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Communication

Response to comment on paper examining the feasibility of changing New York state's energy infrastructure to one derived from wind, water, and sunlight

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HIGHLIGHTS

- New York State's all-purpose energy can be derived from wind, water, and sunlight.
- The main limitations are social and political, not technical or economic.
- This response to commentary reaffirms these conclusions.

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ABSTRACT

Jacobson et al. (2013, hereinafter J13), presented the technical and economic feasibility of converting New York States' all-purpose energy infrastructure (electricity, transportation, heating/cooling, industry) to one powered by wind, water, and sunlight (WWS) producing electricity and electrolytic hydrogen. Gilbraith et al. (2013) question several aspects of our approach. Unfortunately, Gilbraith et al. inaccurately portray what we stated and referenced and ignore many recent supporting studies. They also refer to previous misplaced critiques of our earlier global WWS study but fail to reference the responses to those critiques, Delucchi and Jacobson (2011b) and Jacobson and Delucchi (2013). We fully stand by the conclusions of both the previous and present studies.

1. Introduction

1) First, Gilbraith et al. misled readers by claiming that J13, "… ignores the critical issue of whether such an energy system could reliably meet instantaneous electrical demand (power) throughout the year (e.g. at peak demand, at night, or when the wind is not blowing)…" We addressed this issue in J13 with the following verbatim text: "Several studies have examined whether up to 100% penetrations of WWS resources could be used reliably to match power 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, 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. The former study obtained this conclusion for the California grid over two years; the latter, over the PJM Interconnection in the eastern US, adjacent to NYS, over four years. Both studies accounted for the variability in the weather, including extreme events. Although WWS resources differ in NYS compared with these other regions, the differences are not expected to change the conclusion that a WWS power system in NYS can be reliable." In J13 we specifically relied on these PJM and California analyses to draw conclusions for NYS.

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Those studies accounted for all hours over multiple years thus accounted for times of "peak demand, at night, and when the wind is not blowing".

2) Gilbraith et al. then ask, "how much upward pressure would be exerted on peak demand by requiring that a substantial portion of transportation energy be provided by electricity"? The additional electrical power demand due to the WWS system actually will make matching demand with supply *easier* because the additional transportation load is flexible and can be controlled with demand-response management (Section 1.3). In addition, much of the additional transportation and heating load will occur at night, which is currently during off-peak hours. Such loads can be met by several WWS resources including onshore wind, which often peaks at night; offshore wind, which occurs during day and night; stored concentrated solar power; geothermal power; and hydroelectric power. In addition, oversizing the grid makes matching power demand with supply easier while providing additional electricity that can be used for district heating and hydrogen production (J13). Gilbraith et al. have provided no evidence that loads cannot be matched reliably in a completely electrified WWS world. The studies cited in response #1 here indicate that matching demand with supply does not require breakthrough-developments in theory or technology but rather is a problem of optimizing system design and operation with existing technologies and system components.

3) Gilbraith et al. then implicitly propose their own more polluting, castrophically risky, and environmental damaging non-WWS energy infrastructure by questioning why J13 did not include natural gas or nuclear power. However, J13 briefly referred readers to an earlier study as to why nuclear was not included as a WWS option (Jacobson and Delucchi, 2011) and explained in detail why natural gas was not included (Section 2.1) in the plan. The purpose of J13 was to demonstrate the technical and economic feasibility of a WWS infrastructure.

4) Gilbraith et al. further argued that natural gas, particularly from unconventional sources, should be considered as part of a WWS plan, falsely believing it reduces global warming impacts compared with other current fuels and stating that some estimates of methane emissions from unconventional sources of natural gas are exaggerated. However, natural gas is not a WWS resource. It is a fossil-fuel resource, therefore by definition excluded from a WWS plan. It causes air-pollution induced mortality, which Gilbraith ignores, and carbon equivalent emissions over sixty times that of wind energy per unit electric power generated.

Air pollution concerns are one of the major reasons for our selection of WWS technologies. Table 1 indicates that natural gas production and use in the US emit more carbon monoxide (CO), volatile organic carbon (VOC), methane (CH_4), and ammonia (NH_3) than coal production and use, whereas coal emits more nitrogen oxides (NO_x), sulfur dioxide (SO_2), and particulate matter smaller than 2.5- and 10-um in diameter ($PM_{2.5}$, PM_{10}). Thus, both fuels result in significant local and regional air pollution, although the higher SO_2 and NO_x emissions from coal results in overall greater air pollution from coal than natural gas.

