LESS FOR MORE: THE RUBE GOLDBERG NATURE OF INDUSTRIAL WIND DEVELOPMENT

PROLOGUE

Reuben Goldberg (1883-1970) was an American cartoonist famous for conceiving very complicated and impractical machines that accomplish little or nothing. The term "Rube Goldberg" has passed into the lexicon as shorthand for describing such machinery and their products and services. Contemporary industrial wind turbines epitomize this concept. Physically, they are taller than many skyscrapers, with 300-foot rotors that move nearly 200 miles per hour at their tips. They are usually placed in a phalanx numbering five to eight per mile, which, if erected on forested ridge tops, also require the clear-cutting of at least four acres per turbine, with another 35-65 acres needed for infrastructure support. Functionally, they produce little energy relative to demand and what little they do produce is incompatible with the standards of reliability and cost characteristic of our electricity system. Moreover, wind plants are unable either to mitigate the need for additional conventional power generation in the face of increased demand or to reliably augment power during times of peak demand. Ironically, as more wind installations are added, almost equal conventional power generation must also be brought on line. ***Crucially important, wind technology, because of the inherently random variations of the wind, will not reduce meaningful levels of greenhouse gases such as carbon dioxide produced from fossil-fueled generation, which is its raison d'etre.***

To understand the limitations of wind technology, one should know how energy use enables complex modern society and, especially, how energy in the form of electricity is produced and transmitted to hundreds of millions of people on demand. Enormous energies are required to support the way Americans choose to live and work. Industrial modes of transportation and heating/air conditioning technologies have made it possible for large numbers of people to live in regions historically limited to only the hardiest of souls, such as the swamplands of Florida and the ice of Alaska, while newer communication technologies have encouraged widespread development not only for residential suburbanites but commerce and industry as well. The majority of our energy use involves heating and transportation. Demand for electricity accounts for about 39 % of all energy use, even though electricity accounts for 30% of the energy used for heating. **(1)** We increase both our demand for energy and for electricity at a rate of approximately 2% each year, nearly doubling our consumption every 30 years, as we did from 1970 through 2000. **(2)**

Electricity is the cleanest and most important form of industrial energy; its supply continuity is essential to enable and protect a vast range of services we often take for granted—modern hospitals, traffic controls, information storage and retrieval, entertainment, food storage, to name only a few. As the British engineer, David White, has written, "It is a truism that electrical power supply at a competitive cost underpins the world's economies…." **(3)**

THE GRID ENSEMBLE

Unlike the municipal water supply, electricity at industrial levels cannot be stored in reservoirs. It must be used immediately. Above all, it must be reliable, accommodating demand instantaneously, while its costs, ideally, should be affordable to all. Over the last hundred years, large regional networks known as electricity "grids" have evolved to collect, rhythmically organize, and dispatch a mixture of power sources, considering, among other things, expectations of demand levels, availability, predictability, cost, exactly balancing forecasted supply with demand at all times and transmitting power over a range of distances to a variety of users within their respective regions. In the United States., the North American Electric Reliability Council, working with its regional reliability councils, develops and monitors the reliability standards each grid's power line owners and operators usually follow, taking into account scheduled and reasonably expected unscheduled outages while also accommodating "contingencies"—the unexpected failure or outage of a system component such as a generator, transmission line, circuit breaker, switch or other electrical element.

Although the mix of power fuels varies among grids in the United States, on the whole fossil fuels account for 70.7% of the nation's electricity generation (coal 51.4%, natural gas 16.3% and oil 3%) with the balance coming from nuclear power (20.7%) and renewable sources (8.5%, of which 84% is hydropower). (4) Collectively, along with biomass, geothermal, and a few other fuels, these are known as **"conventional generation."** Except for hydro, they are also called **"thermal generation."**

The conventional fuels heat water (or gas) to create steam that drives turbine rotors around an electro-magnetic motor. In the case of hydro, the turbines are driven by water either falling on or moving past turbine rotors. Conventional generation has a proven ability over many years to produce reliably and continuously at industrial scales. Nuclear and large coal plants, along with certain hydro facilities, are best at providing a base level of supply upon which other levels of supply can be built. Smaller conventional generators are often highly responsive to commands and can be dispatched to cover a range of tactical, even immediate, needs. In fact, this quality of "**dispatchability"** is highly prized by grid operators.

CAPACITY MATTERS

In grid parlance, the term **"capacity"** (5) is used as a measure of firm generation and transmission capability—that is, how reliable a power source is for meeting various levels of demand in timely fashion. Each power plant is engineered to produce a specified amount of electricity over a year's time, a concept known as its **"rated or installed capacity"** (also known as **"nameplate" capacity**). However, because of equipment damage, routine maintenance, machine or human error, etc, no machine works at full power all the time. The energy community has developed a concept known as a **"capacity factor"** to project the average amount of production a machine will yield in a specified amount of time; this is expressed as a fraction of rated/installed capacity. Grid system operators also use a concept known variously as **"capacity credit"** or **"effective**

capacity" to express their level of confidence about how much power a generator will produce at a pivotal stress point known as peak demand; again, this term is expressed as a percentage of the generator's rated capacity. Finally, the term **"Unit Availability"** describes generating units that are available to produce electricity when called upon, given the usual contingencies of start up and ramping time. They must not only be capable of running and producing, but they must also have fuel on board to do so. Organizing the various power generators, each with varying levels, frequencies, and cycles of behavior, into a coherent pool of capacity flexibly responsive to demand is the first order of business.

LOAD

Assembling the necessary power generation is only part of the grid's responsibilities, however. It also must efficiently orchestrate that generation with distributors—the "utility companies"—to connect reliably with electric power consumers at varying levels and cycles of demand. To a grid operator, demand, often referred to as **"load,"** is a dynamic, highly statistical concept, made predictable and therefore manageable within a range of +/- one percent because of well-known, time-tested historical usage patterns and sophisticated "averaging" techniques, which, because of the grid's large number of customers, are able to cushion or smooth-out ever-present demand fluctuations. Knowledge of these patterns and techniques allows grid managers to accurately forecast demand over the course of a year, a day, even in increments of minutes, permitting them to schedule various power generators to come online in a timely, cost-effective fashion while maintaining line voltage at appropriate levels to prevent equipment damage. Collectively this process is called **"load balancing."**

Grid managers estimate demand by dividing it into three broad categories, aligning them with appropriate generating capacity, each with an adequate reserve margin to account for the difference between basic operating generation capacity and the highest demand cycles. Functionally, the grid's imperative to match aggregate production and demand instantaneously and continuously can be met by controlling generation, consumption, or both. But in practice grid operators historically have controlled generation almost exclusively. Creating supply that is sufficiently—precisely—responsive to the vicissitudes of shifting aggregate demand is an exacting craft.

To control costs, the order in which the various generating units are brought on line at every level and cycle of demand is often determined by a concept called **"economic dispatch,"** which means that the units with the lowest variable fuel costs (mainly fuel, though there are others as well), in contrast to fixed costs, are run first, and then the next lowest, etc.

The basic demand level is known as the **"base load."** It is permanent, on-going, 24 hours a day, 365 ¼ days a year bedrock demand, typically served by large, slowly ramping but highly reliable fuel sources (with capacity factors and capacity credits often exceeding 90%), such as nuclear and large coal plants, generating power at a constant rate. Where it is in adequate supply, hydro may also contribute to the base load, although, in periods of drought conditions, it may be seasonably withdrawn. Each of these power generators has high investment and fixed costs, the economics of which dictate they be run uninterruptedly (except for scheduled maintenance) at maximal levels to minimize the cost of power production. As such, they don't typically represent dispatchable generation, although on grids with substantial coal-fired capacity, some may be adjusted for intermediate load conditions, at a cost to efficiency. Once cranked up, however, their fuel costs are virtually nil, especially for nuclear and hydro. Base load generation retains as operating reserves a cadre of smaller, highly flexible, highly responsive power units—often hydro, where it is available, but more often fossil fuel generators that can be switched on and off quickly in response to fluctuations in demand.

During the day, power consumption typically rises well beyond the base load minimum at night as human activity and industrial/commercial enterprise become more active. Much of this activity is also highly predictable, resulting in a demand level known as "**intermediate-** or **mid-load.**" To accommodate it, additional generation can be scheduled as needed. But load balancing here gets trickier as the aggregate demand increases significantly while demand fluctuations intensify. To manage this load situation, the grid brings on a range of operating, regulating reserves consisting of spinning and non-spinning generators. Equipment that automatically adjusts generation to maintain interchange schedules and power frequency levels—**Automatic Generation Control (AGC)**—is used to provide normal regulating margins, fine tuning supply/demand balance much as cruise control does on an automobile. These "load-following" plants produce mainly during the day, when prices and demand are highest.

