Wind Power's Displacement of Fossil Fuels

By Charles Komanoff[1]

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Wind power proponents and opponents share little common ground, but they agree on one point: *the extent to which wind turbines reduce the use of fossil fuels in making electricity is crucial for determining the proper role for wind power*.

The core argument for large-scale development of wind power is that they "keep fossil fuels in the ground" and thus keep the combustion products from those fuels, including climate-altering carbon dioxide, out of the atmosphere. A low rate of displacement of fossil fuels, a premise that many opponents of wind projects swear by, would upend this argument and effectively invalidate the case for large-scale deployment of wind power. Conversely, if, as proponents insist, electricity from wind turbines displaces fossil-fuel use on a 1-for-1 basis, or nearly so, then wind power can be truthfully promoted as a useful tool against global climate change, mountaintop mining and other environmental degradation from the use of coal and other fossil fuels.

In this memorandum, I examine the competing claims and conclude that *when wind turbines are operated as parts of an interconnected grid for which the dominant share of energy is provided by generators burning fossil fuels (coal, oil, natural gas), wind power generation does indeed displace fossil fuel use at a rate close to 1-for-1*. The amount of fossil fuels "saved" or "avoided" by the wind turbines may be estimated at around 90-95 percent of the fuel that ordinarily would be required to generate the same amount of electricity at fossil-fuel generating plants in the absence of the wind turbines.

Capacity vs. Energy

> Wind is intermittent. The power grid cannot be. Accordingly, wind turbines cannot displace capacity provided by fossil fuel stations.

This notion is part of the litany that wind power output does not displace fossil fuels. Yet its points are not germane to the issue. That is because wind turbines' *capacity* need not displace that of fossil fuel plants in order for wind turbines' *output* or *generation* to displace fossil fuel *generation* and the fuels themselves.

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As I wrote a few years ago in a magazine article:

> [S]ince wind is variable, individual wind turbines can't be counted on to produce on demand, so the power grid can't necessarily retire fossil fuel generators at the same rate as it takes on windmills. The coal- and oil-fired generators will still need to be there, waiting for a windless day. *But when the wind blows, those generators can spin down*.[2] (emphasis added)

Note the implicit distinction between a generator's *capacity value* and its *energy value*.[3] Just as a backup quarterback contributes value to a football team even if he never plays, a generator that is never called on to operate but could, if the need arose, contributes value to the grid in the form of dependable capacity. In the matter of climate change and wind power's displacement of fossil fuels, the emphasis is reversed: it is the *output* of the wind facility and not its capacity that matters, since it is the kilowatt-hours of wind generation that reduce the use of fossil-fuel plants which would otherwise be called on to make the same amount of electricity.

Existing fossil generators need not be mothballed, then, for wind turbines to contribute, through their output, to displacing fossil fuels. Retirement (or not) of fossil generators by wind turbines is a red herring, as wind power pioneer and advocate Paul Gipe has noted in responding to the canard that no fossil-fuel power plants have been retired in Denmark despite that nation's claim to obtain 20% of its electricity from wind turbines:

> That a power plant hasn't been "closed" is not a significant fact. One does not need to "close" a power plant to reduce or eliminate its pollution. One need not close a plant to not "use" it. Not "using" the plant is what prevents pollution.[4]

Nevertheless, it should be noted that grid operators increasingly are recognizing that wind turbines *do* have some capacity value. For example, the PJM grid, a major interconnected power system that covers nearly all of Pennsylvania and extends into 14 other states, analyzes wind projects on the basis of their having a capacity value of 20 percent of their

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[2] Komanoff, "Whither Wind: A journey through the heated debate over wind power," Orion magazine, Sept-Oct 2006, http://www.orionmagazine.org/index.php/articles/article/178/.

[3] Electricity capacity is measured in kilowatts (kW) while electric generation is measured in kilowatt-hours (kWh). Newspapers and other media do not always observe these conventions — power is occasionally expressed as "kilowatts per hour" instead of kilowatts, for example — which doubtless contributes to confusion in public discourse.

