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cc: B. Franklin, S. Fernandez
Date: November 19, 2006
From: S. Rashid

Subject: Environmental Impact of Electric Power Production

Brian Franklin has requested that I discuss some of the issues pertaining to the environmental impact of the various forms of electric power production. In today's environmentally conscious climate, there tends to be a lot of myth and make believe regarding what is, and what is not, clean energy. Most of this misunderstanding is due to an incomplete accounting of the relative environmental impact of certain types of energy production.

Energy Density

First, we can simplify the debate by understanding the fundamental environmental premise with regard to energy production. This premise, simply put, is that energy density is the most important figure of merit when one is concerned with the environmental impact of energy production. Energy density is the amount of energy contained within a unit of fuel (in either J/kg for solid fuels, or W/m² for wind and solar). From an environmental perspective, the higher the energy density, the lower the overall environmental impact. In other words, the more energy contained within a unit of fuel, the less fuel one has to mine to provide power, and the less waste one has to bury when the fuel is spent.

This is where energy sources such as wind and solar tend to overlook significant portions of their environmental impact. Because wind and solar power are "free", and have no emissions, we are tempted to think of them as environmentally benign. However, their low energy density means that large land areas must be devoted to the construction of wind or solar farms. The alteration of this land area must be considered part of the environmental impact of wind or solar power. As an illustration, consider the "fuel" required to generate 1000 MWe, adapted from information in Ref. 1, and provided in Table 1.

Table 1: Fuel requirements for the generation of 1000 MWe.⁽¹⁾

| Fuel | Req'd for 1000 MWe | Which Translates To... |
|-------------|-----------------------------|---|
| Coal | 9000 tons/day | 1/5 of the Washington Monument volume |
| Oil | 6449 tons/day | 12 times Washington Monument volume |
| Natural Gas | 3825 tons/day | 147 times Washington Monument volume |
| Uranium | 6.6 Lb/day | about the size of a Rubik's cube |
| Wind | 149,498,756 ft ² | 2115 300 ft diameter turbines |
| Solar | 126,634,240 ft ² | 4.54 mi ² , about the area of a small town |

The Washington Monument is a national symbol most of us are familiar with, so it provides a convenient scale for relative volume. An obelisk just over 555 ft tall, with a base that's just over 55 ft on a side, it's volume of 1,042,761 ft³ is roughly the same as a 10 story building 97.3 ft square at it's base.

Note that the requirements for wind and solar power in Table 1 are only valid if the wind is blowing, or the sun is shining. If not, then additional area will be required to generate the 1000 MWe. This is one of the primary reasons wind and solar power are not cost competitive with other energy generation methods. One has to install more capacity than is required to account for the units that are in inactive conditions on any given day. Also note that a 300 ft. diameter wind turbine is rated at 3 MW, which should translate into 333 units to generate 1000 MWe. However, the average wind resource in the continental U.S. is generally about 200 W/m², and a wind turbine can only capture 36% of that energy, or 72 We/m². Finally, the average solar incident energy is 850 W/m², but the best solar panels can only convert 10% of that energy into electricity, resulting in 85 We/m². Of course, these solar panels would produce no power at night.

Power Generation Capability

The ability to generate power on demand is a primary system requirement for base load units. These units must be able to “take up the slack” in the system by producing whatever power is needed that is not being supplied by “non-demand” units. A non-demand unit refers to any unit which must rely on favorable conditions to generate power, and therefore, is not capable of generating power strictly upon request. For example, a tidal power installation can only produce power when the tide is shifting, and will not be able to respond to power demand at other times.

This means that a power grid must use power from non-demand sources first, since they are subject to their respective conditions, with base load units filling in the gaps. By definition, base load units must be capable of supplying 100% of the power requirements in case there are no alternative power sources available at any given time.

This highlights the difference between “installed capacity” and “generating capacity”. A fossil fired steam plant with a 400 MW installed capacity also has a 400 MW generating capacity because it can be run at rated power at any time. The same can not be said for certain types of alternative energy sources. The wind turbines noted above are rated at 3 MW, their installed capacity. But in typical wind conditions they are only capable of producing 470 kW, or 0.470 MW, their typical generating capacity. Thus, in most areas of the country, base load units will be fossil fired (coal, oil, gas), hydro-electric, or nuclear.

On an individual level, there are numerous designers and architects that claim to have developed energy independent houses which net no power from the grid. While these claims may be true, they are not entirely accurate. Most of these houses benefit from net zero metering, or the ability to become independent power producers when their on site power generation exceeds their demand, thus supplying the excess power to the grid. A

house of this type might supply power to the grid during the spring, summer, and autumn seasons when wind and solar capacity is high, but require power from the grid during the winter months. It's the requirement to draw power from the grid during certain times that makes these designs less than fully energy independent, because the grid, and it's base load generating capacity, must exist to supply that power. Additionally, a certain amount of "spinning reserve" must be on hand at all times in case the sun goes behind the clouds, or the wind dies down.

To bring this discussion down to the everyday personal level, consider the question I usually ask during conversations on energy alternatives, "Would you want your heart-lung machine plugged into a windmill or solar panel?" And if the answer to that question is "no", then what implications does that carry for power generation in general? Base load must be carried by power generation methods that can be ramped up on demand. Alternative power generation sources can fill niche areas of the power generation spectrum, but will always be more costly per MWe generated, and less reliable, simply due to their dependence on the proper conditions for operation.

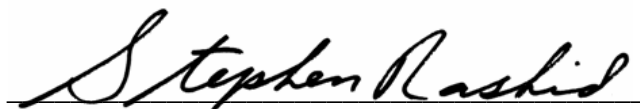
It is well and good to point to installations like the wind farms of Altamont Pass, San Gorgonio Pass, and Tehachapi Pass as producing power for large numbers of people on a regular basis. But it must be recognized that these installations would not be practical without the safety net that the base load grid provides.

Conclusions

Base load power must come from sources which can be accessed on demand (typically fossil, hydro-electric, or nuclear), and must have the capacity to supply the entire potential power demand. Alternative energy sources can be used to off load the base load units when conditions are right, but power from these sources will always be more costly, and less reliable, than the power generated by base load units. Alternative energy sources will never be able to take over base load production without significant redundancy in installed capacity, spread out over a large geographical area, to compensate for the inactive units on any given day.

References

1. Energy in Perspective; J. B. Marion and M. L. Roush; 2nd Edition, Academic Press, 1982



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