enough electricity generation capital stock is built to consume remaining budget for only electricity generation.

Table 5
As for Table 4 but only scenarios that don't use CCS in the next century are included in the grouping means (bold years are future years, after 2015).

Lifetime of capital stock 40 years at 4% annual growth					Year of budget commitment (2006–2100)[e] Without CCS						
	Warming[a]	Likelihood[b] (%)	Budget (CCE)[c] in 2014	Committed CCE[d] in 2014	Cat. 1 450-ppm (430–480-ppm)	Cat. 2 500-ppm (480–530-ppm)	Cat. 3 550-ppm (530–580-ppm)	Cat. 4 580–650-ppm	Cat. 5 650–720-ppm	Cat. 6 720–1000-ppm	Cat. 7 >1000-ppm
[GtC]	<1.5°	66	77	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	118	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		33	200	90	2012	<2006	<2006	<2006	<2006	<2006	<2006
	<2.0°	66	241	90	**2017**	2008	<2006	<2006	<2006	<2006	<2006
		50	322	90	**2029**	**2019**	<2006	<2006	<2006	<2006	<2006
		33	377	90	**2035**	**2027**	2007	<2006	<2006	<2006	<2006
	<3.0°	66	622	90	**2054**	**2050**	**2038**	**2030**	<2006	<2006	<2006
		50	731	90	**2060**	**2056**	**2047**	**2039**	<2006	<2006	<2006
		33	853	90	**2065**	**2062**	**2054**	**2048**	**2021**	**2019**	<2006

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[b] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[c] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios.
[d] Only electricity generation capital stock based on Davis and Socolov [16]: CCCE of 307GtCO_2 (84GtC) in 2012 growing by 4% p.a. (assuming a 40 year lifetime).
[e] Year of budget commitment is the year in which enough electricity generation capital stock is built to consume remaining budget for only electricity generation.

Table 6
As for Table 5 but only scenarios that use CCS in the next century are included in the grouping means (bold years are future years, after 2015).

	Lifetime of capital stock 40 years at 4% annual growth				Year of budget commitment (2006–2100)[e] With CCS						
	Warming[a]	Likelihood[b] (%)	Budget (CCE)[c] in 2014	Committed CCE[d] in 2014	Cat. 1	Cat. 2	Cat. 3	Cat. 4	Cat. 5	Cat. 6	Cat. 7
					450-ppm (430–480-ppm)	500-ppm (480–530-ppm)	550-ppm (530–580-ppm)	580–650-ppm	650–720-ppm	720–1000-ppm	>1000-ppm
[GtC]	<1.5°	66	77	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	118	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		33	200	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
	<2.0°	66	241	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	322	90	**2016**	2010	<2006	<2006	<2006	<2006	<2006
		33	377	90	**2023**	**2018**	<2006	<2006	<2006	<2006	<2006
	<3.0°	66	622	90	**2048**	**2044**	**2031**	**2024**	2013	<2006	<2006
		50	731	90	**2055**	**2052**	**2041**	**2035**	**2026**	<2006	<2006
		33	853	90	**2061**	**2059**	**2050**	**2045**	**2037**	**2015**	<2006

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[b] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[c] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios.
[d] Only electricity generation capital stock based on Davis and Socolov [16]: CCCE of 307GtCO$_2$ (84GtC) in 2012 growing by 4% p.a. (assuming a 40 year lifetime).
[e] Year of budget commitment is the year in which enough electricity generation capital stock is built to consume remaining budget for only electricity generation.

stock' for the global electricity generation sector will be reached in 2017. Even this finding assumes emissions from other sectors shift onto a 2°C consistent pathway, which may well be optimistic. In short, the energy system is now at risk of undermining climate stability, perhaps the most important aspect of our natural capital and a key asset of a 'green economy'.

Our findings raise several fundamental questions, discussed in Section 4.3 below, but they also raise immediate and significant implications for the electricity sector. Logically, achieving the necessary transformation of the global electricity generation sector is going to require some combination of the following four options:

(1) New electricity generation assets are 100% zero carbon as soon as possible.
(2) Existing fossil assets are retrofitted with carbon capture.
(3) Existing fossil assets are stranded early, replaced by zero carbon assets.
(4) CDR technologies are used to hold temperatures below 2°C.

The most cost-effective combination of these four options will depend strongly upon the rates of decline in the costs of the relevant technologies, including nuclear, renewables including hydro, carbon capture, associated grid balancing technologies (including storage) and negative emission technologies. We briefly consider the four options in turn before examining the policy interventions that could support them.

First, numerous studies document the rapid cost declines of renewable energy [42–44], the feasibility of large scale deployment of zero emissions technologies including renewables, biomass, hydro, and nuclear [43,45,46], the overall modest macroeconomic costs such a program would entail [43,47,48], and the significant co-benefits of widespread zero carbon deployment [49,50]. Challenges remain, both on cost and grid integration [51,52], but large-scale deployment of zero carbon electricity appears inevitable; the question is not if but how fast.