Generally, **operating reserves** provide not only for regulation balance but also for load forecasting errors, various outages (met by contingency reserves), and protection against unexpected surges. **Spinning reserves** are fully operational and synchronized to the rhythms of grid mechanics, ready to engage if needed both minute-by-minute fluctuations in both supply and demand as well as any unexpected generation loss. They can also respond to bandwidth frequency changes. **Non-spinning reserves** are not connected or synchronized to the system but are capable of serving demand within a specified time and, since they are interruptible, can be removed from the system with dispatch. Typically, regulating reserves have similar responsive ramping rates and flexible response times as those used to regulate demand flux for base load. For mid load, more of these generators, with high unit availability, are brought on line. To meet short duration demand oscillations, the key requirements are fast startup and low investment cost. As such, fossil fuel generating units are normally used-- particularly natural gas units where they are in good supply—and smaller coal plants engineered to respond rapidly.

PEAK CHOREOGRAPHY

"Peak demand" occurs as the highest hourly load within a given period—a day, month, season, or year—and can often nearly double the base load. Daily peak load often occurs at rush hour on a work day. During the season, it often occurs on a hot workday afternoon in summer or the coldest nights in winter, depending upon the region. During the year, it may result when a convergence of many factors drives demand up, such as a sustained heat wave after a destructive storm. To accommodate this level of demand, all the various reserves join with base load generation in a veritable symphony of dynamic harmonics, with the most skilled personnel working with AGC to protect the system from over or under load. For, in addition to providing enough power, the system must integrate and balance highly fluctuating demand at its most expansive levels with highly fluctuating generation (switching power units on and off), with all the units at play in breathtakingly complex choreography. Peak loading generators typically have the highest operating costs because they don't run continuously but rather flexibly start and stop for short times during this short time period. Peaking plants may operate only a few hours a year or up to a several hours per day.

At times of peak load, grid operatives focus intently upon each power plant's capacity credit, their "confidence" index in a generator's ability to dispatch power reliably and quickly on command. Without that confidence, the grid could not be assured either that all demand could be met or that the system had sufficient protection against an unexpected surge or loss of power that could mortally damage plant equipment and transmission systems.

Concern for supply, costs, and demand levels is a large part of the grid's responsibilities. Power must get to people, however, via the **transmission process**—the way energy is reliably moved around the grid and, through a variety of transformers, transmuted into functional power for various users, minimizing energy loss due to long-distance transmission while intercepting power surges and directing them appropriately. Connectivity of power sources such as natural gas is another aspect of the transmission system; many sources of natural gas supply are far too removed from existing connection points, creating a demand/supply dislocation, which, in the case of natural gas, has recently greatly increased its cost.

There are times when the system falters, and grid officials urge people to reduce their demand or risk brownouts or even blackouts, often importing emergency generation to shore up contingency reserves. Rarely, despite the best attempts to maintain reliability, the system fails, creating short term mayhem for civil society until the problem(s) can be addressed, the system patched, and order restored, usually in a matter of hours or within a week (longer of course after disasters such as Hurricane Katrina). Still, that so many people take electricity for granted, that it is such a ubiquitous presence and responsible for enabling much of modernity, is a tribute to how effective the grid ensemble truly is.

FOSSIL FUELS: CAN'T LIVE WITH THEM; CAN'T LIVE WITHOUT THEM

Although the various fuels used to generate power are effective and relatively low-cost, each has a downside that also has social and environmental costs. A few generations ago, hydroelectric served as a centerfold for renewable power. Today, although hydroelectric plants do produce a lot of electricity from a renewable source, they are so environmentally damaging that many are now being dismantled, at taxpayer expense. Even if a desire existed to build more hydro units, many areas of the country would be unable to construct them because of geography and climate. Nuclear plants also produce at high levels without polluting the environment, but fears about radioactivity and the storage of waste material, not to mention the possibility that nuclear materials may be diverted for terrorist purposes, have given the industry such a problematic reputation that no new nuclear facilities have been built in the US for nearly thirty years.

Partly as a result of these concerns—but mainly because they have been so successful—fossil fuels now comprise almost 75% of the generation mix producing electricity in the United States. In recent years, however, petroleum and natural gas prices have skyrocketed. Petroleum is now a very small part of the generation. Although 39% of the energy used in the country in 2002 was generated from oil, less than 3% was generated from oil to produce electricity. Natural gas supplies are often far away from the areas they serve, requiring costly pipelines to be built, along with expensive interconnections. But generators fueled by natural gas, especially those that combine gas and steam, are highly valued for how cleanly they burn their fuel and for their flexible responsiveness. Gas turbines burn 60 % more cleanly than units fired with bituminous coal. **(6)**

More than 50% of the plants involved in generating electricity in the United States are fueled by coal, essentially carbon plus some hydrocarbons and minerals, which comes in four basic forms, of which the most common and commonly-used is bituminous. **(7)** Although it is abundant and highly effective, it nonetheless has substantial undesirable side effects that have caused many to seek more effective alternatives for it. Strip mining, slurry ponds, and, more recently, mountaintop removal extraction techniques create enormous environmental/public health problems. But the overarching concern is for the pollutants it generates. When burned, it produces, among others, sulfur dioxide, nitrous oxides (both of which have already been and will continue to be reduced as required by the Clean Air Act), and particularly carbon dioxide (CO_2), emitting more of the latter gas per BTU of electricity than any other fossil fuel. **(8)**

Environmentalists and public health officials are rightly concerned about the negative effects of these carbon emissions. They have been implicated as causes of asthma and other respiratory conditions. They may also be a contributor to global warming, where greater than usual accumulations of CO_2 in the atmosphere are thought to be intensifying a phenomenon known as the “greenhouse effect,” precipitating a series of events that may jeopardize the future of life on this planet as we know it.

However, controlling the coal industry’s impacts is enormously complicated. The various health and environmental consequences of coal use have only recently begun to be properly understood. Congressional legislation and regulations restricting the amount of carbon emissions from coal–fired plants through the installation of cleaner-burning, more efficient equipment have been partially successful, particularly for abating SO_2 and NOx emissions. But because of the ubiquity of coal, along with other fossil fuels, as sources of effective energy, the problem remains of vast proportion. Petroleum contributes 44% of the nation’s CO_2 emissions (virtually all for transportation and heating), while coal and natural gas produce 36 and 20% respectively. Within the electricity sector, coal accounts for 82.4% of CO_2 emissions, followed by natural gas (12.9%) and petroleum (3%). Moreover, coal generates about 2.117 pounds of CO_2 per kWh; petroleum, 1.915 pounds per kWh; and natural gas, 1.314 pounds per kWh). **(9)**

NO SAFE WAY TO PRODUCE ELECTRICITY AT INDUSTRIAL SCALE?

Because coal is such a pervasively effective fuel, and coal plants are likely to increase in number, continued advances in cleaner coal technology may be much more globally effective in reducing harmful emissions, offering a lot more bang for the buck, with applications for electric utilities, steel mills, cement plants and other industries.

Nonetheless, much public subsidy in recent years has been invested in **“renewable”** fuels other than hydro that are also sustainable and burn cleanly, without producing carbon emissions. However, technology such as solar cells, which convert sunlight directly into electricity, has thus far not proven successful for industrial energy needs, principally because of the intermittent nature of its power source, although local applications in large buildings and clustered facilities show promise at that scale. Except for certain uses where distribution lines aren’t available, such as highway signs, traffic counters, and hand-held calculators, cost is still an important issue for solar energy.

On a per kilowatt hour basis, no other form of industrial energy has recently received higher public subsidy than wind. **(10)** Wind energy is produced by atmospheric convection forces influenced by the sun. People have harnessed this energy for much of their history, mainly for transportation, pumping water, and grinding grain. More effective technologies supplanted wind energy for these uses some time ago. However, because wind energy does not directly emit pollutants into the air and its source of energy is recurrent, it offers the prospect of a clean, renewable alternative to fossil fuels, along with a reduction in the significant environmental problems they generate. Indeed, the understandable desire to reduce the emissions caused by reliance on fossil fuel combustion, as well as to eliminate such draconian extraction techniques for coal as strip mining and mountaintop removal, has enabled industrial wind energy advocates to make strong gains in recent years. As a result, the substantial monetary and regulatory subsidies now provided to wind developers have propelled the industry to record growth.