[4] Paul Gipe, "Warming Up Wind Chill," p. 4, available at http://www.wind-works.org/LargeTurbines/Warming%20up%20the%20Wind%20Chill%20by%20Paul%20Gipe.pdf.

“nameplate” (nominally rated capacity) value.[5] A comprehensive 2006 report on integration of intermittent-output capacity into the United Kingdom’s electricity system found similarly that intermittent supplies — wind units, for the most part — were being granted capacity credits at the rate of 20-30 percent of their installed capacity, and it concluded that this practice was economically justified. From the report:

> *Capacity credit* is a measure of the contribution that intermittent generation can make to reliability. It is usually expressed as a percentage of the installed capacity of the intermittent generators. There is a range of estimates for capacity credits in the literature and the reasons for there being a range are well understood. The range of findings relevant to British conditions is approximately 20–30% of installed capacity when up to 20% of electricity is sourced from intermittent supplies (usually assumed to be wind power). [6]

PJM’s chief went on to say, in a 2007 interview:

> As we study the feasibility of interconnecting a proposed wind project with the grid, we anticipate that, during the summer peak demand periods, we will receive from that project an average of 20 percent of its maximum output. Experience is telling us that the amount is somewhat less than that, but *wind does definitely have a capacity value. As the amount of installed wind capacity becomes more substantial, it will displace the need for some conventional, typically fossil-fuel-based, generation capacity* (emphasis added).[7]

Thus, though wind turbines need not have capacity value to displace fossil fuels, they do have some, which contributes to their economic value as a power supply source.[8]

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[5] See “PJM on Wind,” interview with Karl Pfirrmann, Interim President and CEO of PJM Interconnection, published by PennFuture, in E-cubed, Vol. 9, No. 5 – December 5, 2007, <http://www.pennfuture.org/media_e3_detail.aspx?MediaID=843>. The PJM region runs from Delaware in the East to Illinois in the West and New Jersey in the North to Kentucky in the South.

[6] Robert Gross et al., *The Costs and Impacts of Intermittency — An assessment of the evidence on the costs and impacts of intermittent generation on the British electricity network: A report of the Technology and Policy Assessment Function of the UK Energy Research Centre, with financial support from the Carbon Trust*, Imperial College, London, March 2006. The quoted passage is from Paragraph 18, page v (p. 7 of 112).

[7] PennFuture Interview, “PJM on Wind,” op. cit.

[8] Some wind power opponents have dismissed statements on wind power integration by grid operators such as PJM as inherently biased. It is therefore worth noting that grid operators view themselves as unbiased with respect to generating technologies and having no interest other than maintaining a high degree of

Energy Displacement I: Load Cycling

One of the most vociferous exponents of the argument that wind does not displace fossil fuels is John Droz, Jr., a retired real estate broker living in upstate New York. In a 2008 article for the *Adirondack Explorer* magazine, Droz, who claims to have worked as a physicist in the 1970s, wrote:

> [W]hen adding wind power to the grid, backup from conventional sources (like coal and nuclear) must still be built. Even in the short term, the complexity of nuclear and coal-fired power plants means they cannot simply be "turned down" when wind power is available. The net result: cuts in emissions of carbon dioxide, the main cause of global warming, are small.[9]

Two things are being asserted here. The first, that wind power's intermittency prevents grids that add wind power from being able to dispense with *capacity*, was just shown to be irrelevant to the issue of fossil fuel displacement, as well as exaggerated. The second assertion, that other generators can't be turned down when the wind turbines produce power, does speak to the issue, but misleadingly and incorrectly.

From a factual standpoint, Droz's insinuation that nuclear and coal-fired power plants are incapable of following load (varying in output) is simply incorrect.

Let's start with coal-fired plants, since they not only are the mainstay of fossil-fuel power generation in the United States but also emit the most climate pollution per kilowatt-hour generated.[10] Thus, while wind turbine output that leads to lower operation of gas- or oil-fired generators reduces CO2 emissions, even greater reductions result when operation of coal-fired plants can be reduced.

