GETTING TO ZERO:

STATEMENT OF FINDINGS AND POLICY IMPLICATIONS FROM AN EXPERT WORKSHOP ON DECARBONIZING THE GLOBAL ELECTRICITY SECTOR HELD JULY 14-15 2015[1]

I. Introduction

Stabilizing atmospheric concentrations of greenhouse gases such as carbon dioxide (CO2) will require nearly complete decarbonization of the electricity sector in the coming decades, an extraordinary transition that must occur during the same period when demand for global electricity services is expected to grow dramatically. The challenge of greatly expanding the world's electricity supply while transforming it to zero-carbon technology in the space of a few decades is unprecedented. Enabling practical pathways for such a far-reaching systemic transformation of electric generation is a complex challenge that will require a rigorous commitment to pragmatic analysis.

II. Key Points of Agreement

- *Near-total decarbonization of the electricity sector should be the primary goal for policymakers. This requires a focus on the long-term transition of energy systems, rather than short-term policies and narrow preferences for particular technologies.*

- *Effective and affordable decarbonization of the power sector will require building a reliable and integrated system of multiple low-carbon technologies.*

- *Current business investments, policy decisions, and research and development can facilitate the development of a zero-carbon future—but they can also lead to dead ends that constrain or prevent future progress.*

- *Technological advances and system adaptations have increased our ability to integrate variable generation sources such as solar and wind. However, the best available information and analysis indicates there are important technical and economic*

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[1] On July 14-15, 2015, two dozen experts met in Cambridge, Massachusetts to consider lessons from a suite of studies on strategies for developing electric systems that are decarbonized, reliable, and affordable. The workshop, sponsored by the Clean Air Task Force and the Energy Innovation Reform Project, included presentations on systems analysis of low-carbon electricity pathways, including the interaction of multiple forms of electric generation with transmission, storage, and demand management. Case studies of various low carbon energy combinations in the United States and Europe, from regional to state-scale, were considered, with a substantial focus on systems involving high levels (>50% of annual energy) of variable renewable energy sources (wind and solar) because such approaches are under consideration in several countries and states and are a central focus of global decarbonization discussions. The workshop also considered issues not answered by present research and identified future priorities for research.

constraints on the extent to which variable resources can be used to achieve the required level of zero-carbon supply.

- *Avoiding low-carbon dead ends will require the pursuit of a diverse portfolio of low-carbon resources and technologies, including a mix of variable and fully dispatchable generation resources. Innovation is urgently needed to develop more options for affordable, dispatchable, synchronous zero-carbon power sources that will be required in a nearly completely decarbonized power system.*

III. Discussion

Near-total decarbonization is the goal: this requires a focus on the long-term transition of energy systems, rather than short-term policies and narrow preferences for particular technologies.

Much of the current energy discussion confuses means and ends, promoting specific technologies to the detriment of a systemic focus on long-term, deep decarbonization. Technology-specific policies are means, not ends. The utility of policies must be measured by their ability to bring about deep decarbonization cost-effectively, rather than simply their ability to advance particular technologies.

Additionally, more sophisticated analysis is required to make decisions about zero-carbon energy deployment. The common use of "levelized cost of electricity" as a metric oversimplifies comparisons of different technologies and fails to capture system-level costs and benefits. Instead, policymakers and system planners should evaluate various portfolios of options at a systems level in terms of GHG emissions, cost, reliability, and other factors.

Effective and affordable decarbonization of the power sector will require building a reliable and integrated system of multiple low-carbon technologies.

The power grid is a ***system***. In considering policies that would support a long-term systemic transition of that system, the goal is not to choose a single technology but rather to enable a ***portfolio*** of zero-carbon options that is most likely to work best together in such a system over the long term.

Like today's power systems, any future systems that are affordable, reliable, and zero-carbon will require a portfolio of resources and will need policies and technologies that integrate multiple generation sources. The key components of such a system will likely include three broad classes of resources:

1. *More flexible baseload resources*—nuclear, geothermal, and fossil-fuel plants with carbon capture and sequestration (CCS)—that traditionally have been economic only when operating at a relatively high capacity factor. These should be flexible enough,

technically and economically, to accommodate long-cycle (daily to seasonal) changes in net demand and form a dispatchable baseload supply for a zero-carbon power system.

2. *Variable resources* with no fuel costs, such as wind and solar energy, can play an expanded role in zero-carbon power systems. A number of variable resource options that have become increasingly affordable in recent years can add zero-carbon generation relatively quickly, and are economic in a growing number of locations at relatively small scale. However, their variable output and asynchronous nature will limit their potential market penetration based on currently available technology.

3. *Load-following resources* (also known as mid-merit and peaking resources) can fill the gaps between variable renewable and baseload energy output, flexibly ramping up and down to follow short-cycle (sub-hourly to weekly) changes in net demand. These generation sources combine high capacity value with the ability to operate economically at medium to low capacity factors. Hydroelectric plants often play this role in areas where this resource is available, but in most locations combined- and simple-cycle natural gas combustion turbine plants are the primary choices. Zero-carbon power systems will need new, economic low-carbon options for load-following generation, including gas with CCS or turbines powered by zero carbon liquid and gas fuels. Other possible options include energy storage and demand response.

Together, these three broad classes of resources—baseload, variable and load-following resources—could form the core components of an affordable, reliable, zero-carbon power system. Policymakers, scholars and system planners must evaluate the contributions each can make to future power systems and the policies that could best facilitate the development of a system that incorporates all three resource classes at appropriate levels.