Second, significant carbon capture deployment seems essential to enable existing or soon to be created carbon-emitting infrastructure to be retrofitted in order to reduce committed cumulative emissions (especially if mitigation in other sectors turns out harder than expected). Whilst CCS technologies are amongst the most expensive mitigation options available today, nearly all 2°C consistent pathways depend on significant CCS deployment in order to provide net negative emission capabilities, and excluding CCS technologies increases the modelled cost of meeting 2°C by around 2.5 times [12,38].

Third, new fossil assets deployed after reaching the 2°C capital stock could be retired early and replaced by zero carbon assets. While this is unlikely to economically superior to investing in zero carbon assets in the first place, there may be some value in delay; the costs of zero carbon technologies are declining rapidly and on average remain more expensive than fossil fuels. However, recent research shows that the cost declines are significantly attributable to increases in cumulative production volumes of zero carbon technologies [53], thus delay may significantly slow such price declines. Thus earlier action to shift to investments in zero emissions new capital stock may not only avoid later stranding of assets, but also accelerate the decline in costs of zero emissions technologies.

Finally, given the current trajectory of the global energy system and timeframes required to shift all new global energy investment to zero carbon, the probability of overshooting the 2°C capital stock is significant. Increased investments in CDR technologies might help mitigate such overshoot and to minimize asset stranding. However, given the current costs and technical challenges with widespread CCS deployment [54] it would not be prudent to rely

Table 7
Year in which generation budget is committed (assuming 40 years lifetime and 4% growth p.a.) for mean, median, min, and max electricity emission pathways in 2 different scenario groupings and peak warming budgets (bold years are future years, after 2015).

Lifetime of capital stock 40 years at 4% annual growth					Year of budget commitment (2006–2100)[e]							
	Warming[a]	Likelihood[b] (%)	Budget (CCE)[c] in 2014	Committed CCE[d] in 2014	450-ppm (430–480-ppm)				500-ppm (480–530-ppm)			
					Average	Median	Min	Max	Average	Median	Min	Max
[GtC]	<1.5°	66	77	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		50	118	90	<2006	<2006	<2006	<2006	<2006	<2006	<2006	<2006
		33	200	90	<2006	<2006	<2006	2008	<2006	<2006	<2006	2007
	<2.0°	66	241	90	<2006	<2006	<2006	2014	<2006	<2006	<2006	2013
		50	322	90	**2017**	**2016**	2006	**2024**	2011	2013	<2006	**2023**
		33	377	90	**2024**	**2024**	2014	**2029**	**2019**	**2021**	<2006	**2029**
	<3.0°	66	622	90	**2048**	**2049**	**2043**	**2048**	**2045**	**2046**	**2031**	**2048**
		50	731	90	**2055**	**2056**	**2052**	**2055**	**2053**	**2054**	**2041**	**2054**
		33	853	90	**2062**	**2062**	**2059**	**2061**	**2059**	**2060**	**2051**	**2060**

[a] Warming due to CO_2 and non-CO_2 drivers. Temperature values are given relative to the 1861–1880 period.
[b] Fractions of scenario simulations meeting the warming objective with that amount of CCE.
[c] CCE at the time the temperature threshold is exceeded that are required for 66%, 50%, and 33% of the simulations assuming non-CO_2 forcing follows the RCP8.5 scenario (similar emissions are implied by the other RCP scenarios). For the most scenario–threshold combinations, emissions and warming continue after the threshold is exceeded. Nevertheless, because of the cumulative nature of the CO_2 emissions these figures provide an indication of the cumulative CO_2 emissions implied by simulations under RCP-like scenarios.
[d] Only electricity generation capital stock based on Davis and Socolov [16]: CCCE of 307GtCO$_2$ (84GtC) in 2012 growing by 4% p.a. (assuming a 40 year lifetime).
[e] Year of budget commitment is the year in which enough electricity generation capital stock is built to consume remaining budget for only electricity generation.

Table 8
Year in which generation budget for ⩽2°C (50% probability) is committed (assuming 40 years lifetime and different annual growth rates of CCCE) for mean, median, min, and max realised emissions in 2 different scenario groupings and peak warming budgets (bold years are future years, after 2015).