WIND ENERGY’S PREMISE

Supporters of wind technology claim it is a formidable mechanism for reducing carbon and other greenhouse emissions, as well as a clean fossil fuel alternative, capable of replacing conventional generation while obviating the need for future conventional power plants. Wind developers frequently state that their projects will serve many thousands of households while displacing millions of pounds of CO_2 and other toxic emissions. They maintain that Americans should emulate Denmark, which has installed nearly 6,000 wind turbines throughout its tiny country, and Germany, with now over 18,000 wind turbines generating about 6% of that nation’s electricity supply. Implicit in their message is the notion that more wind installations will mean less conventional generation, especially coal and nuclear.

Modern wind turbines use large airplane-like propellers to turn electric generators, producing energy proportional to the cube of the wind speed and directly proportional to the area swept by the turbine blades. From base to blade tip, they range in size from 340 to nearly 500 feet, and their rotors, often larger than a football field, rotate from 15-20 rpm. They are typically designed to begin generating electricity at wind speeds of about 8 mph and stop at speeds approaching 55 mph. Their rated capacities depend upon the individual turbine design and placement, typically ranging from 1.5 to 5 MW (a Mega Watt is one million watts). They can be located onshore or in the oceans.

Onshore, wind developers seek terrain rich in wind potential (usually Class 4-7 winds) for siting their facilities. Although over 70% of the nation's most potent wind areas are in the Midwest, and less than 5% of the country east of the Mississippi River qualifies as good wind potential, **(11)** the lack of adequate transmission systems in the Midwest has encouraged wind developers to pursue projects closer to existing transmission areas, even though the wind potential in those areas, in states like New York or Pennsylvania, doesn't approach that of the Midwest. The use of Renewable Portfolio Standards throughout Eastern states, which require utilities doing business in those states to purchase a certain percentage of renewal fuels, also has greatly attracted wind developers. Wind facilities are therefore often placed in rural areas near good transmission lines and close to rural residences in or near states that have passed RPS legislation. Wind energy physical plants range from six to hundreds of turbines arranged usually in rows extending from a few to dozens of miles. If placed on prominent ridgetops, they can be seen for many miles in all directions; their differentially moving rotors make them appear especially conspicuous.

To illustrate one such wind plant, let's assume it has 50 turbines, each with a rated/installed capacity of 2.0 MW, giving it an aggregate rated capacity of 100 MW. Each turbine would be over 400 feet tall, occupying at least four open acres of land to minimize wind turbulence and located near a newly-constructed maintenance access road and of course transmission lines and a substation. The turbines would spread over nearly nine miles of terrain. Developers argue that the project would "serve more than 35,000 households in the region" and "displace 368 million pounds of CO_2 annually." **(12)**

Using these assumptions, wind developers expect to build thousands of similar wind plants in suitable wind-rich terrain, ostensibly to hold the volume of carbon emissions in check. Environmental organizations such as the Sierra Club and Greenpeace point to the recent work of Robert Socolaw and Stephen Pacala, researchers at Princeton University who show what would be necessary for one "wedge" of wind to displace coal power plants across the country, resulting in a 50-year cumulative total savings of 25-billion tons of atmospheric emissions of carbon. The "wind power for coal" wedge (the slice of total generation produced by coal) would generate 2.1-million MW from wind turbines- - installed at an annual rate of 38,000 MW through 2056. **(13)** Although Socolaw and Pacala only engage in a thought experiment in their writings and do not purport to show the feasibility of actually installing a million wind turbines to replace coal generation in this country, wind developers and their supporters use this work as evidence of what ought to be done to save the planet.

THE ROULETTE WHEEL OF WIND AND THE IMPERATIVE FOR RELIABILITY

The whole point of the modern grid is that one can count upon availability precisely when it is needed: one throws a switch and the lights come on or off. At the moment a hundred people blip their television sets, grid operators remove the power that supplied them. When a thousand people engage their air conditioners, power sufficient to make them work is brought on board in that instant. In too many ways, the unpredictably intermittent and volatile nature of the wind, the cycles of human activity, and the limitations of wind technology itself, are together dysfunctionally incompatible with the system that brings electricity reliably home to millions of people. Moreover, the grid mechanics involved with "load balancing," whereby power generation meets forecasted demand immediately in ways that also protect the security of the grid, subvert claims that wind energy can displace conventional generation and significant amounts of carbon emissions from that generation.

Let's examine these issues by:

- comparing wind with other forms of industrial power generation;
- identifying problems with integrating its intermittent energy fluctuations into the grid system, producing little or no capacity;
- investigating its compatibility with peak demand times;
- describing the difficulties inherent in the process of displacing or avoiding carbon emissions; and
- looking at its performance in Denmark, Germany, and other areas, using actual production data.

CAPACITY FACTOR LIMITATIONS

Because of wind energy's intermittency and the limits of technology, the capacity factors of wind facilities, which indicate expectations of annual production, average between 20% and 30% of their rated capacity. Less than one-half of one percent is able to meet or exceed 30%. **(14)** On average, a wind plant rated at 100 MW would therefore annually yield about 25 MW. Consequently, wind developers often dwell on their projects' installed capacity rather than focus upon capacity factors. **(15)**

No other type of industrial power generator has such a low capacity factor because of its inherent technical limitations and the nature of its power source. Nuclear plants, even with outages for maintenance, have capacity factors in excess of 90%; their national average approaches that level. **(16)** Individual large modern coal plants also approach this level (the national average capacity factor for coal generation is 71%), as do many gas-fired facilities, if they are targeted to serve base load. **(17)**

Low aggregate capacity factors for generally reliable energy sources such as hydro and natural gas are the result of management choice, not a function of their intrinsic behavior, as is the case with wind energy. **(18)** Wind developers frequently cite low capacity factors for hydro, claiming weather and climate limit its availability. But these conditions, such as drought, are often seasonable and can be projected (and compensated for) by reasonable planning efforts. Hydro is also typically storable and, day-by-day, week-by-week, highly reliable. If grid controllers are able to use it as part of base load supply, the capacity factor for hydro is high, frequently more than 95% **(19)**, far more than capacity factors that will ever be achieved for industrial wind energy. Many small turbine (and internal combustion) generators have extremely low capacity factors because they are built and/or make economic sense only for peak load operation. Capacity factors under 5% are very common among these units.

The low capacity factor for wind energy has enormous implications. Without considering any other variables, simple arithmetic shows that over 2000- 2.0 MW wind turbines, each with a generous capacity factor of 30% and spread over hundreds of miles, would be necessary to equal the output of one 1600 MW coal plant situated on a few acres. But even this equation assumes, incorrectly, that wind technology could actually supplant the capacity from this coal facility because, for wind energy to produce comparable capacity at times of peak demand, many more turbines would be required, as we will see.

All other industrial power generators produce a steady, reliable stream of electricity over specified periods of time. Outages are generally very predictable, allowing grid operatives hours, days or weeks to find suitable compensation. Only wind energy fluctuates so widely, minute by minute, struggling just to produce. But, as Charles Simmons, an engineer who worked with Appalachian Power Company for forty years, recently testified: “the capacity factor of a conventional plant is not dictated solely by its ability to produce but by the need to serve customer load.” **(20)** For this reason, it is often called the load factor.

Beyond the meager capacity factors for wind technology, but linked to them, is the quixotic and volatile nature of its power source. Our illustrative 100 MW wind facility might produce 80 MW one hour, then, 15 minutes later, produce only 30 MW. And ten minutes later, it may generate 65 MW. An hour later it my produce no electricity at all.

According to the Dutch energy engineer, J.A.Helkema, the aggregate power of a wind plant varies continuously during a year between full capacity and near zero. **(21)** There will be many days when the wind won’t blow and many more when wind generation is depressed. It is this sort of instability that creates enormous compensatory problems for grid managers, especially as wind energy penetration increases. Most utilities operating their own grid don’t count on any wind power during seasonal peaks. As more wind plants are added to the system, “overestimating could mean a blackout, while underestimating could mean paying a lot of money for unneeded standby generators.” **(22)**

Wind developers are quick to claim that, at small levels of penetration, the grid can absorb wind volatility in the same way it does for the fluctuations of demand created by people turning their television sets or computers off and on. For example, in Wyoming County, New York, two proposed wind facilities are rated at 190 MW. **(23)** Using a capacity factor of 30%, these wind plants might variably contribute an annual average of 57 MW into New York’s grid, which has an installed capacity of 37,000 MW. **(24)** These wind projects would inject such a small fraction of energy into the system that it could be compensated within the existing regulating reserve system, without undue strain.

