Batteries for energy generation and storage: A perspective from MIT professor and entrepreneur Yet-Ming Chiang

With a founding role in four companies, Massachusetts Institute of Technology (MIT) Professor of Materials Science and Engineering Yet-Ming Chiang exemplifies the entrepreneurial spirit that nourishes the American high-tech sector. Beginning in 1987, he was one of four MIT co-founders of American Superconductor, a startup that has become the world's leading supplier of high-temperature superconducting wire. Fourteen years later in 2001, Chiang joined with a Boston-area venture capitalist and others to form A123 Systems, which has become an industry leader in the development of nanophosphate-based lithium ion batteries, whose high power, long life, and safe operation make them ideal for power tools, electric and hybrid vehicles, and grid storage systems. Subsequently, in 2007, with an MIT colleague, Chiang co-founded a third company called SpringLeaf Therapeutics, which is turning battery-derived technology into a smart transdermal patch to infuse drugs at a controlled release rate. The most recent startup is a company called 24M Technologies, which is working on a new type of flow battery, a form of rechargeable battery in which electrolyte containing one or more dissolved electroactive species flows through an electrochemical cell that converts chemical energy directly to electricity. In our interview with Chiang, we asked him to draw on his entrepreneurial and MIT research experience on advanced materials and related device technologies while giving his perspective on the state of battery technology for energy generation and storage.

***MRS BULLETIN*: You have started four companies so far. What motivates you to pursue this special kind of tech transfer so frequently?**
YET-MING CHIANG: I don't want people to get the impression that starting a company is something that I—or, really, any other academic I know whom has done it—spend all my time thinking about, that my objective is to start companies. It's truly one of those things that, in carrying out research, once in a while and, typically infrequently, all the elements coalesce in the right way.

The way it is—for me, at least—is that I have a research portfolio that ranges from fundamental research funded by DOE's Office of Basic Energy Sciences or NSF, to projects that are a little more applied, and at the other end, to projects that are rather mission oriented and typically backed by either DARPA or ARPA-E. Every once in a while, all of the key elements come together: a research result that occurs simultaneously with a clear, technological, and societal need and then, very importantly, the other people that are necessary to form a startup.

How did this process work in the case of A123 specifically?
We thought we had some ideas for a new way to make batteries based, in part, on the discovery that cells with cathodes made from doped lithium-transition metal-phosphate nanoparticles had vastly increased charge–discharge rates, as fast as once every three minutes. That really was the key observation that led us to believe that there was a technology that could be built around this.

Based on those small-scale lab tests, we thought that the chemistry and materials had a lot of potential for batteries to address large-scale, high-power applications. And, in looking around at what existed, we converged on power tools—then a $4 billion worldwide market—rather than the high-energy-density, portable electronic devices that had dominated the lithium-ion market.

The kinds of questions that had to be answered were: Could these materials be made cost-effectively and in quantity while still preserving the properties that we observed in small samples? The second was whether a complete battery chemistry and battery design could be developed that would take advantage of what we saw at the laboratory scale. A battery, even though it looks very simple, is a complicated chemical, electrical, and mechanical device. A123 was formed in 2001 to find out.

Your initial direction was power tools. Have you expanded beyond that? Have the other applications, such as transportation and the electricity grid, captured the interest of A123?
Those are the two main markets that A123 is going after. In 2001, there was almost no commercial interest in

electric vehicles, but by the middle of the decade, the widespread acceptance of climate change and the need for decreasing petroleum consumption ramped up interest very quickly, and A123 was fortuitously in a position to develop products for electric vehicles first and then later for the grid.

On the transportation side, much of the emphasis in the public's eye is on passenger vehicles. But the other part of it that is, often less visible, heavy-duty vehicles—trucks, delivery vans, and fleet vehicles. And, in some ways, those are a more logical first step because the use-models for delivery work fleets are very well understood. So A123 is producing batteries for a number of heavy-duty vehicles that have been already announced, and there are more to come, in addition to passenger vehicles. Lithium-ion battery technology has not peaked yet, and my opinion is that it will be the mainstay of electric transportation for at least the next 10 to 15 years.

Storing energy for the grid is very different from that for vehicles because energy density is not such an issue, and there can be a large footprint. What are your thoughts about the kinds of batteries that might work here?
I think one thing to realize about the grid, which I've only recently learned about, is that there are many more storage applications there than in electric vehicles. When we think of electric vehicles, we have micro-hybrids, hybrids, plug-in hybrids, and all-electric vehicles. So you've got this handful of potential applications. For the grid,

just for stabilizing wind as a renewable resource, there can be nearly a dozen specific roles for storage. So it's really a wide-open field at this point.

If we think in terms of the power-to-energy ratio, there is a very broad range that the grid will eventually need. To me, the progression is very logical. Automotive lithium-ion technology can provide value to the grid in high power, short duration applications, meaning 15 minutes, a half hour, or an hour. The bigger challenge for conventional lithium-ion technology is at the long-duration end, let's say four to eight hours or longer. For this, new technology needs to be developed. And that's one of the reasons that we're working on a new type of flow battery with 24M Technologies, a spin-off of A123.

Lots of chemistries have been proposed for flow batteries, and it isn't clear yet which are in the lead or which have been eliminated. What's your sense of that field and, more specifically, what is 24M doing?
I would agree with you that there's a great deal going on right now, and there hasn't been a clear frontrunner. The main thing that we tried to do is to come up with electrodes or flowing fuels that will have an order of magnitude higher energy density than now exists, in order to decrease the size of the physical plant and thus lower costs. One of the main contributors to the cost of flow batteries is the size of the plant—the pumps, stacks, storage, and plumbing necessary to accommodate flowing electrolytes that have a very low energy density and therefore take up a lot of space.

When we first started thinking about flow batteries, we ran into a different language from that used in the lithium-ion battery field, where almost no one calculates storage concentrations in terms of molar units. But when you do so, you come up with some surprising results. It becomes clear that if you want to store a high concentration of working ions, you really want to store it in the solid form. The concept we hit upon is to make highly energy-dense

solids into flowable suspensions that are electrochemically active. But I think it's just one example among different approaches that will ultimately develop to higher energy-density chemistries for flow-battery systems.

Natural gas reserves are growing and prices are falling (more than 60% since June 2008). This will favor cheap on-demand electricity generation from gas relative to expensive battery electricity storage. Will large-scale stationary batteries be able to withstand this trend?
There are a couple of interesting points here. First of all, if natural gas prices stay at a low level, this will make natural gas turbines cheaper for backing up renewable energy sources in the near term. If this helps the growth of renewables, that's great. But of course, they'll produce greenhouse gases that offset some of the advantages of renewable generation, so ultimately zero-emission storage technologies are still the better option. However, another way in which natural gas could work hand-in-hand with storage is by displacing coal and producing lower carbon electricity for transportation. This would help to make electricity a low-cost domestically sourced fuel for transportation, displacing petroleum.

Yet-Ming Chiang was interviewed by *MRS Bulletin* representatives **George Crabtree** and **Arthur L. Robinson**