

Response to Dr. Jim Hansen's Comments Posted on December 29, 2015 at

http://www.columbia.edu/~jeh1/mailings/2015/20151229_Sleepless.pdf

by Mark Z. Jacobson (jacobson@stanford.edu; @mzjacobson)

December 30, 2015

Comment 1 by JH: The urgency of expanding clean energy implies that nuclear power, presently the largest source of carbon-free energy and historically the clean-energy source of fastest scale-up, likely must play an important role in meeting needs for dispatchable electric power, carbon-neutral fuels, and fresh water.”

Summary Response: Nuclear is an opportunity cost relative to clean, renewable wind, water, and solar (WWS) energy because of (a) the significant lag time between planning and operation of a nuclear plant relative to a wind, solar, or geothermal plant; (b) higher carbon emissions of nuclear per unit energy; and (c) nuclear weapons proliferation risks, meltdown risks, waste disposal risks, and uranium mining risks. As such, the only basis for nuclear growth is if 100% wind, water, and solar (WWS) is not possible. However, because the technical feasibility of 100% wind, water, and solar (WWS) across 139 countries and 50 states has been shown to be possible, evidence suggests at this time that a solution can be obtained without nuclear.

Response 1a: The scale-up time for existing nuclear (10-19 years between planning and operation compared with 2-5 years for wind or solar) is too slow to help solve climate problems.

Nuclear power requires 10-19 years between planning, permitting, financing, and operating, in all countries of the world. This time includes 3.5-6 years to find a site, obtain a permit for the site, and obtain financing for the reactor, 2-3 years for the review and approval of the construction permit, 0.5-1 years between permit approval and issue, and 4-9 years for construction (Jacobson, *Energy and Environmental Science*, 2, 148-173, 2009, <http://web.stanford.edu/group/efmh/jacobson/Articles/I/ReviewSolGW09.pdf>)

On the other hand, onshore wind and solar require an average of 2-5 years. A wind farm takes an average of 1-3 years for siting, purchasing or leasing land, monitoring winds, negotiating a power-purchase agreement, and permitting. The construction period for a large wind farm is 1-2 years. A solar PV or CSP plant is also 2-5 years. Geothermal requires 3-6 years (see citations in Jacobson, *Energy and Environmental Science*, 2, 148-173, 2009).

Response 1b: Nuclear is not carbon free and emits 6-24 times more carbon-dioxide equivalent emissions than wind per unit energy produced over the same 100-year period. Such emissions include those during (a) planning, permitting, constructing, operating, refurbishing, and decommissioning a nuclear plant versus a wind turbine and (b) the

emissions associated with reducing carbon sequestration in soil by covering the soil with impermeable material or by mining.

Whereas, the emissions associated with constructing, operating, and decommissioning a plant are accounted for in the standard lifecycle assessment (LCA), those associated with the time-lag between planning and operation and downtime due to refurbishment (OC, opportunity cost emissions), and emissions associated with the loss of carbon from soil, are not.

IPCC (2014) Section 7.8.1 (P. 540) of IPCC (2014) suggests that the range in lifecycle carbon emissions from nuclear is 4-110 g-CO₂-eq/kWh: *The ranges of harmonized lifecycle greenhouse gas emissions reported in the literature are... 4-110 gCO₂eq/kWh for nuclear power...*

The high-end of IPCC (2014) is 40 g-CO₂-eq/kWh higher than the high end of 9-70 g-CO₂-eq/kWh provide in Jacobson (*Energy and Environmental Science*, 2, 148-173, 2009, <http://web.stanford.edu/group/efmh/jacobson/Articles/I/ReviewSolGW09.pdf>), suggesting the LCA results of Jacobson (2009) are well within the range of accepted norms.

However, when comparing different energy technologies for mitigating climate change, it is essential to account for the full emissions associated with the choice of one technology over the other over a similar period. This necessitates including emissions from the background grid associated with the difference in time-lag between planning and operating one technology versus another, the difference in emissions from the grid during downtime of each plant due to refurbishment, and the emissions associated with covering the soil with impermeable materials in each case.

Table 3 of Jacobson (*Energy and Environmental Science*, 2, 148-173, 2009, <http://web.stanford.edu/group/efmh/jacobson/Articles/I/ReviewSolGW09.pdf>) summarizes the opportunity cost emissions of nuclear power (59-106 g-CO₂-eq/kWh) relative to wind and solar (0 g-CO₂-eq/kWh, since the opportunity cost is taken relative to the generators with the shortest time-lag).