Based on the underlying gridded and time-dependent emission inventory used to derive Table 1, three-dimensional computer modeling of air pollution and its health effects performed with the GATOR-GCMOM model for this response suggest natural gas mining, transport, and use cause the premature mortality due to particulate matter and ozone of on the order of 5000 people per year in the United States. Wind, water, and solar technologies reduce these emissions and mortalities to well under 100/year.

Further, Gilbraith et al. did not show that natural gas reduces the greenhouse gas footprint relative to other fossil fuels (let alone WWS energy). To the contrary, the greenhouse gas footprint of natural gas is larger than that of any other fossil fuel when viewed over the critically important time period of the next few decades and when the major components of warming and cooling are accounted for. Gilbraith et al. ignore recent data-driven studies (Petrone et al., 2012; Townsend-Small et al., 2012; Peischl et al., 2013; Wennberg et al., 2013; Wunch et al., 2009; Miller et al., 2013) that have found that methane levels over oil and gas drilling and consumption regions are much higher than estimated in previous emission inventories. The studies Gilbraith et al. relied on did not provide measurements of methane mixing ratios over oil and gas regions to verify their results or account for these under-estimates in emission inventories. Such studies have not shown consistency between what they claim are natural-gas-associated emissions and actual local mixing ratios of natural gas in the air.

Next, Gilbraith et al. mischaracterize the discussion in J13 on natural gas emissions when they say it is based on a single study (presumably Howarth et al., 2011). J13 cited 15 publications and reports on natural gas and considered both the issue of high methane emissions and low sulfur emissions of natural gas. Gilbraith et al., on the other hand, ignore the low sulfur emissions of natural gas when arguing natural gas has a low climate impact compared with coal, as do the five papers they refer to. As such, the comparison of natural gas versus coal in those five studies is not relevant to whether coal or gas causes more warming per unit energy. Regardless, three of those five studies brought up by Gilbraith et al. were discussed in Howarth et al. (2012b), which was referenced in J13. Those five papers as well as Howarth et al. (2011, 2012a) relied on bottom-up inventory emission estimates for methane, often using similar or identical emissions per well, but often scaling them to different expected lifetime production values for the

Table 1
2008 US national emissions from natural gas (NG) and coal (metric tonnes/yr).
Source: US EPA (2011). VOCs include methane.

	Coal all uses	NG all uses	NG mining & production	NG public electricity	NG Industrial boilers	NG non-boiler industrial/chemical	NG commercial/institutional	NG residential	NG CNG
CO	6.8×10^5	9.0×10^5	1.2×10^5	8.0×10^4	3.9×10^5	4.0×10^4	9.0×10^4	8.0×10^4	1.0×10^5
VOC	4.0×10^4	1.13×10^6	8.7×10^5	3.0×10^4	1.8×10^5	1.0×10^4	3.0×10^4	1.3×10^4	0
CH_4	5.0×10^3	3.1×10^5	1.1×10^5	2.3×10^4	1.3×10^5	8.0×10^3	2.4×10^4	1.3×10^4	0
NH_3	1.1×10^4	5.4×10^4	0	1.0×10^4	6.0×10^3	1.0×10^3	1.0×10^3	3.5×10^4	1.0×10^3
NO_x	2.8×10^6	1.54×10^6	2.3×10^5	1.6×10^5	7.3×10^5	6.0×10^4	1.3×10^5	2.1×10^5	2.0×10^4
SO_2	7.6×10^6	1.23×10^5	5.1×10^4	1.3×10^4	3.4×10^4	2.3×10^4	1.0×10^3	1.0×10^3	0
$PM_{2.5}$	2.9×10^5	6.1×10^4	2.0×10^3	1.7×10^4	2.5×10^4	8.0×10^3	5.0×10^3	4.0×10^3	0
PM_{10}	4.2×10^5	7.1×10^4	2.0×10^3	2.0×10^4	3.0×10^4	1.0×10^4	5.0×10^3	4.0×10^3	0

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gas wells. Although this expected lifetime production is uncertain, the latest and best information indicates production rates far lower than those used in most studies on methane emissions (US Geological Survey, 2012; Hughes, 2013). Thus, the methane emissions per unit of gas produced have been severely underestimated in studies such as Burnham et al. (2011) and Jiang et al. (2011). See discussion in Howarth et al. (2012b).

A more important difference, though, between our view in J13 and the five papers cited by Gilbraith et al. is the time frame over which the influence of methane on global warming is considered. J13 and Howarth et al. (2012b) stressed the importance of the decadal time scale because of possible impending tipping points in the climate system – such as melting of the Arctic sea ice and the resulting change in albedo – which may occur over the next 2–3 decades. Without controlling emissions of methane and black carbon, such a warming is inevitable, even with stringent control of carbon dioxide (Jacobson, 2010; Shindell et al. 2012; UNEP, 2012; J13). The five papers cited by Gilbraith et al. ignore this critically important decadal time scale and ignore sulfur emissions of different fuel types. In sum, given any reasonable estimate of methane emissions from natural gas, gas is a poor energy choice from the standpoint of avoiding potentially imminent global tipping points. It is especially poor compared with WWS technologies.