But not without cost, both in terms of dollars and likely increased thermal generation beyond what would be necessary without the addition of the wind energy, since it can't produce a steady stream of electricity. As Halkema wrote, "The annual kWh production by wind turbines is always the sum total of hundreds of small [extremely variable in time and scale] portions of kWh." Since grid managers seek to avoid waste as they balance existing load/generation flux, even small amounts of wind flux require additional balancing. **(25)** As wind variability increases beyond 5% of grid capacity, additional balancing costs rise commensurately, not to mention the rising costs for grid security. This also has major consequences for carbon emissions' savings, as we will see later.

WIND CAPACITY BLUES

For grid operators, the most important question concerns "what capacity is available at the time of peak load?" **(26)** Simmons, using four years of data comparing wind speeds and availability with demand cycles, concluded that "wind generation is at its lowest when the need for capacity is at its greatest." **(27)** Moreover, Simmons continued, "The variation in wind generation would make it very difficult to incorporate a specific capacity for that source in the day-ahead planning which is an essential part of maintaining a reliable system." In reviewing Germany's extensive wind plants, E.ON Netz, manager of one of that country's largest grid systems, showed that at no point in 2003 did wind energy exceed 80% of its rated capacity. For more than half the days in 2004, the sum of wind plant output to the grid was lower than 11% of its rated capacity. **(28)**

That same E.ON Netz report revealed sizable weather forecasting errors for wind energy—ranging from -370 MW to + 477 MW on 6250 MW of installed capacity, and that, during individual hours, the error was as large as +/-2900 MW. **(29)** Furthermore, when reviewing the results of a timed study of eight-hour-ahead wind production forecasts over 6650 MW of installed wind capacity from 7,000 widely dispersed wind turbines, E.ON Netz found that, although forecasting errors of more than 1000 MW were "fairly rare," about one-third of the time they exceeded 500 MW. This casts doubt on persistent claims that better forecasting of wind availability will allow grid operators sufficient knowledge to accurately plan the amount of backup generation necessary to safely compensate for the widest wind fluctuations. Such evidence reinforces the axiom that wind patterns are inherently random. Moreover, the size of the E.ON Netz sample demonstrates that spreading large numbers of wind turbines across the landscape—diversifying the aggregate wind supply--would not vastly improve the stochastic likelihood of more accurate forecasting, as many wind developers maintain.

Recent data compiled by the Renewable Energy Foundation in Britain, looking at eight widely-separated wind regions, showed that, although aggregating does reduce the wind flux somewhat, "the overall power output is far from smooth." In January, for example, the output variations over 12 years varied by 94% of the installed capacity, causing the remaining power plants on the grid to work harder in order to compensate. **(30)** Although the sum of two or more random occurring phenomena "will always be random," (31) grid managers, using sophisticated statistical techniques, may tame the volatility somewhat, as they do for load flux. Actual performance data for wind plants, however, suggests that to do so effectively would mean thousands, likely tens of thousands, of very widely scattered wind turbines.

CAPACITY CREDITS: SINGLE DIGIT ACCOUNTING FOR WIND

Analyses of existing wind facilities also demonstrate energy peaks from wind are basically incompatible with load consumption cycles. Studies from Denmark and Germany to Texas and California, from Alberta and Toronto to New York and Pennsylvania, confirm wind technology's anemic capacity credit. Reports (such as the General Electric Wind Power Integration Study released in October 2006) projecting relatively high wind capacity credits—from ten to nearly 30%—were conducted by those who have a financial stake in the implementation of wind technology. (32) Independent analysis of actual wind plant production reveals a far different picture.

Peak wind production typically occurs at night during base load conditions. Seasonally, during summer afternoons of peak load, stationary high weather fronts dominate many regions of the country, creating low wind conditions. In winter, similar fronts stall the wind on the coldest days, making it virtually unavailable at times of peak demand for heat at night. (33) According to a recent paper released last year by faculty from the University of Victoria in Canada (Pitt, et al), which focused on wind's capacity credit, the data "illustrate the existence of a law of diminishing returns with respect to increasing wind penetration when measured by wind's effective capacity, fuel displacement or CO_2 abatement." (34) The same report also showed the difficulty in generalizing about the capacity credit for wind, since "it is a highly site-specific quantity determined by the correlation between wind resource and load," with values ranging "from 26% to 0% of rated capacity." (35)

In a 2003 study, the California Energy Commission, aggregating three wind plants that collectively represented 75% of California's deployed wind capacity, estimated they had relative capacity credits of 26.0%, 23.9% and 22.0% respectively. (36) Although specific data is not available on how these three particular facilities performed during the energy crisis in California this summer, the CEC's estimates don't seem congruent with actual performance data. As was widely publicized in the press, California wind power produced at 254.6 MW (10.2% of wind's rated capacity of 2,500MW) at the time of peak demand (on July 24th, 2006) and over the preceding seven days (July 17-23) produced at 89.4 to 113.0 MW, averaging only 99.1 MW at the time of peak demand—or just 4% of rated capacity. (37) The California Independent System Operator estimates that the capacity credit for wind energy in that state will be 5%. (38)

The following excerpt from the Electricity Reliability Council of Texas' (ERCOT) 2005 study suggests a more conservative assessment of wind's effective capacity in that state:

> In addition to meeting the state's energy needs, the electric system must also meet expected peak demand. Generation resources other than wind will be needed to meet most of the projected growth in peak demand, as maximum output from wind resources does not correspond to system peak demand. ERCOT currently assigns 10% of the installed capacity of wind turbines to its calculation of the ERCOT peak capacity reserve margin. Based on a review of historical data of actual wind turbine generation during ERCOT system peaks (from 4 p.m. to 6 p.m. in July and August), the average output for wind turbines was 16.8% of capacity. However, the data also showed that for any hour during these months, the output of the wind turbines could range from 0% of installed capacity to 49% of installed capacity. Stakeholders comprising the ERCOT Generation Adequacy Task Group have expressed concern that use of an average number (i.e., 16.8%) was too optimistic because it fails to adequately recognize the intermittency of wind generation. Accordingly, the group is working to assign a peak capacity value for wind using an appropriate "confidence factor." While the group has not yet formally made a recommendation to the ERCOT Technical Advisory Committee, it is currently considering recommending a wind capacity value of 2%. In summary, in order to reliably meet system peak demand, dispatchable resources (such as gas, coal, biomass) would be required to replace the wind resources when wind is not blowing." **(39)**

ERCOT's view is shared by Energy Probe's recent study of Ontario wind plants:

> In Ontario, the IESO assumes that 10% of the installed capacity should be considered as firm capacity for meeting peak demands. A Pembina Institute study has commented on this assumption, "Given that the capacity factor for modern land-based wind turbines is accepted to range from 25%–40%, and that wind generating capacity in Ontario will be relatively geographically distributed, this may be an excessively conservative assumption."
>
> Both the GE Study conclusion and the IESO's forecast about firm summer peak reliability are inconsistent with Ontario's actual experience. During July and August 2006, the actual average frequency of hours when there was little or no wind output in Ontario—output less than 2%—was 18.6%. These very low production hours were about as likely to occur during the daily peak period as any other time during the day. Ontario's experience in 2006 shows that the conclusion of the GE Study that wind can reliably supply power in summer equal to 17% of its rated capacity significantly over-estimated the actual results. The actual results for the summer of 2006 also suggest that the IESO should review its forecast that even 10% of the installed wind capacity should be considered as firm capacity for meeting peak demands. During the summer of 2006, wind power provided no firm generation capacity during the peak months. **(40)**

In its 2005 Annual Report, E.ON Netz reported that:

> Wind energy is only able to replace traditional power stations to a limited extent. Their dependence on the prevailing wind conditions means that wind power has a limited load factor even when technically available. It is not possible to guarantee its use for the continual cover of electricity consumption. Consequently, traditional power stations with capacities equal to 90% of the installed wind power capacity must be permanently online in order to guarantee power supply at all times. (41)