I studied the performance reliability of coal-fired (and nuclear) power plants many years ago, even publishing a book on the subject, *Power Plant Performance* (now out of print),

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generation and transmission reliability — an assessment I consider justified from my observations of and interactions with electricity sector officials since the early 1970s.

[9] John Droz, Jr., "Against the Wind," *Adirondack Explorer*, July-Aug. 2008. Not Web-available.

[10] Mathematically, coal-fired electricity's pre-eminent place in climate-damaging emissions is the product of three factors: (i) roughly 50% of U.S. electricity is generated by burning coal; (ii) per Btu of energy, coal produces 30-40% more CO2 than petroleum and 70-80% more than natural gas — see coefficients in http://www.eia.doe.gov/oiaf/1605/coefficients.html (some conversion required); and (iii) the newest gas-fired power plants are able to generate the same electricity as coal-fired plants, with 25-30% fewer Btu's.

in 1976. I recall this rule of thumb: to accommodate diurnal variations in aggregate demand, large, modern coal-fired units could be banked down from 100% load to as little as 25% of full capacity, and then back up again, without incurring "thermal stress" that could lead to tube leaks, pipe cracking, or other damage, so long as the transition was gradual rather than abrupt.

If this rule of thumb still holds, then a typical coal-fired unit could routinely shed, or add, as much as three-fourths of its load over a 4-6 hour period, without compromising performance reliability. This would translate into the ability to vary output up or down at an average rate of around 15% of full load each hour, and probably at steeper rates for shorter periods.

Most nuclear power plants also have considerable load-following capability, despite an additional level of complexity (e.g., the need to maintain a constant neutron flux distribution within the reactor core). A recent paper by the Electricity Policy Research Group at the University of Cambridge (U.K.) found that most pressurized water reactors — the dominant reactor technology in both the United States and worldwide — "are capable to [sic] follow loads in a power range of 30-100% at rates from 1 to 3% per minute … [with] exceptional rates of 5% per minute or even 10% per minute … possible over limited ranges." (The other reactor type in large-scale use, boiling water reactors, is less flexible with respect to load.) The paper goes on to note that in France, with nuclear power accounting for more than 80% of electricity supply, "most NPPs [nuclear power plants] have to often operate occasionally at part-load and some plants must be sufficiently flexible to load-follow to ensure grid stability."[11]

Consider now that essentially all wind farms operate as part of large grids that typically comprise tens of thousands of megawatts of capacity.[12] The New York State grid contained approximately 39,000 MW of capacity in 2007, according to the grid operator, the NYISO.[13] Applying the conservative 15% per hour figure for coal plants, above, to these 39,000 MW, it should be possible for the grid to both shed and absorb 5,000 to 6,000 megawatts of capacity per hour, or 100 MW per minute, if necessary.

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[11] Pouret, L. and Nuttall, W.J. (2007) "Can nuclear power be flexible?" Electricity Policy Research Group Working Papers, No.07/10. University of Cambridge. The quoted passages are on pp. 8 and 16, and the paper is Web-available at <http://www.electricitypolicy.org.uk/pubs/wp/eprg0710.pdf>.

[12] Total U.S. installed generating capacity in 2007 was approximately one million megawatts, of which 770,000 MW was fossil-fueled. (See *Statistical Abstract of the United States, 2007*, Table 904.) This capacity, in turn, is managed by several dozen "system operators" that link and govern all of the generating facilities in one or more states or other contiguous areas.

[13] NYISO 2007 Annual Report, p. 1 http://www.nyiso.com/public/webdocs/company/about_us/annual_report/areport07final.pdf.

Thus, even the nearly instantaneous loss of an entire several hundred-megawatt wind farm due to a rapid change in weather should be able to be managed by varying the output of other units on the grid. Conversely, if and when wind conditions shift suddenly from calm to robust, causing the output of one or more wind turbines to go from zero to full in a matter of minutes, it should be possible for the grid to efficiently reduce fuel intake at fossil-fuel generators.