5) Gilbraith et al. also claim that a WWS system will cause short-term warming to the extent that it reduces the use of coal because of the reduction in cooling aerosols related to coal use. In the short term (<5 years) WWS displacing coal will cause much less warming than natural gas displacing coal, since natural gas emits more than 60 times the CO_2-equivalent emissions per unit energy than wind. In the medium term (5–50 years), WWS will reduce warming relative to coal, whereas natural gas will increase it. In the long term (>50 years), WWS will ultimately eliminate warming; whereas natural gas will allow warming to persist. In all cases, WWS will eliminate air pollution mortality almost immediately, whereas neither coal nor gas will.
6) Gilbraith et al. state that J13 did not account for the hydrogen electrolysis infrastructure. However, a cost analysis of wind-electrolysis to produce hydrogen for transportation is given in Jacobson et al. (2005), cited in J13. In addition, Delucchi and Jacobson (2011a), which provides general background analysis for J13, discuss other cost studies involving electrolytic hydrogen. Similarly, the general global demand analysis of Jacobson and Delucchi (2011) also accounts for the energy requirements of electrolysis. (Note that J13 did not propose the use of hydrogen for electric power production per se.)
7) Gilbraith et al. state that J13 did not justify the assumed cost of short-distance transmission. However, the footnote to Table 3 stated the source of this number (Delucchi and Jacobson, 2011a). J13 also stated that long distance transmission would be added on top of the short-distance transmission cost. Delucchi and Jacobson (2011a) provided a detailed analysis of long-distance transmission costs.
8) Gilbraith et al. mislead readers into thinking that New York State cannot obtain wind capacity factors of 30% or higher and that the capacity factors of existing wind turbines in the state are only 20%. First, our proposal is for installations in onshore regions where the mean 100-m wind speed exceeds 7.5 m/s, giving a capacity factor exceeding 34% for most turbines, and in offshore regions, where the mean wind speed is 8.5 m/s or higher, giving a capacity factor of 42% or higher. Figure 2 of J13 shows that, based on high-resolution numerical simulation evaluated against data as provided in Dvorak et al. (2012), such regions are abundant in NYS and offshore. In the plan, 40% of total NYS energy would come from offshore wind and only 10% from onshore wind. Thus, Gilbraith et al.'s assumption of an overall capacity factor for wind based on onshore capacity factor alone is misleading.

   Second, the mean capacity factor of onshore wind turbines in NYS is not 20%, as claimed by Gilbraith et al. Mean capacity factors are increasing yearly because modern wind turbines have higher hub heights and are more efficient that the previous generation of turbines. As such, the old data that Gilbraith et al. relied on are not valid. Instead, the mean NYS capacity factor increased from 23.3% in 2010 to 25.6% in 2012 (National Wind Watch, 2013). Even these capacity factors exclude curtailed power generation. J13 proposed that no wind power curtailment will occur; instead, excess wind will be used to generate hydrogen and district heat for other sectors of the energy economy. Without curtailment, wind turbine capacity factors are higher than with curtailment (Wiser and Bolinger, 2012). In fact, the four-year moving average capacity factor of wind turbines on land in the US in 2011 was 33%, an increase over previous years (Wiser and Bolinger, 2012).
9) Finally, Gilbraith et al. claim that J13 should account for the cost of overturning legal and cultural precedents and cite an example of a wind farm being placed within the Adirondack Park in the plan. Nothing in our plan states that a wind farm should be located in the Adirondack Park. This example is made up by Gilbraith et al. Only some of the high wind speed locations need to be developed. The location of development will depend on several factors, taking into account environmentally sensitive areas.

   Moreover, Gilbraith et al. ignore the marginal utility lost by failing to convert to WWS in NYS. Namely, the potential destruction of wilderness landscape, decline in property values, the loss in property tax revenue, the adverse impact on industries in upstate New York, and the costs to communities due to increased demand on police, fire departments, first responders, social services, local hospitals, and roads due to the drilling of 50,000 to 100,000 shale gas wells and the resulting hydrofracking for natural gas that will occur in NYS if WWS is not implemented. These costs are discussed in detail in Dutzik et al. (2012) and Barth (2013). Gilbraith similarly ignore the financial and environmental impacts of increased drilling for oil and mining for coal that will be needed if WWS is not implemented.

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