Electrical Energy Storage

Storage of carbon-free energy sources such as nuclear, wind, and solar key to success

Taking Charge

Jay Schecker
1663: We often hear about the need to conserve energy or to find alternative energy sources but rarely about the need to store it. Why does the DOE consider electrical energy storage "crucial" to our secure energy future?
Thorn: The answer is really that the world uses about 17 trillion joules of energy per second, and that rate is likely to double by 2050. We're going to need energy and lots of it. Simply burning more coal and oil isn't a solution, partly because oil supplies are dwindling, but mostly because the carbon dioxide that's emitted when you use those sources drives global climate change. To meet the impending energy need, we'll have to ramp up the use of carbon-free energy sources such as nuclear, wind, and solar.
Electrical energy storage comes into play because wind and solar generate electricity intermittently—we can't control when or how much they supply. Now Albert will tell you that because of the conservation of energy, the electrical supply must always meet the instantaneous demand. If it doesn't, even for just a few seconds, large portions of the power grid can go down. So by increasing the use of wind and solar power, we introduce a degree of uncertainty into our electric supply and actually make the grid less stable. Electrical energy storage lets you save electricity for later use, so it mitigates wind and solar's inherent variability. It enables the expansion of those two energy sources, since now they can be added to the grid without de-stabilizing it.
Migliori: Consider how New Mexico's public utility, PNM, sees it. Suppose the wind really kicks up in the dead of night, when the demand for electricity is low and is already being met. They can't put that electricity on the grid, so if there's no place to store it, they have to shut the wind turbines down. Not only is that a waste of a capital investment, but the wind farm is idle when it could be making more power than a coal-fired power plant.
Conversely, in Albuquerque at about 4 p.m. during the summer, many air conditioners come on as people get home from work and PNM has to deal with a huge surge in electric usage. Solar power would help, but the sun is waning, so you're well off the peak for generating solar electricity. Unfortunately, in New Mexico, the strong winds blow in the spring at night, not in the summer in the afternoon, so the wind farm doesn't help meet that demand either. With storage, you can collect solar energy during the day and then use it at night or store the spring winds and offset the summer's air conditioning energy needs.

1663: Store the spring winds? Isn't that a lot of energy?
Migliori: Yes. There are minutes in New Mexico when 25 percent of our power comes from wind farms—over 200 million watts from wind power! It's the highest fractional utilization of any state. There's enough energy generated by New Mexico wind farms in March and April to run a utility grid for weeks without turning on a coal or nuclear plant.
Thorn: The problem is we don't have the means to store that much electrical energy, and conservative, incremental improvements in storage technology won't get us there. We need revolutionary changes.
Migliori: But even if you develop a high-tech battery or something that could store two-months worth of wind energy, all-that energy would be parked on a windswept ridge miles from anything. To get it to Albuquerque, you'd have to build a costly, high-power transmission line.

The idea is to go to a distributed storage system. This is something the Laboratory has looked into and is ready to contribute to in a major way.

There's already a utility grid that carries power to every New Mexico home. What if every house had a little bit of electrical-storage capacity, say a bank of lithium-ion batteries that sat in a box beneath the electric meter? You could then use the existing grid to distribute the output of your wind farm to thousands of these storage boxes. There would be no need to build new transmission lines.

Plus, with distributed storage, a state or regional utility could run its coal-fired or nuclear power plants all the time under optimum conditions so that the plants generated the minimum amount of atmospheric carbon or nuclear waste per unit of electricity. The utility would charge up these storage boxes when there was power to burn, so to speak, then recover the electricity when needed. Ultimately, the utility would have some control over when electricity went to, say, the boiler, air conditioner, and dishwasher in a house. Then during the summer, they could stagger air conditioner "on” times, even if it was just for 10 minutes or so, to allow time for more power sources to come online and supply electricity.

Thorn: A similar idea is being floated right now because once you put that kind of communication and control in place, a utility could really optimize the use of its resources. But the grid is a massive network, and distributed storage entails integrating thousands of storage units into it. Making it work efficiently would involve a significant modeling and computation effort that would be just as important as developing the electrical-storage units themselves.

Migliori: With our expertise in both modeling and computation, that problem is tailor-made for Los Alamos. It's a wonderful opportunity.

Thorn: We also have to consider that in the United States, about one-third of our energy goes towards heating homes and buildings, one-third goes towards producing electricity, and one-third goes towards transportation. Because transportation is strongly dependent on foreign oil, there's a great motivation, maybe even an imperative, to develop alternative fuels and/or electrical storage systems that could be used to power an electric car.

1663: Transportation is a different storage need?

Thorn: Yes. The main obstacle there is the energy density of the storage medium. We're used to gasoline, which has a remarkably high energy density of about 11 kilocalories per gram (kcal/gm). When you burn an entire tank of gasoline, you liberate about 250,000 kcal of energy—a billion joules!