Here, E.ON Netz distills one of the most salient issues about wind generation: *flexibly responding, very active conventional generation with capacity approaching the capacity of the installed wind facilities will be required as wind penetration increases to 10-20% of the grid's total power generation. Consequently, for wind energy to "replace" a 1600 MW coal plant (with a capacity factor of 80%) at the crunch time of peak demand—a time when it is genuinely wanted—over* **20,000** *– 2.0 MW wind turbines, with capacity factors of at least 30%, must be in place. Or new or expanded conventional generation with an installed capacity of 1440 MW, sufficient to cover 90% of wind energy's installed capacity.*

An average capacity credit for U.S. wind plants has not been calculated. The national average capacity factor for wind has recently improved to 29% for 2005 (42)—far better than those of most other nations. However, empirical evidence available from Texas, California and Ontario suggests that wind facilities sited on land will achieve capacity credits averaging only in the medium single digit range. As the Victoria report concluded, the best way to obtain this information is with real time performance data, which is difficult to find. Wind developers maintain their projects are "proprietary." They are often unwilling to share relevant information for independent assessment. For example, when Canada's independent energy consumer organization, Energy Probe, asked to see the complete monthly production data for a single Windshare turbine located in Toronto, Windshare not only refused the request but subsequently removed incomplete monthly production data from its website. (43)

WIND FLUX INTEGRATION PROBLEMS

Because of wind unreliability, wind technology cannot be depended upon at any level of demand to provide capacity, that is, power on command, which is the definition of unit availability. A random doubling of wind speed from, say, 5 mps to 10 mps increases energy generation from 6% to 73% of rated output. (44) Unlike the highly predictable variations of load, manageable within one percent of forecast, wind variations are not manageable because they can't be forecast within a range that would allow grid operators to plan with specificity how much compensating generation is needed at any given time. Both the E.ON Netz report and the Ontario wind study demonstrate that wind flux variations far exceed those for load.

The intermittent pulsations of wind energy cannot by themselves service any households or agencies, contrary to the claims of the industry widely reported in the press, unless people wish to pay for a service that delivers only on a hit-or-miss basis—or unless they install expensive battery storage systems that would provide only partial compensation. Since wind energy cannot be stored at bulk levels (despite hopes of wind developers, the technology enabling such storage does not, and may never, exist at bulk levels), and since wind generation and grid load are not correlated in time, "this requires large amounts of conventional balancing power for frequency control and stabilization," **(45)** causing generators to cycle up and down more frequently, reducing their capacity factors as well as their availability to balance the usual generation/load fluctuations within the grid. **(46)**

What this idea demonstrates unequivocally is that ***wind energy, at industrial scales operating within the grid system as a whole, must be considered as only one of the reciprocals in a fuel mix; it must be entangled with conventional fuel to make it viable even as a sporadic fuel substitute.*** Wind energy simply cannot be loosed on the grid by itself. Grid stability requires that the fluctuations of wind be backed or compensated for immediately by conventional, reliable generation on a minute by minute basis—that is, generation from highly flexible, rapidly responsive thermal or hydro units.

There are several consequences arising from this fact:

- existing conventional generation must run harder just to stand in place, using more fuel to compensate for wind's fluctuations, while
- the more wind energy that is installed on the grid, the greater the need for expanded or new conventional generation, as suggested by E.ON Netz's engineers.

Moreover, as the percentage of wind penetration encroaches upon the grid's ability to compensate for it, new interconnection systems must be established to shunt unexpected, unneeded wind energy, particularly at times of low demand and high wind productivity, to other areas, averting the prospect of power surges that mandate the use of expensive reserve compensation and jeopardize the function of the grid.

THE PROBLEM WITH WIND ENERGY AND CARBON EMISSIONS AVOIDANCE

Grid management is already at work balancing and stabilizing the flux both of demand and power generation. Adding even more volatile wind flux introduces another level of complexity. As wind energy is introduced on the grid, what fuels might it replace and what fuels would be available to compensate for its rapid, unpredictable variability? And how will wind production affect the operation of compensating generators, in terms of efficiency and cost? The key to answering these questions must involve:

(1) identifying fuel sources with generators capable of being efficiently and quickly turned off and on, as well as harnessing fuel sources with generators that are rapidly responsive; and

(2) estimating any emissions abatement from wind by considering net reductions in light of the overall system-wide emissions produced on the grid as a result of wind generation, since wind energy must exist entangled with other fuel sources that have highly responsive generators. Any calculation of the CO_2 emissions reduced by wind

generation must take into account both the fuel that is replaced and the compensating conventional fuel generation. Such a calculation, involving a randomly intermittent renewable like wind, cannot be done using a single emissions factor.

With these ideas informing analysis, performance data from Britain, Denmark, Ireland, and Germany shows that "a substantial part of the theoretical CO_2 saving does not accrue in practice. In some circumstances there may be only minimal benefit." **(47)**

IN SEARCH OF A DANCE PARTNER

Given the ramping limitations (that is, the difficulties in turning the generators off and on quickly) of base load nuclear and large coal generators, it is unlikely, both for reasons of technical feasibility and cost, that wind would generally replace some output from them. **(48)** As it does via Norway and Sweden, wind energy in Denmark displaces a significant amount of hydro-powered generation, and could do so in the United States where hydro is available. However, since hydro emits no greenhouse gases, there would be no net carbon savings. **(49)**

Wind might also replace some power from any of the other thermal fossil-fueled generators, including natural gas and coal. Nonetheless, belief that wind energy will replace this fossil fuel capacity on a MW for MW basis is incorrect. **(50)** Voltage and frequency support offset some of the energy that may be displaced. More to the point, calculations of carbon emissions savings due to fuel displacement must account for any carbon emissions that might be added to the system as a result of the need to compensate for wind energy flux. As stated earlier, such a calculation must account for the system as a whole, not just focus on a narrow linear consideration.

If, on a large scale, wind energy could replace coal, even more efficiently burned coal, and then be compensated by hydro generation, such a circumstance should result in meaningful carbon emissions abatement. But there are many areas of the country with no hydro facilities and little prospects for building them. At the same time, those areas of the country with good hydro supply are already using the existing hydro facilities maximally as base load generation, load balancing, or both. In most cases, diverting hydro to balance the variations of wind would be either impractical or impossible.

Since natural gas-fired plants emit up to 60% less greenhouse gases than many coal-fired units, a better scenario for wind energy would have it replacing certain coal plant generation while backed by natural gas units. But a number of problems converge to limit the scope of this application. First, extraction techniques for natural gas are often environmentally very damaging; most environmentalists would not agree that the trade-offs involved with mining more natural gas were salutary. Secondly, there will be for some time to come a serious dislocation between the sources of natural gas supply and high demand areas, necessitating costly realignments of supply connections, making the already high cost of the fuel even higher. Third, demand for dwindling supplies of natural gas as a source of heat will resist the demand for its increased use for electricity. Finally, an Irish ESB National Grid (2004) study, among others, considering quarterly hour time increments, rather conclusively showed that high penetrations of wind energy, even backed by flexibly responsive natural gas units emitting relatively low levels of greenhouse gases, produce "diminishing returns, this time in terms of the realizable fuel saving and consequent CO_2 reduction potential of wind power…." (51) The overall "impact of wind penetration on the presumed–to-be-wind-friendly thermal gas plant is dramatic…." (52) It is likely the problem would have been even worse if the study had examined minute-by-minute wind flux.