Moreover, changes in the output of wind farms are rarely as abrupt as just hypothesized, as PJM chief Karl Pfirrmann indicated in his interview with PennFuture:

> **PennFuture:** You now have several years' experience with wind generation. How variable is wind in reality?
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> **Pfirrmann:** Wind is not as variable as people may think. Our experience shows that, if a wind generator is operating at a certain level at present, there is an 80 percent probability that it will be operating within ±10 percent of that level one hour from now. And, there is a 60 percent probability that it will be operating within ±10 percent of that level five hours from now. We're also encouraged that better forecasting will enable us to better predict the output from the wind generators on our system.[14]

This suggests that rapid changes in wind output requiring rapid turndown or ramp-up of fossil plants on the grid are relatively infrequent; and that *unanticipated* rapid changes are even more rare.

Energy Displacement II: Wind Turbines' Need for Grid Reserves

We come now to the heart of wind power opponents' non-displacement claim: wind power's intermittency, they insist, requires that grids maintain extra stores of reserve capacity; and *maintaining this capacity in a state of readiness necessarily entails additional fuel consumption that cancels out the fossil fuel savings that would otherwise be ascribed to the wind output*.

PennFuture's dialogue with PJM chief Karl Pfirrmann again frames the matter well. Pfirrmann parses grids' reserve requirements into three types — synchronized, regulation and supplemental — and shows that the additional requirements imposed by wind turbines are either small or nil.

[14] PennFuture Interview, "PJM on Wind," op. cit.

PennFuture: We hear questions about whether wind energy, because of its variable nature, needs to be "backed up" by conventional generation resources. For example, does having wind on the system increase the need for operating reserves?

Pfirrmann: The costs of managing wind as a variable resource are modest, and the owners of wind generators bear their allocated portion of that cost.

The principle reserve we maintain is **synchronized reserve**. It's comprised of generation units which are synchronized to the grid and ready to deliver energy on extremely short notice. They serve as protection against a sudden loss of the single largest generating unit on the entire system, and the amount we maintain is based solely on the size of that largest generating unit.

Since the largest generating unit on almost every U.S. grid is on the order of 1,000 megawatts, whereas individual wind turbines are only several megawatts and even entire wind farms are rarely more than several hundred megawatts, it's clear that wind power imposes no additional synchronized reserve requirements on power grids.

Pfirrmann, continued: We also maintain a "regulation reserve" to manage the short-term variability in demand. Although demand, or usage, varies in predictable ways which we manage by scheduling resources we can reasonably anticipate needing, demand also varies in less-predictable ways. To match these moment to moment variations in usage, we pay generators to be ready to deliver additional energy on a near-term basis if needed. The costs for maintaining this state of readiness are allocated to power users.

Since regulation reserve pertains to variability in *demand* and not supply, wind resources have no bearing on the amount of regulation reserve required.

Pfirrmann, continued: *The one form of reserve for which wind can create a need is the "supplemental reserve."* Supplemental reserve protects the system from falling below the amount of generation needed to serve demand and to maintain the synchronized reserve I discussed earlier. If a generator goes off line suddenly, some of the synchronized reserve may actually be required to serve load, pushing the synchronized reserve below its required level. This in turn requires the activation of

> supplemental reserve in order to replenish the synchronized reserve that has been converted to energy. *PJM pays generators to be available to provide this supplemental reserve.* Because the need for this reserve is based partially on supply-side considerations, *we allocate a portion of the costs to the generators in instances when their actual production deviates from their scheduled production.* Its cost is deducted from the payments they otherwise receive for their energy deliveries. *The cost is nominal, however, ranging from about 75 cents to $2 per megawatt-hour.*[15] (emphasis added)

