Scope: This article explores some of the challenges facing renewable energy and energy storage if significant CO_2 emissions reductions are to be achieved. For the full set of articles as well as information about the contributing authors, please visit http://acee.princeton.edu/distillates.

Article 6: Multi-hour Storage and Climate Change

The rising concentration of carbon dioxide (CO_2) in the atmosphere contributes to climate change. This concentration has been climbing recently at about one-half percent per year, and most of the increase is due to a global energy system that continues to be dominated by fossil fuels. Because coal and natural gas power plants are concentrated sources of emissions, and because they now produce roughly 40 percent of the carbon dioxide emissions from the world's energy system, existing and future coal and gas plants are the first target of emissions reduction strategies.

To what extent could the CO_2 emissions from coal and natural power plants be eliminated by wind and solar energy, for some specific region or grid? A substantial literature makes the case that an electricity system powered by 80 percent and even 100 percent renewables is potentially achievable. However, formidable challenges would need to be overcome for such an outcome to emerge.

Clearly, the whole job could not be done just by wind and solar, both of which are not only intermittent, but partially unpredictable. The fraction of the load over a year that could be supplied by an individual facility is, typically, one-third or less. A considerably larger fraction can be provided by wind and solar when the grid incorporates multiple facilities located hundreds of miles from each other, each with its own time variation, linked by grid transmission lines. Multiple sources of renewable energy that are geographically diverse will experience distinct weather conditions, and, moreover, in many regions, wind is night-peaking. But even when there is considerable linkage of different intermittent renewable energy sources, it is likely that there will still be considerable mismatches between supply and demand. A deeper understanding of the limits to managing intermittency via multiple sources will be available once correlations among sites become better known.

After taking into account transmission opportunities, the rest of the job could be done by some combination of four options.

A. The grid could include renewable energy sources that can run all the time and that are predictable ("dispatchable"). Examples are hydropower, biopower, and (in some locations) geothermal energy produced from heat deep underground.

B. Demand for power could be shifted to align with the intermittency; for example, a clothes dryer can be set to run only on windy days. Such load shifting is a key element of the emergent "smart grid."

C. There are strategies based on building so much capacity that demand can be met even when winds are moderate. It then becomes necessary to "spill" wind energy when winds are strong, rather than to collect and sell it.

D. Additional wind and solar facilities could be built, and the extra electricity produced could be stored in still other facilities that would hold the extra power for delivery when it is needed, typically many hours later. The high cost of multi-hour storage is one of the most serious detriments to an all-renewable power system.

Second best, from the standpoint of CO_2 emissions, would be a system where energy from natural gas fills in the troughs where renewable energy supply falls below grid demand and also compensates for any unpredictability. Natural gas systems have the needed flexibility to accomplish both of these assignments. They can provide power for many hours at a stretch and are also capable of modulating their output and relatively easily turning on and off. In this sense natural gas is the default partner for intermittent renewables.

How low-carbon is this hybrid system? Imagine a regional grid where over the course of a year electricity is produced half by carbon-free renewables and half by natural gas. That system would produce one-fourth as much carbon as a system producing the same amount of electricity entirely from coal – since natural gas power on its own emits half as much CO_2 as coal power, and the use renewable energy, in some guises, entails negligible CO_2 emissions. For many, "one-fourth of coal," it must be noted, is too high.

A variant of such a hybrid system would reduce the total CO_2 emissions from the system by adding CO_2 capture at the natural gas power plant and storing the captured the CO_2 deep underground ("geological sequestration"). This modification is called carbon capture and storage (CCS); adding CCS to a natural gas plant could reduce its CO_2 emissions by as much as 90 percent. But the result is probably a mismatch: the modified natural gas plant would be less nimble and better suited for running at constant output. From the perspective of project economics, coupling intermittent renewable power and load-following natural gas power becomes less attractive when CCS is added, because the plant becomes more "capital intensive," meaning that the fraction of the plant's total costs assignable to building it (fixed costs) is large, relative to running it (operating costs). The more a system is capital-intensive, the more it is advantageous to operate the plant nearly all the time so as to spread the fixed costs over as many hours of sales as possible, which militates against including CCS in a load-following plant. A second handicap of a load-following system with CCS arises from its greater operational complexity; a CCS plant is less suited to frequent up and down ramping of its power output, as compared with the same plant without CCS. Accordingly, and unfortunately from the perspective of reducing CO_2 emissions, natural gas power accompanied by CCS is a less credible partner for intermittent renewables than natural gas power on its own, without CCS.