The figures at <http://web.stanford.edu/group/efmh/jacobson/Articles/I/CO2eTotalEmisEnergy.pdf> further summarize the comparison of all emissions from nuclear (LCA, OC, soil emissions, and others) relative to all WWS technologies.

The net result of the data in the figures is that nuclear carbon-equivalent emissions per unit energy range from 6-24 times those of wind power, thus they are not zero.

Response 1c: Dr. Hansen argues that nuclear power “must” play an important role in the future. However, there is no scientific basis for this statement and his claim does not address the problems with nuclear power identified by the international community. First, whereas

IPCC (2014) suggests that nuclear could play a role, they also imply that a solution can be obtained without nuclear. Specifically, they state that some proposed mitigation options may not be necessary:

IPCC (2014) FAQ 7.2. P. 569. *The main mitigation options in the energy supply sector are energy efficiency improvements, ..., use of renewable energy, use of nuclear energy, and carbon dioxide capture and storage (CCS)..A combination of some, but not necessarily all, of the options is needed.*

Second, in the executive summary, IPCC (2014) also clearly summarizes significant issues regarding nuclear power that Dr. Hansen does not discuss and that have not been resolved to date. IPCC (2014) states there is “*robust evidence and high agreement*” regarding these issues:

IPCC (2014) Executive Summary. P. 517. *Barriers to and risks associated with an increasing use of nuclear energy include operational risks and the associated safety concerns, uranium mining risks, financial and regulatory risks, unresolved waste management issues, nuclear weapons proliferation concerns, and adverse public opinion (robust evidence, high agreement).*

Finally, IPCC (2014) points to several studies that show that large penetrations of clean, renewable energy could do the job pending more grid integration studies:

IPCC (2014) Section 7.6. P. 533. *Studies of high variable RE penetration (8 citations, including Delucchi and Jacobson, 2011) and the broader literature (2 citations) suggest that integrating significant RE generation technology is technically feasible, though economic and institutional barriers may hinder uptake...The determination of least-cost portfolios of those options that facilitate the integration of fluctuating power sources is a field of active and ongoing research (citations).*

Since the publication of IPCC (2014), Jacobson et al. (Proc. Natl. Acad. Sci., 112, doi: 10.1073/pnas.1510028112, 2015), located at

<http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/CONUSGridIntegration.pdf>

found multiple low-cost solutions to the grid integration problem across the 48 contiguous United States when 100% wind, water, and solar (WWS) generation for all energy sectors (electricity, transportation, heating/cooling, industry) was combined with low-cost storage, demand-response, and hydrogen production. Roadmaps were subsequently developed for 139 countries at

<http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html>

In sum, if 100% wind, water, solar (WWS) works for each state and country as suggested in these studies, there appears to be no need for the growth in nuclear power. Because of the significant lead time, lesser carbon benefit, weapons proliferation risk, meltdown risk, waste risk, and uranium mining risk, nuclear appears to be an opportunity cost relative to clean, renewable energy.

Comment 2 by JH: Nuclear power will need to complement renewable energies, providing sufficient baseload electric power to help address the challenge of replacing energy presently obtained from fossil fuels.

Response 2a: At high penetrations of intermittent renewables, baseload power becomes more expensive and more difficult to complement renewables. This effect is summarized in IPCC (2014), Section 7.6.1.1, P. 534, which states, *..high shares of variable RE power, for example, may not be ideally complemented by nuclear, CCS, and CHP plants (without heat storage).*

Comment 3 by JH: Several blatant falsehoods about nuclear power were repeated in that session (AGU, December 2015), including that (1) nuclear power has a large carbon footprint (it is actually as low as that of renewables, and it is even lower with advanced generation nuclear power), (2) nuclear power is a slow way to decarbonize (in fact all of the fastest decarbonizations in history occurred via nuclear power), (3) nuclear power gets inordinate subsidies (in fact renewable subsidies dwarf nuclear subsidies).

Response 3a: Regarding (1) carbon footprint, see Response 1b.

Response 3b: Regarding (2) slow decarbonization by nuclear, see Response 1a.

Response 3c: Regarding (3) subsidies, IPCC (2014) states the following about nuclear:

IPCC (2014) Section 7.12.4. P. 567. *Nuclear has received significant support in many countries...*

IPCC (2014) Section 7.8.2. P. 542. *Without support from governments, investments in new nuclear power plants are currently generally not economically attractive within liberalized markets,...*

Comment 4 by JH: Referring to Jacobson et al. (*Energy and Environmental Sciences*, 8, 2093-2117, 2015). Not included in this chart is the “water” portion of this proposed renewable power installation: it is equivalent to 50 Hoover dams, one for each state; although the proposition is to do this with a larger number of smaller dams, it is not clear that these dams would be welcomed by all environmentalists.