Migliori: Remember that only about 20 percent of that energy is used to move the car. The rest is lost in the form of heat and through inefficiencies in the car's power train. An electric car would have a much-higher efficiently.

Thorn: So given what Al said, and considering that the best lithium-ion battery has an energy density of at most 0.4 kcal/gm, we've got to develop an electrical storage device that has roughly five times the energy density of our best battery if we want an electric car that performs as well as a gasoline-powered vehicle. We don't know how to do that yet, but I'll wager it will happen not through engineering but through an understanding of fundamental science.

1663: What about using hydrogen?

Thorn: Hydrogen is an energy storage medium. A common scenario is to use electricity from a power plant to produce hydrogen through water electrolysis. Two electrodes are placed in water. When a current is run between them, the electrical energy overwhelms the chemical bonds, and the water separates into hydrogen and oxygen. You store the gases separately, then when needed, feed the hydrogen into a fuel cell to generate electricity.

Migliori: Hydrogen gas has such a low density that it's hard to imagine its becoming a commodity the way oil or gasoline is. For example, to carry enough hydrogen to power a car for 200 miles, you'd have to load it into a "bottle" at extremely high pressure, which raises all kinds of flags about safety, refueling, delivery, etc. So people have been looking at ways to store hydrogen not as a gas but as part of a molecular compound.

Thorn: Currently, one of our best hopes is ammonia borane, a relatively dense solid at room temperature that's about 18 percent hydrogen by weight. You chemically remove the hydrogen to run your fuel cell. Los Alamos established collaborations for working on ways to improve the efficiency and lower the cost of regenerating the spent material. We're also heavily engaged in research to make fuel cells less expensive, more robust, and more accommodating of fuels other than hydrogen. And across the Laboratory, scientists and engineers are working to improve power plant designs and researching grid stabilization, nuclear power, etc.

1663: Suppose a hydrogen-powered car becomes reality. How will that affect the oil industry and the economy?

Thorn: Any changes to our current energy paradigm will have far-reaching consequences. There's no simple, single answer. We have an Energy Security Center here at the Laboratory that focuses on those questions.

Migliori: Getting back to what Dave said earlier about revolutionary change coming from basic science, I believe we must understand the fundamental electrochemical processes that occur at the electrode surfaces in batteries and other storage devices. Consider this. During electrolysis, electric fields develop in nanometer-size regions of the electrode surface—regions that contain less than a few hundred atoms—that have strengths on the order of 10 billion volts per meter. That's about 10,000 times the electric field in a lighting bolt. We're talking enormous energies, enormous electric fields. But after 250 years of electrochemisty, we still don't know exactly what these nanoscale fields look like or how they behave. All of our equations fail miserably at the nanoscale.

Thorn: That's partly because we haven't had the tools to measure the electric field at that scale. You can't just stick a voltmeter in there. Most techniques probe much-larger areas, so you end up measuring the properties of the surroundings and not of the tiny nanoscale interface.

Migliori: But the wonderful thing about nanotechnology is that we can carve up a silicon wafer, coat it however we want with one or several layers of metal atoms, and make thousands of identical nanoscale test devices. So we can get a greatly enhanced signal and know that it's coming from the structures we're interested in.

With the Center for Integrated Nanotechnology right here at Los Alamos, plus a strong collaboration with the College of Nanoscience and Engineering in Albany, New York, we can make the nanostructures needed to do this research. Couple that with advanced measurement techniques and the most-sophisticated computational tools in the world, and we can begin to acquire knowledge about the most-fundamental electrochemical processes and use that knowledge to build a better theoretical model.

Thorn: From a device scenario, if you had a lithium battery based on huge numbers of nano entities fabricated the right way, they would probably fail one at a time in a way that you could probably tolerate. So the actual construct will offer advantages to doing things in bulk.

Migliori: And from a research perspective—you know the old saw that you can't have an electric field inside a metal? Not true. But to eliminate that electric field, the free electrons in the metal have to migrate and form a surface layer of charge, which creates an electric field that effectively cancels any field in the metal.

At a nanoscale interface—maybe a hundred metal atoms sitting on a silicon substrate—there aren't enough electrons to cancel the field. Instead, the electrons will be pushed around by any external electric field and pressed into a smaller volume. When that happens, the Heisenberg uncertainty principle says that the kinetic energy of the electrons goes up.

In fact, that additional kinetic energy becomes a significant fraction of the energy stored. This is called “quantum capacitance.” All of a sudden you've taken a potential-energy storage problem and introduced a component that's a kinetic-energy storage problem. What a fantastic thing for the Lab to be working on, understanding the details of that.

Thorn: Still, the challenge as I see it is how to devise nanostructures that are different enough from the bulk materials to give us large gains in energy densities. The possibility is there, but we don't understand how to do it.

Migliori: I believe it will happen. Our job is to work on gaining a fundamental understanding of the juncture between physics, chemistry, and nanotechnology. If we do our job, others will have a chance to develop really good revolutionary storage devices, and the game will be over.