A few areas of the country may achieve net carbon savings by switching off some coal plants, backing the variable wind energy with some shared combination of hydro and natural gas, although the scope of this application would be limited, both for reasons stated above and because the efficiency of the coal plant in this circumstance will be reduced, creating lower capacity factors for it because the plant would be started and stopped more frequently than it was engineered to do. Even small declines in efficiency have significant adverse effects on emissions. (53)

For most areas of the country, the question about emissions avoidance would devolve around how wind energy replaced coal-or-oil fired generation while being backed by rapidly responding coal-or-oil fired units. This will be especially true for peaking plants within the nation's largest grid system, the PJM (Pennsylvania, New Jersey, Maryland), with an installed capacity of nearly 165,000 MW and a generation mix including 57% coal, 34% nuclear, only 5% natural gas, and a trifling 0.9% hydro. (54)

As David White wrote over two years ago, the more wind energy introduced into the grid, "the more of lower efficiency capacity will be required to operate on part-load with increased emissions." (55) The Irish study, using excellent wind data, reported that wind energy reduced thermal plant capacity factors of "both base load and load following plants, [creating] large increases in the frequency of plant starts and stops." (56) This, too, has implications for cost. But it has devastating implications for wind energy's case for abating carbon emissions, especially in regards to coal. The Irish experience with coal shows that as the level of wind penetration increases, CO_2 emissions also increase as a direct result of having to cope with the variations of wind. (57)

According to Simmons, one of the most serious constraints in optimizing the economic dispatch of the various power sources available on the grid for meeting demand is imposed at base load circumstances by coal-fired units. (58) Recall that economic dispatch is achieved by assigning generators with the lowest delivered cost to meet intervals of forecast demand. "For safety reasons," Simmons testified, "coal-fired units cannot be operated at levels significantly below half load unless supplemental firing (oil or natural gas) is used for flame stability. The time to return a coal-fired unit to service (8 to 24 hours from start-up to full load) precludes taking such units off line to respond to the lightest loads on the system. These lightest loads are commonly referred to in the industry as light load minimums." (59) Simmons further stated that wind generation, since it can't be dispatched or be stored, "contributes to the difficulty of meeting light load minimums" because "This leads to supplemental firing, generally with oil, to maintain flame stability on coal-fired units.” **(60)** The supplementary firing of oil-fired units would add carbon emissions to the system.

More problematically, if one or more of the generating units in a coal plant are swiftly throttled back and forth as they are replaced by wind energy, reducing the efficiency of the coal facility, any net benefit from carbon emissions saved because of the fuel replacement could be completely negated. **(61)**

When coal-fired turbines are frequently and rapidly ramped up and down to compensate for wind variation, “the unit emission of CO_2 per kWh increases …to cope with load. This can easily be 2% or more…depending on the degree of ramp-down. On a coal-fired boiler, a 2% reduction in efficiency increases the unit emissions from 950 grams per kWh to nearly 1,100 grams per kWh, a change of 150 grams per kWh….”—a 16% increase in emissions. **(62)** Liik et al in their report about wind energy and Estonia analogized thusly: “Operating a thermal plant with and without the need to compensate the fluctuations of wind power is similar to the running of a car in the city and on the highway, respectively. Fuel consumption of a car can be even double in the city compared with the highway due to constant accelerating, braking and idle….” **(63)**

The Electric Power Research Institute in California affirmed this finding, agreeing it is technically incorrect to assume that wind energy will displace fossil generated power and decrease CO_2 emissions on a kWh for kWh basis. Its report concludes that in a real operating situation, because storage of electricity is not possible, any CO_2 saving will be small. **(64)**

NO THERE THERE

These observations should be sufficient to demonstrate that any consideration of net CO_2 abatement because of wind energy must account for both the fuel that wind might displace and the type of capacity that compensates for wind’s variability. If wind’s turbines were power plants that produced with the relatively static constancy of thermal facilities, one could indeed use linear methods to calculate the savings from fuel replacement. Adjusting for the way the grid must deal with wind variations, however, better calculations show that wind energy at higher levels of penetration would increase the fuel consumption and emissions from compensatory thermal stations about 8 to 10%, at least, “which will reduce the environmental effect of wind plants substantially.” **(65)**

Various wind energy associations and environment groups continue to publish linear projections about how much carbon savings could be achieved through wind generation. White rather conveniently summarizes three United Kingdom abatement calculations, each of which examines projections from coal and gas-fired units, none of which considers the system effects of efficiency changes in variations on load, stops or ramping. **(66)** More recently, Maryland’s Power Plant Research Program estimated that a 40 MW wind facility would save 63,000 tons of CO_2 annually but admitted that this calculation assumed an unsubstantiated capacity factor of 38 % and a linear conversion, where the wind energy would displace the dirtiest burning coal units and without accounting for other grid system effects. **(67)**

Simmons has concluded: “You can make no rational judgment as to the extent of any emission reduction without knowing which units will be affected. The grouping of units as coal, gas or oil is far too simplistic to produce meaningful results. The variation in heat rate between units and variation over the load range on the same unit, the presence or absence of pollution controls and their effectiveness, the fuel characteristics and transmission constraints—all will have an effect that can be determined only by knowing the units affected.” **(68)** Indeed, what is the informational value of conflating the dirtiest coal generators with those equipped with scrubbers working at 98% efficiency?

The American astronomer, Harlow Shapely, once said, “Theories crumble, but good observations never fade.” **(69)** The only way to get an informed handle on the extent of any system-wide net reductions from wind energy would be through a series of simulations using actual performance data showing how various levels of wind generation affect various conventional plants, as well as its effect on the consequent compensatory generation units. Forecasts from these simulations must then be compared with actual grid operations over many cycles and specified times for validation. This has not been done.

Tom Tanton, vice-president and senior fellow with the Institute for Energy Research, estimated ten years ago that an industrial wind plant must be in operation for at least seven years of production to offset the carbon emissions created in the manufacture and use of concrete for wind turbine placement. Given better economies of scale, Tanton’s projection may be on the high side today. But when all the carbon emissions from the installation of a wind facility, its maintenance and operational electricity use, are also factored, any offset may take more than several years. **(70)** Moreover, it is unclear what the functional life of large wind facilities will be, given that wind developers can depreciate the capital costs of their plants on a double declining basis in little more than five years, while associated federal production tax credit incentives expire after ten years of operation. Given these observations, in tandem with the facts of life involved with grid mechanics assuring reliability and stability, one could rationally assume wind energy might existentially be responsible for increasing carbon emissions.

Finally, without considering these other factors, how would the role of economic dispatch play out in the attempt to integrate wind energy on the grid in order to mitigate carbon emissions? In many regions of the country, wind is considered **“bound”** generation, energy which the grid must accept because of political decisions in the form of Renewable Portfolio Standards. However, economic dispatch obligates grid managers to allocate the most economical generation units to satisfy various demand levels. Will they deload more expensive but cleaner burning natural gas-fired plants in favor of wind, keeping coal plants on line because of their lower cost? **(71)** Specifically, how would price considerations affect the type of conventional generation wind energy might displace, since the principle of economic dispatch insists upon choosing the lowest cost units to be displaced, then proceeding to the others in order of their cost? And how might decisions based upon these considerations affect carbon emissions abatement?

WIND REALITY

A few months ago, the Electricity System Operator of Alberta, Canada, decided to limit wind energy development in that province to 900 MW, 500MW more than the current installed capacity. It did so after a review of wind performance in the province showed a lack of correlation between aggregate wind production peaks and demand for electricity, especially in the dead of winter when usage is high and wind generation extremely low. The system operator also concluded that high wind generation at time of low demand presented a threat to the security of the system, since the province did not have adequate transmission interconnections allowing the excess wind energy to be sent elsewhere, and was unprepared to invest billions of dollars to do so. Moreover, the only viable flexible conventional generation available to compensate for wind variably was hydroelectric, which is in low supply and already fully deployed engaging load flux. **(72)**

Close examination of wind generation in Denmark and Germany affirms concerns about wind technology, both as a fuel substitute and a means of avoiding carbon emissions and as a problem for grid mechanics.

DENMARK

As elsewhere, Denmark's demand peaks are antithetical to the peaks for wind generation. Consequently, although the country's 6000 wind turbines do provide around 20% of Danish installed electricity capacity, they only contribute a ration of about 1 or 2% to Denmark's supply of power when viewed in their true context. West Denmark's system operator, Eltra, is part of a much larger transnational system, with interconnections to Sweden and Norway (similarly, East Denmark's Eltra grid connects with Germany). Since there is a substantial differential between the timing of Danish demand for electricity and the peak generation wind cycles, Eltra sends more than 80% of West Danish wind energy to Denmark's Nordic neighbors, which "act as large sinks to drain excess wind production." **(73)** Unfortunately for the abatement of Europe's carbon emissions, Danish wind energy displaces hydroelectric, the dominant power source in Norway and Sweden.

Meanwhile, the bound wind energy that remains in Denmark must be balanced with conventional generation, which overwhelmingly comes from coal's thermal generators, most of which are slowly responsive and non-dispatchable. Those coal-fired units that are relatively flexible must work much harder and much more inefficiently to balance wind flux. **(74)** Denmark remains near the bottom of all nations in the European Union in meeting its Kyoto Accord emission reduction goals. Despite being blanketed with industrial wind facilities, the country finally achieved a one percent reduction in greenhouse gas emissions last year, due primarily to increased use of hydro from its Nordic neighbors. **(75)**. According to Elsam's development director, Flemming Nissen, "Increased development of wind turbines does not reduce Danish carbon dioxide emissions."

