Commentary

Nuclear Energy for Economic Variable Electricity: Replacing the Role of Fossil Fuels

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Fossil fuels are the traditional technology currently used to produce economic variable electricity to match production with demand. The cost of the natural gas or coal plant is low. The money is spent in collecting the fuel (natural gas, oil, coal) and bringing it to the fire. As a consequence, it is economically viable to operate a fossil plant at part load when there is little demand for electricity with limited impact on total electricity costs. In contrast, nuclear, wind, and solar plants have high capital costs and low operating costs. If they operate at half their full power, electricity production costs approximately double. This is why, historically, nuclear plants have operated at baseload, leaving variable electricity to be produced by fossil plants. However, concerns about climate change are creating a push toward eliminating use of fossil fuels.

The question is then, *What replaces fossil fuels in their role of providing economic variable energy to meet society's demand for low-carbon energy?* Can nuclear economically replace fossil fuels?

Because energy is 8% of the global economy, significant increases in energy costs imply a lower global standard of living and potentially leave much of the world in poverty. Meeting variable energy demand by operating nuclear reactors—as currently configured—at part load can produce variable electricity but not *cheap* variable electricity.

Today, wind and solar have the lowest levelized cost of electricity, but large-scale deployment has raised electricity bills in California by more than 20% and in Germany by more than 50% while natural gas prices have gone down. What happened? At times of high wind and solar output, the wholesale price of electricity collapses because production exceeds demand. California has had its first month where 20% of the time wholesale electricity prices were negative (around midday). Worse yet, wind and solar cannot provide assured generating capacity, so we need to keep existing power plants to provide electricity when the sun does not shine and the wind does not blow. This results in massive subsidies to cover the costs of wind and solar and to pay for all those power plants sitting around waiting to be used when there is no wind or solar output—money that gets added to home electric bills.

Storage can be used to partly match production with demand—but what type of storage? Wind and solar photovoltaic (PV) produce electricity and thus couple to electricity storage technologies (batteries, pumped hydro, etc.). Nuclear reactors and concentrated solar power systems produce heat that is converted to electricity; thus, heat storage can be used before converting heat to electricity. Heat storage (steam accumulators, hot oil, concrete) costs an order of magnitude less than electricity storage.

For this reason, some of the concentrated solar power systems have added gigawatt-hour heat storage systems to maximize revenue. Heat storage enables concentrated solar power systems to sell electricity when the price is high and minimize selling electricity when prices are low. However, storage coupled to solar or wind does not fully solve the problem, because any storage system can be depleted with the wrong weather—backup electricity generating capacity is still required. Some solar thermal power systems have added steam boilers for assured generating capacity if storage becomes depleted—matching many of the characteristics of a fossil plant.

Nuclear could fill the ideal role, with its controllable fuel source. The same heat storage options used for solar thermal also exist for nuclear. When coupling nuclear to heat storage, when electric prices are low: (1) operate reactor at full power, (2) operate turbine at minimum load to minimize electricity sales and enable rapid return to full power, (3) send excess steam to heat storage (steam accumulators, hot oil, concrete), and (4) buy negative and low-price electricity for additional heat input into storage using resistance heaters. When electric prices are high: (1) send all reactor steam to turbine or feedwater heaters, (2) send added steam from storage to the turbine or feedwater heaters, and (3) produce peak power greater than baseload power with an oversized turbine or use a separate peaking turbine.

A nuclear plant with an added steam boiler burning natural gas, oil, or biofuels can assure peak electricity production when storage is depleted at one-third the cost of the next-best option—the simple gas turbine. If one has a heat storage system, most of the time, peak power will be generated using heat from storage. In most electricity grids this implies that the steam boiler will be used less than 100 hours per year, implying almost no fuel costs. This assured peak generating capacity enables the nuclear plant to collect capacity payments from the grid for the added assured peaking capacity at a lower cost than having fossil plants on standby.

Heat storage coupled to nuclear reactors is not a new idea. Early studies were done after the oil embargo of the early 1970s, which made it expensive to operate oil-fired plants for variable electricity. What has changed is (1) the market and (2) the solar thermal community deployment of heat storage at the gigawatt-hour scale. The economics are simple: (1) maximize revenue by selling electricity when prices are high and avoid selling electricity when prices are low, and (2) minimize costs by operating at baseload. This also turns nuclear energy with storage into the preferred enabling technology for large-scale use of wind and solar by providing variable electricity and lower-cost assured generating capacity.

The message from the market is clear. The near-term priority should be a utility- and government-funded demonstration program of several heat storage technologies at the 100-MW scale or larger coupled to existing reactors. The longer-term priority is research to develop advanced heat storage systems for Generation IV reactors to maximize revenue *and* the benefits to society.

Editor's note: For further reading, this issue of *Nuclear Technology* contains a technical paper by Dr. Forsberg on heat storage coupled to light water reactors. Dr. Forsberg is also a coauthor of the recent Massachusetts Institute of Technology study titled *The Future of Nuclear Energy in a Carbon-Constrained World.*

—Andrew C. Klein, *Editor*