PJM's charge for wind power's intermittency in 2007, then, was <u>$0.75 to $2.00</u> per MWh generated. (The Pfirrmann interview was published in December 2007 and presumably took place earlier that year.) Using the average cost of coal burned to make electricity in Pennsylvania in 2006 (the most recent year available), which was $1.72 per million Btu, we can translate Pfirrmann's cost range into the quantity of fuel consumed by units on the grid to provide supplemental reserve.[16]

Assuming conservatively that the entire cost of wind power's supplemental reserve requirement is attributable to fuel (and none to operation and maintenance), and dividing $0.75 per MWh (the low end of Pfirrmann's range) by $1.72 per million Btu, we calculate that each MWh produced by wind required that other power plants on the grid expend an average of <u>436,000 Btu</u> to provide supplemental reserve. A similar calculation for the $2.00 high cost yields an energy expenditure of <u>1,160,000 Btu</u>.[17] By comparison, by applying the average power-industry "heat rate" for fossil-fuel plants of 10,000 Btu per kilowatt-hour, we see that conventional generation of an equivalent MWh at coal and other fossil-power stations requires, on average, <u>10 million Btu</u>.

We thus have, for the PJM system, the answer to the central question of wind power's displacement of fossil fuels. *Each megawatt-hour of wind generation directly displaces (on average) 10,000,000 Btu of fossil fuel use while requiring a range of 436,000 to 1,160,000 Btu of fossil fuels to be expended for provision of supplemental reserve.* The grid's fuel expenditure to provide reserve for wind turbines offsets only 4.4% (436,000/10,000,000) to 11.6% (1,160,000/10,000,000) of the direct fuel savings.

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[15] <u>Ibid.</u>

[16] U.S. Energy Information Administration, Electricity State Profiles, Pennsylvania, Table 6, <http://www.eia.doe.gov/cneaf/electricity/st_profiles/pennsylvania.pdf>, downloaded April 2, 2009.

[17] The calculation is as follows (using $0.75): $0.75/MWh = ("X" Btu / MWh) x $1.72/million Btu. Canceling the MWh terms and dividing both sides by $1.72/million Btu yields: "X" = $0.75 / $1.72 x million Btu, or X = 0.436 x million Btu, or 436,000 Btu. The same calculation using $2.00/MWh yields 1,163,000 Btu.

Equivalently, **88%-96% of the "theoretical" fossil fuel savings for wind power — the savings that would be calculated from equating each kilowatt-hour of wind generated with a kilowatt-hour of fossil fuels avoided — remain after allowing for reserve requirements.**

This result is conservative (it understates the true savings) for two reasons. First, the fuel baseline it uses, $1.72 per million Btu, is predicated on 100% coal and ignores much-higher-priced natural gas that is also part of the PJM grid fuel mix. Second, it implicitly assumes that 100% of the supplemental reserve cost is attributable to fuel, when some portion conceivably could be associated with maintenance and/or administrative costs.

Energy Displacement III: Further on Wind Turbines' Need for Grid Reserves

The takeaway from the PJM interview — that reserve maintenance uses up only a small percentage of the fossil fuel savings from wind power generation — is evidenced in essentially every major study of wind integration on utility grids. Here, I summarize two such studies, selected largely at random.

One study, the Midwest Wind Integration Study, was mandated by the Minnesota legislature in 2005 and published in 2006 as a report to the Minnesota Public Utilities Commission. Following is its key finding on the cost of wind power's intermittency:

> [R]elative to the same amount of energy stripped of variability and uncertainty of the wind generation, there is a cost paid by the load that ranges from a low of $2.11 (for 15% wind generation, based on year 2005) to a high of $4.41 (for 25% wind generation, based on year 2003) per MWh of wind energy delivered to the Minnesota companies. This is a total cost and includes the cost of the additional reserves (per the assumptions) and costs related to the variability and day-ahead forecast error for wind generation.[18]

Extrapolating from the reserve costs and wind penetration percentages, one can conclude that at current penetrations of less than 10%, reserve costs for wind generation in Minnesota are within the range reported for the PJM grid.