Annual growth rate of CCCE[a] (%)	Year of budget commitment (2006–2100) for <2°C (50% probability)								
	Cat. 1 450-ppm (430–480-ppm)				Cat. 2 500-ppm (480–530-ppm)				Cat. 3–7 (>530-ppm)
	Average	Median	Min	Max	Average	Median	Min	Max	Average
0	**2021**	**2021**	2006	**2033**	2011	2014	<2006	**2034**	<2006
1	**2019**	**2019**	2006	**2030**	2011	2013	<2006	**2030**	<2006
2	**2018**	**2018**	2006	**2027**	2011	2013	<2006	**2027**	<2006
3	**2017**	**2017**	2006	**2025**	2011	2013	<2006	**2025**	<2006
4	**2017**	**2016**	2006	**2024**	2011	2013	<2006	**2023**	<2006
5	**2016**	**2016**	2006	**2022**	2011	2013	<2006	**2022**	<2006
6	**2016**	**2016**	2006	**2021**	2011	2013	<2006	**2021**	<2006
7	**2015**	**2015**	2006	**2020**	2011	2013	<2006	**2020**	<2006

[a] Assumed annual growth rate of CCCE from 2012; assumed 40 year lifetime of capital stock.

on CDR in later years as an alternative to rapid de-carbonization of the electricity generation system.

4.2. Policy instruments

In the introduction to this paper, we noted that annual CO_2 emission reduction targets only indirectly address the ultimate goal; it is possible to meet short-term flow targets while simultaneously installing new coal-fired power stations that make it economically impossible to meet cumulative emission targets. Better is to directly target cumulative emissions, and better still are policies that are a function of an index of attributable warming. In contrast, targets that are a function of time do not map directly onto cumulative emissions or to the observed climate response.

This distinction becomes relevant in the debate about the virtue of coal to gas substitution, which would reduce near-term emission flows. A stock-based analysis makes clear that coal to gas switching is only worthwhile if it reduces the expected future CCE. This may well be achieved if the fuel switching from coal to gas involves no new construction; existing gas-fired plants are run at a higher load factors, coal-fired plants are run at lower load factors. However, if new capital expenditure on gas is required, the analysis is more complicated. For instance, a 1GW coal-fired power station with emissions intensity of 1tCO$_2$/MWh and a load factor of 70% will emit 6.1MtCO$_2$ per annum.[9] With a residual lifetime of 10 years, expected future cumulative CO_2 emissions are therefore 61MtCO$_2$. Suppose this plant were retired early and replaced by a 1GW combined cycle gas turbine (CCGT) plant with emissions intensity of 0.5tCO$_2$/MWh a load factor of 70%, hence emitting 3.05MtCO$_2$ per annum. With a lifetime of 40 years, expected future cumulative emissions from the CCGT would be 122MtCO$_2$, compared to 61MtCO$_2$ from the coal plant. While annual emissions are cut in half over the first ten years, it is impossible to determine whether such switching reduces emissions unless it is specified what occurs after the coal-fired power station is closed in 10 years. If it would have otherwise been replaced with clean renewable energy, perhaps driven by continuing cost declines, then the strategy of switching from coal to gas will have been counterproductive. More careful analysis is required [55,56].

We now examine policy instruments that are candidates for constraining cumulative emissions to meet a 2°C target. Each

[9] 1GW × 365 days/year × 24h/day × 70% load factor = 6132GWh × 1000 MWh/GWh = 6,132,000 or 6.132 mio. MWh × 1 tCO$_2$/MWh = 6.132 mio. tons of CO_2 per annum.

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instrument incentivises one or more of the four options in Section 4.1.

4.2.1. Carbon prices

Carbon prices support action on all four options. They create incentives for actors to invest in new zero carbon assets, to retrofit (where economically and technically feasible) existing assets with carbon capture, to retire the highest emitting stock earlier and to develop negative emissions technologies. Carbon prices have the benefits of being technologically neutral and create incentives to de-carbonize efficiently. They work simultaneously on the demand and the supply side, increasing the costs to consumers of polluting fossil fuels, and reduce the returns to producers. They may also provide an economic 'double dividend' [57–60] of accelerating the transition to a green economy while simultaneously permitting reform and greater efficiency of the existing tax system, which tends to tax goods rather than bads.

However, the analysis in this paper makes clear that the scale and pace of the energy sector transformation required is dramatic. The level of carbon prices required to deliver, without other interventions, this rapid transformation would be far higher than is politically feasible in most countries, especially when it is considered that current effective net carbon prices may be negative, accounting for fossil fuel subsidies [52]. But this does not mean that carbon prices should be rejected; they should be implemented to the extent politically feasible (whether by a carbon tax or a quantity constraint and trading scheme). Pragmatism requires additional policy instruments.

4.2.2. Cumulative cap and trade

One more novel form of carbon pricing would be a *cumulative* emissions cap and trade system (cf [61]) consistent with estimates of the remaining carbon budget and the energy sector's appropriate share of that budget. This is different to existing cap and trade systems, which largely operate on a period-by-period basis, even if future emissions trajectories are sometimes described decades into the future. A cap on cumulative emissions would provide visibility of the carbon budget across the full lifetime of the assets. If it were credible, it would create incentives for de-carbonization of new capital stock and optimization of the existing portfolio (retrofits and retirements). Unfortunately, however, credibility over many decades is very difficult to achieve in practice, given the nature of changing governments in democratic societies.