Current business investments, policy decisions, and research and development programs can facilitate the development of a zero carbon future—but they can also lead to dead ends that constrain or prevent future progress.

Power systems that can attain near-zero CO2 emissions will very likely look quite different from systems designed to reach more modest abatement goals. Business and policy decisions designed to drive incremental, short- and medium-term reductions should not rely upon untenable assumptions about how far these strategies can take us in the longer-term. An excessive focus on wind or solar technologies at the cost of innovation and investments in dispatchable low-carbon generation can be self-defeating and may lead to major long-term commitments to fossil fuel infrastructure. Enthusiasm for variable renewable technologies should not obscure the need to develop a balanced portfolio of all three classes of low- and zero-carbon resources. Over-commitment to any one of the three resource classes can undermine the development and deployment of the others for decades to come. For instance, policy decisions to exclusively push variable resource penetration at a system level beyond their optimum share of production can make it economically unattractive to deploy the kind of zero-carbon baseload resources that are likely to be necessary for deep decarbonization. Excessive penetration of variable resources can force baseload low-carbon generators to operate in an uneconomic manner, requiring them to recover their capital costs over a smaller number of hours. It is important that decisions taken in the near to medium term pave the way for long-term *full* decarbonization rather than steering us into dead-ends.

Technological advances and system adaptations have increased our ability to integrate variable generation sources such as solar and wind. However, the best available information and analysis indicates there are important technical and economic constraints on the extent to which variable resources can be used to achieve the required level of zero-carbon supply.

Some argue that we can decarbonize electricity based almost entirely on variable renewable resources. Although these resources can play an expanded role in the transition to a decarbonized power system, a broad range of independent research and analysis indicates that there are important limits to the extent to which such variable resources can be relied upon to decarbonize electric systems without undermining their affordability and system value.

The costs of wind and solar power have decreased dramatically in recent years—but as market penetration of these technologies increases, their marginal value begins to fall. Different technologies decline in marginal value at different rates with increasing market share, and various strategies can be employed to extend their ability to add value, but there are limits to how far this can be pushed.

Wind and solar output show significant seasonal variations. These variations represent a potential challenge for achieving high penetration levels of these resources. In the northern hemisphere, solar output is highest in June, lowest in December. In the central United States, winter is windier while summers tend to be calm. Strategies that contemplate high penetrations of wind and solar tend to produce very large seasonal surpluses. In order to reliably meet annual energy demand, either these seasonal surpluses would have to be stored for weeks or even months, or such surplus generation would have to be curtailed while reliability is provided by reserves of dispatchable resources, undermining the economics and emissions performance of the system.

The only seasonal-scale storage technology available at present is pumped hydro, which is expensive to build and constrained by both public acceptance and geographic availability of suitable sites. While other energy storage options and demand response can address much of the hourly or daily variations in renewable production, they cannot address the *seasonal* variations. Because we currently lack technologies for utilizing these large surpluses, systems should be designed to avoid large long-cycle mismatches between supply and demand. [2]

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[2] The need for system inertia may also impose limits on the share of variable renewables at system level. Inertia has traditionally been provided by massive rotating turbo-generators whose rotation is synchronized to the system's frequency ("synchronous" power plants). Solar PV cells and wind generators are "asynchronous" machines, not connected synchronously to

We cannot know precisely what the technical and economic limits to the use of variable, asynchronous renewables will be; they will vary from one system to the next and will depend to some extent on future cost reductions. Most systems are still far from pressing against those limits, but some states are setting renewable energy targets that, were they to be adopted at a regional or national system level, would very likely approach or exceed those limits. We are concerned that some of these plans make untenable assumptions about how far variable, asynchronous renewables can take us toward deep decarbonization over the long term (post-2030).

Avoiding low-carbon dead-ends will require the pursuit of a diverse portfolio of low-carbon resources and technologies, including a mix of variable and fully dispatchable generation resources. Innovation is urgently needed to develop more options for affordable, dispatchable, synchronous zero-carbon power sources that will be required in a nearly completely decarbonized power system.

We stand the best chance of achieving deep decarbonization of the power system affordably and reliably if we have a sufficiently diverse portfolio of low and zero carbon resources, and each resource will perform best if its role is scaled to a level at which it can add value. Pushed too far, variable renewables would foreclose deployment of dispatchable and baseload zero-carbon resources, leaving decarbonization vulnerable to the challenges described above. Alternatively, too much emphasis on baseload zero-carbon options would leave the system too rigid and reverse the progress achieved in developing renewables as a mainstream zero-carbon energy option. Over-commitment to natural gas-fired load-following infrastructure risks high-carbon lock-in and could undermine development of zero-carbon load-following alternatives.

Each available zero-carbon energy resource also faces challenges of cost and scaling-up; narrowing the low-carbon toolkit to a sub-set of zero-carbon resources requires absolute confidence that every obstacle to their use at scale can be overcome. Innovation to develop a broad and integrated portfolio of resources will expand the options for low-carbon generation and minimize the risk of technology or market failures on the path to decarbonization.

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By focusing on the pathway to deep decarbonization, developing a portfolio of options in which a variety of resources contribute to an integrated electricity system, and proactively managing risk and uncertainty, we can lay a solid foundation for a low-carbon future.

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the grid. Without sufficient inertia a power system cannot maintain the desired quality of power. For a detailed discussion of the issue and potential solutions, see, e.g., http://www.caiso.com/Documents/Report-FrequencyResponseStudy.pdf

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