GERMANY

Germany is the world's largest user of wind technology, having erected over 18,000 large wind turbines in the last twenty years that produce about 6% of the nation's total generation. E.ON Netz manages the transmission grid in Schleswig-Holstein and Lower Saxony, about a third of Germany, hosting 7,050 MW of Germany's 16,394 MW installed wind-generating capacity at the end of 2004. The total production in their system was 11.3 TWh in 2004, representing an average feed of 1,295 MW (18.3% of capacity). **(76)** It produced two brief reports in 2004 and 2005 summarizing its recent experiences with wind energy on such a vast scale. Some of its conclusions have previously been mentioned. Here are a few others:

- On Boxing Day, 2004, wind generation on the grid fell to below 40 MW. **(77)**

- The 2004 study found that adding 1000 MW of wind energy to the grid increased the grid's firm generation capacity by only 80 MW—8% of the installed wind capacity. Additional wind generation reduced firm generation capacity even further. "The German analysis found that the proposed tripling of wind capacity in Germany by 2020 is, in and of itself, driving a need for quintupling [conventional] generation reserve requirements." "In concrete terms, this means that in 2020, with a forecast wind power capacity of over 48,000 MW, 2,000 MW of traditional power generation can be replaced by …wind…" Moreover, E.ON Netz's CEO, Martin Fuchs, commented in his press release statement for the wind report that, if the 2020 target of 20% wind penetration were achieved, this 8% would become only 4%. **(78)**

- The massive increase in construction of new wind power plants in recent years has greatly increased the need for wind-related reserve capacity (conventional generation). This new generation would be apart from firm generation necessary to meet expectations of increased demand, and installed at 90% of the nameplate capacity of aggregate wind plants, using more conventional fuels in the process, producing copious carbon emissions—as much or more than if wind facilities had never existed. **(79)**

In February, 2005, a German government's energy agency released a report that concluded the country's wind plants were an expensive and inefficient way of generating sustainable energy. Instead of spending billions on installing new wind-related infrastructure, the emphasis should be on increased efficiency. **(80)**

ZUGZWANG

To summarize, let's imagine a small electricity grid with an installed capacity of 1000MW, generating around 500MW to satisfy base load (400MW of which are produced by nuclear and large coal units), with typical peak loads of about 900MW. Let's further assume that over 95% of the generation mix is comprised of coal, natural gas, nuclear and hydro, in the same ratio as the national level. Finally, let's introduce wind energy from a plant with a rated capacity of 200MW, consisting of 100-2.0 MW turbines spread over 20 miles, rarely generating more than 80% of its rated energy and, more than half the time, likely producing lower than 11% of its rated capacity, creating forecasting errors well beyond those involved with demand flux.

Stronger winds at night will add bursts of wind energy into the grid base load generation, with variable, unpredictable ebbs and flows. In one hour, the wind plant might provide 160MW and, 15 minutes later, drop back to 100 MW, then back up to 150 MW, and, an hour later, drop to 40 MW. Since 400 MW of conventional grid generation is dedicated to firm, steady base load supply using slowly ramping units that generally should not be interrupted, that leaves 100 MW of flexibly responding regulating reserves available to compensate for the levels and fluctuations of the wind energy. But these regulating reserves are already dispatched to compensate for the flux of the conventional generation and the demand. The system operator must consequently bring 180MW of additional firm generation online, ostensibly at levels near 90% of the wind plant's installed capacity, most of which would be fast-ramping, highly responsive intermediate or peaking units with much higher fuel and other costs (but not hydro or natural gas units, since the former would be tapped out and the latter is very costly). Otherwise, the system operator would compromise the grid's reliability and security—unless expensive interconnections were built to shunt the unnecessary wind energy to other grid systems, as is the case in Denmark. Throughout the night, flexible coal-fired units would be switched on and off, over and over, to backstop the wind flux.

Throughout the day, as demand increases to 600, then 700, then 800 MW, wind energy drops off significantly; but it is still widely fluctuating—at 100 MW levels, down to zero, up to 40, etc. And more conventional generation must be added to compensate. But the crescendo of flux is much greater now, given the increased volume of generation/demand fluctuations. At peak demand, all units are engaged. If 160 MW of wind then hit the grid unexpectedly, this would exceed the cushion built into the grid's installed capacity to compensate for it, even though all the generating units are working furiously, most extremely inefficiently.

The cumulative effects of high wind penetration will be extraordinary. According to Helkema, multitudes of large power station operators must simultaneously turn the fuel supply for their generators on and off continuously, endlessly, "the whole year around. When you look at the total of the varying aggregate wind power in Germany (a staggering 7050 MW), you will see that this comparison is in no way exaggerated. In the E.ON Netz region it would take the operators of twelve huge [conventional] power stations to produce the same effect." **(82)** Germany's present overwhelming dilemma with wind energy should be a cautionary tale, presenting as it does the predicament of *zugzwang,* a chess term for a situation in which a player would like to make no moves at all, since any move will damage his prospects. As E.ON Netz's engineers concluded in their 2005 report, "We have no solution for these problems." **(83)**

In the not distant future, if wind developers are politically successful, hundreds of thousands of massive wind turbines in stationary parade will march throughout the countryside, their blades whirling as they dominate the landscape as far as the eye can see, their height and scope a constant threat to migrating wildlife and civil accord. Despite their ubiquity, many more coal plants would be puffing away, many of them burning inefficiently. Despite the political commitment and vast public subsidy to wind entrepreneurialship, carbon and other pollutants would remain largely unabated. (81) Energy corporations such as General Electric, Florida Power and Light, and BP, which together presently own well over 75% of the nation's wind facilities, are even now capitalizing on wind's unearned environmental cachet for public relations purposes while using cap-and-trade mechanisms to trade within and among themselves, offsetting the extensive retooling required for installing cleaner burning equipment on their coal and oil generators. Most of the power these corporations now generate is considered "dirty." In addition, the Renewable Energy Credits associated with the technology, allowing wind developers to increase their earnings beyond the price paid for wind energy and any production tax credits achieved, are financial equivalents of the Roman Catholic Church practice of selling indulgences to a gullible congregation. Wind developers earn those energy credits because their turbines spin, not because there is a causal relationship between wind energy and reduction of carbon emissions on the grid.

Demand for electricity will have doubled present levels in this near future wind energy scenario, but our grid systems will doubtless prevail as they maintain in public a decorous presence while privately engaged in a monumental struggle to provide electricity reliably on demand—no mean feat given the roulette wheel of random wind energy they must accommodate safely.

Rube Goldberg would admire the utter purity of the pretensions of wind technology in pursuit of a safer modern world, claiming to be saving the environment while wreaking havoc upon it. But even he might be astonished by the spin of wind industry spokesmen. Consider the comments made by the American Wind Industry Association's Christina Real de Azua in the wake of the virtual nonperformance of California's more than 13,000 wind turbines in mitigating the electricity crisis precipitated by last July's "heat storm." "You really don't count on wind energy as capacity," she said. "It is different from other technologies because it can't be dispatched." (84) The press reported her comments solemnly without question, without even a chortle. Because they perceive time to be running out on fossil fuels, and the lure of non-polluting wind power is so seductive, otherwise sensible people are promoting it at any cost, without investigating potential negative consequences—and with no apparent knowledge of recent environmental history or grid operations.

Eventually, the pedal of wishful thinking and political demagoguery will meet the renitent metal of reality in the form of the Second Law of Thermodynamics (85) and public resistance, as it has in Denmark and Germany. Ironically, support for industrial wind energy because of a desire for reductions in fossil-fueled power and their polluting emissions leads ineluctably to nuclear power, particularly under pressure of relentlessly increasing demand for reliable electricity. Environmentalists who demand dependable power generation at minimum environmental risk should take care about what they wish for, more aware that, with Rube Goldberg machines, the desired outcome is unlikely to be achieved. Subsidies given to industrial wind technology divert resources that could otherwise support effective measures, while uninformed rhetoric on its behalf distracts from the discourse—and political action— necessary for achieving more enlightened policy.