4.2.3. Licensing requirements

Rules could be established to (1) require all new power plants to have zero (or close to zero) emissions; and (2) prevent high-emitting plants from being granted life extensions. Licensing rules have the political benefits of simplicity and clarity, and could potentially reduce the political economy challenges of allocating permits either within or between countries [62]. This approach might also reduce the political economy challenges of asset stranding. A more gradual version is to regulate carbon intensity in $kgCO_2/kWh$. China has taken this approach in its 5-year plan, as have several U.S. states [63]. Such rules could have the perverse effect of incentivizing a rush to build high emitting assets before the intensity target ratchets down to zero, but our analysis suggests the target should reach zero faster than the time it takes to plan and consent a new power plant.

4.2.4. Technology-based deployment support

Another approach is to regulate, subsidize, or tax specific energy producing technologies. Examples include:

- Subsidies or other regulations for accelerated renewable deployment (e.g. a feed-in-tariff or renewable portfolio standard).
- Subsidies for nuclear plans.
- Requiring all new coal plants to have CCS.

However, technology-based regulation has significant disadvantages. They tend to be inefficient, and more prone to regulatory capture than broad-based economic instruments. A well-designed ramp down to zero emissions for new electricity generation would be more effective, for it would not support one specific technology over another. For instance, renewable portfolio standards ignore potential contributions from non-renewable zero carbon sources (nuclear, fossil with CCS).

4.2.5. Research and development support

Finally, given that one of the most important variables is the relative cost of clean and dirty technologies, and given that there are well-understood market failures in research and innovation, there is a clear and well-accepted role for government to support clean technology research and development [63]. The surprise is that so little funding, relative for instance to implicit fossil fuel subsidies, is directed towards the brainpower that might actually provide solutions to vital human problems. The recent announcement at the first day of the COP21 of a coalition of countries and private sector investors to invest several billion dollars in clean energy R&D is well grounded in economic and political logic. The initiative is being led by Bill Gates and includes at least 20 countries (e.g. the U.S., France, India and others), which are expected to double the amount of R&D investment for clean energy from $5 to $10 billion over the next five years.

In addition, a policy offering a balance of effectiveness, efficiency, and political tractability may be an agreement that all *new* electricity generation (and any lifetime extensions) be zero carbon by a date in the near future, with countries agreeing their own ramps to that goal (cf [62]). Careful thought would need to go into designing such an agreement to minimize gaming during the transition period, but a zero carbon new build target by a fixed date has the advantages of simplicity and ease of monitoring.

4.3. Broader questions and directions for future research

Our finding that the 2°C capital stock for the global electricity generation will have been built by 2017 is based on the assumption that the transport, industry, land-use, etc. sectors also transition to a 2°C compatible pathway. Further detailed analysis of the committed emissions of these other sectors of the economy is needed. Taking into account the lifetime of transport assets (i.e. ships, trucks, cars, airplanes), industry assets (factories, mines, etc.), and residential assets (buildings, etc.) a closer analysis of the historic and expected development in these sectors would likely suggest that we have already passed the point of a 50% probability of 2°C without negative emissions or asset stranding.

Given the implausibility of all new electricity generation assets being zero carbon from now onwards, the role of both CCS and CDR are brought into focus [12]. How realistic is it to expect the successful large-scale deployment of CCS and CDR technologies? At present, rates of investment and deployment of these technologies are entirely negligible compared to the scale at which they appear to be required. Without major changes in policy or remarkable reductions in cost, both potentially important areas for further research, it does not appear realistic to expect these technologies to be deployed at scale.

If so, the only remaining logical outcomes are either that there is significant early stranding of fossil assets over the coming few decades – perhaps because accelerated cost declines in clean energy make this economically rational – or humanity accepts risks above 50% of exceeding 2°C warming. The implications for risks to investors in fossil fuels are rapidly becoming obvious. Further research is urgently needed on both the technologies, policies and institutions that could bring the costs of clean energy down as quickly as possible. So too is research on managing the process of asset stranding.

Finally, the analysis in this paper also raises a range of broader questions about the sustainability of our energy and economic systems. Existing policies are clearly inadequate to tackle global environmental problems, such as climate change or biodiversity loss. Much greater effort is required to create prices – including carbon prices – and economic incentives to ensure that individuals and corporations protect the natural environment. Carbon and other environmental prices form part of a broader shift in green fiscal policy away from taxing goods (labour) to taxing bads (pollution). Such a tax shift can generate a 'double dividend'. It is certainly time, as the IMF has argued, to cut subsidies for fossil fuel use [64].

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