The other study is the U.K "Costs and Impacts of Intermittency" report referenced earlier. Following are excerpts from the executive summary:

[18] Enernex Corp., Final Report - 2006 Minnesota Wind Integration Study, Volume I, p. 72. Available at http://www.uwig.org/windrpt_vol%201.pdf.

> The cost to maintain system reliability [with substantial penetration of wind power] lies within the range £3 - £5/MWh under British conditions … relative to a comparitor plant operated at maximum utilisation. This assumes around 20% of electricity is supplied by well dispersed wind power. Current costs are much lower; indeed there is little or no impact on reliability at existing levels of wind power penetration.[19]

If "much lower" denotes a factor of five, and applying a £/$ exchange rate of 1.5, then the cost range to accommodate wind power's variability in the U.K. translates to $0.90 - $1.50, or roughly the range given in the PJM interview.

Conclusion

Many wind-power opponents assert that industrial-scale wind turbines displace little or no fossil fuels. I find, however, that when wind turbines are operated as parts of an interconnected grid for which the dominant share of energy is provided by generators burning fossil fuels (coal, oil, natural gas), wind power generation displaces fossil fuel use at a nearly 1-for-1 rate. The amount of fossil fuels "saved" or "avoided" by the wind turbines may be estimated at around 90-95 percent of the fuel that ordinarily would be required to generate the same amount of electricity at fossil-fuel generating plants in the absence of the wind turbines.

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[19] Robert Gross et al., *Costs and Impacts of Intermittency*, op. cit., p. vi. Note that in the year the report was published, 2006, wind power provided 1% of U.K. electricity generation — 4,225 GWh of 398,327 GWh total (calculated from International Energy Agency data at http://www.iea.org/Textbase/stats/index.asp).

About Charles Komanoff

The report author is a consultant on U.S. energy, transport and environment; electricity generation costs; energy usage and supply; road pricing; social and environmental costs and benefits of competing energy and transport modes. He is also an activist and advocate for bicycle transportation and pedestrians' rights; and co-director of the Carbon Tax Center.

Komanoff has published widely on energy policy and technology, including three books: *Power Plant Cost Escalation: Nuclear and Coal Capital Costs, Regulation and Economics* (KEA, 1981, republished by Van Nostrand Reinhold, 1982, available via his Web site), *Power Plant Performance: Nuclear and Coal Capacity Factors and Economics* (Council on Economic Priorities, 1976), and, as co-author, *The Price of Power: Electric Utilities and the Environment* (Council on Economic Priorities, 1972, republished by M.I.T. Press, 1974). He has published magazine articles in *Orion*, *New York* and *The New York Review of Books*, among others; op-ed essays in every major U.S. newspaper including *The New York Times*, *Wall Street Journal*, *Washington Post*, and *Los Angeles Times*; book chapters in *Encyclopedia of Energy* and *Sustainable Transport*, and journal articles in *Nuclear Safety*, *Journal of the American Pollution Control Association*, *Electricity Journal*, and *Bulletin of the Atomic Scientists*.

Throughout the 1970s and '80s — a period of intense debate over the economics of nuclear power — Komanoff was the leading U.S. source of credible information on reactor costs. Through painstaking data collection, rigorous analysis, numerous articles and books, and clear articulation to journalists, he helped policy-makers and the public grasp the true dimensions of nuclear power's spiraling costs. During this period, Komanoff consulted for two Congressional agencies, the U.S. Department of Energy, and close to two dozen states including New York, California, Texas and Florida; presented expert testimony before the U.S. Nuclear Regulatory Commission and 20 Public Utility Commissions; testified before four Committees of Congress and the Select Committee on Energy of the House of Commons (U.K.); and tutored a generation of journalists on the extent and causes of cost escalation in the U.S. nuclear power industry.

Since 2002, Komanoff has researched many aspects of the debate over wind power, including energy potential, displacement of fossil fuels, and noise — and has distilled his findings in popular articles, links to which are available here: http://www.komanoff.net/wind_power/. More on Komanoff's work is available via his Website: http://www.komanoff.net/.