Jon Boone
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ABOUT THE AUTHOR

I have been a formal intervenor in two Maryland Public Service Commission hearings from 2003 to the present. With David Beaudoin, a graphic designer and principal with Insignio Design, I produced and directed the documentary, *Life Under a Windplant,* which has been freely distributed within the United States and many countries throughout the world. I also developed the website Stop Ill Wind, www.stopillwind.org, where, under document downloads, one can read my complete direct testimony, with many related documents, in the Synergics wind case before the Maryland Public Service Commission. Also of interest may be my speech given in Wyoming County New York in June, *The Wayward Wind.* A lifelong environmentalist, I helped found the North American Bluebird Society and am a consultant with the Roger Tory Peterson Institute in New York. I am a former university administrator and now a painter who receives no income from my interest in industrial wind development, and neither I nor any members of my family live near property within sight of industrial wind development. Aside from environmental protection concerns, I seek informed, effective public policy.

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Hewson Jr, Thomas A, is a principal (since 1981) with Energy Ventures Analysis, Inc, Arlington, Virginia, directing the firm's environmental studies. He earned a BSE degree from Princeton University. He has testified as an expert witness at a number of regulatory hearings about wind energy. Notable for the present discussion are his testimonies regarding a proposed Redington Mountain Wind Project in Maine in August 2006: www.windaction.org/documents/4591 and his analysis in January, 2005 about CO2 savings from a Gray County wind installation in Kansas: www.windaction.org/documents/718. He also provided cogent written testimony on April 22, 2005 to the Maryland Public Service Commission, Case No. 9008 about how wind technology produces energy but not capacity: http://webapp.psc.state.md.us/Intranet/CaseNum/NewIndex3_VOpenFile.cfm?filepath=C:\Casenum\9000-9099\9008\Item_053\%5CHewson%20Testimony.pdf.

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Tanton, Tom. He is vice-president and senior fellow with the Institute for Energy Research, with more than 35 years experience in the energy, economy, and environmental fields. Until 2000, he was the principal policy advisor with the California Energy Commission. He has provided voluminous personal correspondence about industrial wind issues.

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ENDNOTES

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7. Bradley, page 22.

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9. Environmental Protection Agency, US Department of Energy, *Carbon Dioxide Emissions from the Generation of Electric Power in the United States, July 2000*, page 2.

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11. Elliott, D. L, and M.N. Schwartz, *Wind Energy Potential in the United States, www.nrel.gov/wind/wind_potential.html.* See Figure 4, Wind Electric Potential as a % of Contiguous US 1990 Total Electric Consumption. See also Table 2 for a brief discussion of wind energy projects at wind levels with power class 4- 7. See also Helkema, pages 14-15 for a good discussion about "Understanding the Beaufort Wind Scale."

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13. Socolaw, et al, *Scientific American*.

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15. Golden, *As Heat Sizzles….*

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18. Simmons, pages 13-14.

19. See *Capacity Factor* from Wikipedia: en.wikipedia.org/wiki/Capacity_factor.

20. Simmons, page 13.

21. Helkema, page 30.

22. Golden.

23. Horizon Wind, LLC seeks to place 65 turbines around the county. Orion Wind, IIC has stated it wants to put 40 turbines there—for a total of 105. The rated capacity of each Horizon turbine is 2MW; Orion's turbines may be rated at 1.5 MW. These 105 turbines would have a combined rated capacity of 190 MW.

24. New York's Independent System Operator—Fast Facts: www.nyiso.com/public/company/about_us/index.jsp.

25. Helkema, page 19.

26. Simmons, page 26.

27. Simmons, page 10.

28. White, page 29.

29. White, page 29.

30. Oswald, pages 8, 17-18.

31. Halkema, page 17.

32. Adams, page 13. The GE Study was co-sponsored by the Canadian Wind Energy Association. GE Energy is the fourth largest supplier or wind generating equipment in the world. As Adams notes, the GE Study used no actual production results, only its own

forecasts, despite the fact that several months of actual results were available when GE released its report.

33. White, page 12.

34. Pitt, et al, page 4.

35. Pitt, et al, page 31.

36. Dixon, "*Wind Generation Performance….*"

37. Dixon.

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39. Electricity Reliability Council of Texas, *Transmission Issues Associated with Renewable Energy in Texas*.

40. Adams, pages 13-14.

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42. Hewson, from his testimony regarding the proposed Redington Mountain Wind project in Maine, August, 2006.

43. Adams, page 6.

44. Oswald, page 4.

45. Leonhard, page 1.

46. Oswald, page 20.

47. White, page 8.

48. See Simmons for an excellent overview of large coal facilities and light load conditions, pages 4-5, 8. Also, see White, page 15. See also *Base Load Power Plant* from Wikipedia: en.wikipedia.org/wiki/Baseload_power_plant.

49. Liik, et al, pages 5-6.

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56. White, page 26. See ESB National Grid, Impact of Wind Power Generation in Ireland on the Operation of Conventional Plant and the Economic Implications (ESB National Grid, February 2004) page 18.

57. White, page 26.

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62. White, page 16.

63. Liik, et al, page 7.

64. From Save Our Unspoilt Landscape, under *Windpower and CO2 Emissions:* www.soul-online.co.uk/10.html.

65. Liik, et al, page 65.

66. White, page 36.

67. Proposed Order of the Hearing Examiner, David L. Moore, of the Maryland Public Service Commission in the matter of Synergic's Application for a CPCN, Case No. 9008, October 30, 2006, page 15.

68. Simmons, page 19.

69. Harlow Shapely: www.daviddarling.info/encyclopedia/S/Shapley.html.

70. Tanton, Tom, personal communication. Tanton writes on December 10, 2006: "the analysis was done using the 'way back' machine—around 1995 or 1996, and was a simple calculation, but ONLY refers to the concrete used in the foundation for the towers. (Production of cement for concrete emits A LOT of C02.) The analytic approach is referred to as 'life cycle analysis' or sometimes 'cradle to grave'—but the analysis of

concrete for turbine foundations is only one of several emission-causing tasks in developing wind farms that are ‘not seen by the public’ The seven years is a function only of the marginal concrete per kW compared to conventional technologies. That is, while all power generators require concrete (foundations etc), wind requires MUCH MORE concrete per kilowatt (and obviously then much more per kilowatt-hour), and the difference (wind amount minus ‘base amount’) is what I based the seven years on.” Later, he writes, “given the changes in wind turbines, I’m not sure the old estimate is necessarily ‘conservative’ today, but not necessarily otherwise (i.e., the unit amount of concrete, per Kw installed may be somewhat smaller, with economies of scale). I do remain convinced it is still significant.” On the other hand, John Etherington believes the offset would occur, at least for the concrete involved, in about one year—which is consistent with the estimate of a parliamentary inquiry response in 2004 (personal correspondence from Etherington).

71. Simmons, pages 7-8.

72. Adams, page 6.

73. Pitt, et al, page 28.

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75. European Environment Agency: www.eea.europa.eu/pressroom/newsreleases/GHG2006-en.

76. E.ON Netz GmbH website: www.eon-energie.com.

77. E.ON Netz GmbH *Wind Report*, 2005.

78. E.ON Netz GmbH *Wind Report*, 2004. Also cited in Adams, page 13.

79. E.On Netz GmbH *Wind Report*, 2004.

80. *German Government Study Questions Value of Wind Power,* Environment News, June 1, 2005.

81. Tom Hewson, from his testimony and rebuttal testimony regarding the proposed Redington Mountain Wind project in Maine, August, 2006. See especially page 8 of his rebuttal testimony, in which he states: “…even if the project competes against fossil fired generators, any emissions subject to cap and trade environmental control programs may be displaced but will never be avoided. If the RMW project displaced any emissions, the generator could simply sell and/or transfer his unused emissions credits to another source that would allow that source to emit more.”

82. Helkema, page 17.

83. As quoted in Helkema, page 25.

84. Whieldon, Esther, *CAL-ISO Offers Sobering Wind Assessment: It's Growing but can't be Relied On as Capacity.*

85. See the Second Law of Thermodynamics. In any energy conversion, such as electric energy into light, much of the energy is "wasted" because it is dissipated into the environment. It is not "lost," for that would violate the First Law of Thermodynamics. For an excellent concise discussion of this law, see Isaac Asimov's *New Guide to Science*, Basic Books, Inc, New York, 1984, pp. 398-399. The central problem with harnessing any form of energy is that enormous energies seem to be wasted in the process of producing and channeling a relatively small amount. Hydroelectric dams, for example, transformed whole ecosystems, but the resulting supply of electricity was only a small percentage of the total energy within the ecosystem before the dams were built. This "loss" of energy was really the loss of valuable natural dynamics that previously functioned to maintain wetlands and mitigate erosion.

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