Response: This statement is incorrect. Table 2 of Jacobson et al. (2015), which can be found at

<http://web.stanford.edu/group/efmh/jacobson/Articles/I/USStatesWWS.pdf>

shows that the 50-state roadmaps call for only 3 new conventional hydroelectric plants (thus dams), not 50, and they are all proposed for Alaska (thus none in the 48 contiguous states). The ones in Alaska can also be substituted for wind. The 48-contiguous-state grid integration study, (Jacobson et al., Proc. Natl. Acad. Sci., 112, doi: 10.1073/pnas.1510028112, 2015), located at

<http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/CONUSGridIntegration.pdf>

similarly calls for zero new hydroelectric dams in these states. It does allow for pumped hydroelectric storage facilities that are existing plus those with pending licenses and preliminary and pending preliminary permits, as defined at <http://www.ferc.gov/industries/hydropower/gen-info/licensing/pump-storage.asp>, but many of these exist already and they are nothing like Hoover dams.

Similarly, the 139 country 100% wind, water, solar (WWS) roadmaps, which can be found at

<http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html>

propose zero new conventional hydroelectric dams for any country. The efficiency of existing hydroelectric plants is proposed to increase, and existing plus planned pumped hydroelectric will also be used.

References:

Delucchi, M.Z., and M.Z. Jacobson, Providing all global energy with wind, water, and solar power, Part II: Reliability, System and Transmission Costs, and Policies, *Energy Policy*, 39, 1170-1190, doi:10.1016/j.enpol.2010.11.045, 2011, www.stanford.edu/group/efmh/jacobson/Articles/I/susenergy2030.html.

IPCC (Intergovernmental Panel on Climate Change) full citation: Bruckner T., I.A. Bashmakov, Y. Mulugetta, H. Chum, A. de la Vega Navarro, J. Edmonds, A. Faaij, B. Fungtammasan, A. Garg, E. Hertwich, D. Honnery, D. Infield, M. Kainuma, S. Khennas, S. Kim, H.B. Nimir, K. Riahi, N. Strachan,

R. Wiser, and X. Zhang, 2014: Energy Systems. In: *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Jacobson, M.Z., Review of solutions to global warming, air pollution, and energy security, *Energy & Environmental Science*, 2, 148-173, doi:10.1039/b809990c, 2009, www.stanford.edu/group/efmh/jacobson/Articles/I/revsolglobwarmairpol.htm.

Jacobson, M.Z., M.A. Delucchi, G. Bazouin, Z.A.F. Bauer, C.C. Heavey, E. Fisher, S. B. Morris, D.J.Y. Piekutowski, T.A. Vencill, T.W. Yeskoo, 100% clean and renewable wind, water, sunlight (WWS) all-sector energy roadmaps for the 50 United States, *Energy and Environmental Sciences*, 8, 2093-2117, doi:10.1039/C5EE01283J, 2015, <http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html>.

Jacobson, M.Z., M.A. Delucchi, M.A. Cameron, and B.A. Frew, A low-cost solution to the grid reliability problem with 100% penetration of intermittent wind, water, and solar for all purposes, *Proc. Nat. Acad. Sci.*, 112, doi: 10.1073/pnas.1510028112, 2015, <http://web.stanford.edu/group/efmh/jacobson/Articles/I/CombiningRenew/combining.html>.

Jacobson, M.Z., M.A. Delucchi, Z.A.F. Bauer, S.C. Goodman, W.E. Chapman, M.A. Cameron, Alphabetical: C. Bozonnat, L. Chobadi, J.R. Erwin, S.N. Fobi, O.K. Goldstrom, S.H. Harrison, T.M. Kwasnik, J. Liu, J. Lo, C.J. Yi, S.B. Morris, K.R. Moy, P.L. O'Neill, S. Redfern, R. Schucker, M.A. Sontag, J. Wang, E. Weiner, and A.S. Yachanin, 100% clean and renewable wind, water, and sunlight (WWS) all-sector energy roadmaps for 139 countries of the world, 2015, <http://web.stanford.edu/group/efmh/jacobson/Articles/I/WWS-50-USState-plans.html>.