Fuel Cells and Energy Storage Systems

"Cost and durability are major challenges to fuel cell commercialization and achieving a hydrogen economy." – Department of Energy

Dr. Wang in lab

One of the leading innovators in fuel cell research is Penn State professor of mechanical engineering and materials science and engineering Chao-Yang Wang. Wang is the founding director of the Penn State Electrochemical Engine Center (ECEC), which conducts fundamental and applied research on fuel cells and advanced batteries for electric propulsion, stationary power generation, and portable electronics. The Electrochemical Engine Center is arguably the world leader in water management and cold start fuel cell technology.

Because of their advanced materials requirements, fuel cells are at the interface between energy and materials. Wang's research places him squarely in both communities, a role he relishes as a member of both the Energy Institute and the Materials Research Institute at Penn State. "I'm working on energy storage and conversion systems such as batteries, which are a good example of storage, and fuel cells, a good example of conversion," Wang explains. "Both systems are based on electrochemical principals, so they are clean and efficient. At the same time, materials play a major role in both systems."

Batteries and fuel cells for transportation

Hybrid electric vehicles are already widely commercialized, with over 230,000 sales in the U.S. in 2006. Most automakers have a hybrid vehicle program of some sort that is beyond the R&D stage. A major requirement for hybrid electric vehicles is a reliable, long-lasting electrical storage system. The system of the future may be the lithium-ion battery.

Batteries of this kind are still very expensive, Wang says, on the order of $2,000 to $3,000 per battery, though the high cost is partly due to the economy of scale. "We probably need to get the cost down three-fold. It's not like we have miles to go. Further reducing the cost could generate some profit margin for auto makers. We are always in search of low cost materials, but it is not a show-stopper."

Currently, Wang's group is looking into degradation mechanisms for battery cycling and trying to come up with some solutions to extend battery lifetimes. In order to be competitive with fossil fuel-powered vehicles, the battery needs to be warranted for 10 years, similar to gas engines. To that end, they are studying the interfacial phenomena between electrodes and electrolytes to overcome capacity fade as the battery goes through multiple cycles. Again, he says, this is primarily a materials issue.

They are also concerned with safety. Not long ago Sony had to recall several million lithium-ion batteries used primarily in lap top computers because a relatively small number of the batteries had caught fire. "When we are trying to develop a high-energy, high-power system, we have to keep in mind that they are very dangerous. So in my classes I teach students that when we engineer systems and try to improve performance we always have to keep safety in mind, because otherwise those systems become something similar to bombs. They are very energetic systems, so we have to add certain things into the electrolyte in order to retard flammability and prevent explosions. It's a tough challenge to address, so you have to make compromises to meet seemingly conflicting requirements."

Whereas hybrid electric vehicles are already competitive with internal combustion vehicles in terms of price, the situation is just the opposite for fuel cell cars. Wang estimates that the fuel cell SUV that Nissan brought to Penn State for the recent Hydrogen Day event cost on the order of $1 million to produce. Like advanced vehicle batteries, this is a matter of economy of scale. The Nissan vehicle was essentially built by hand, Wang points out. "Fuel cell cars are still in the R&D arena. But one study by DOE estimated that if you were to build a half million units using current technology and current materials, the cost would be roughly $110 per kilowatt. Since the typical car is 80 kW, you're talking around $8,800 for the engine. That number should be compared to $2,000 - $3,000 for a gasoline engine. For me, that is not a big price gap, especially since our time horizon is 15 to 20 years before widespread use."

Nissan sent a Fuel Cell Vehicle to Penn State for Hydrogen Day

An area in which his group is extremely strong, in fact the world leader, is subzero start-up of fuel cell engines. For years, automakers and consumers had come to expect a fuel cell to emit only clean water, but when the temperature reaches -20 to -30 degrees C the fuel cell is going to produce ice rather than water. In a climate such as the northern U.S., that can be a daunting challenge in winter. The ice will become stuck in the fuel cell, shutting down the whole process.

This has been a great challenge for industry, Wang says. "The ability to start up a fuel cell engine in such a cold environment is a requirement for automotive applications. There are also materials consequences when you produce ice in a fuel cell. The expansion and contraction as the water freezes and the ice melts can lead to degradation of the materials. Other automakers, national labs, and universities are just beginning to recognize this issue and are starting research. At Penn State, we have been doing research on this topic for the last four years, and recently we released six journal papers covering all aspects of this problem. It's exciting. We are working with a number of companies to implement the know-how and technology developed at this university."

Understanding what goes on inside a fuel cell during its operation is crucial. At the ECEC, Wang and his students and post-docs have pioneered many of the simulation and diagnostic techniques that will tell them what is happening inside the fuel cell. They call these their "advanced in situ diagnostic methods." Whereas other groups on campus work on specific aspects of fuel cell technology, at the Electrochemical Engine Center they can take a comprehensive view of fuel cells, looking at all the issues from a systems level. For instance, they look at how the membrane interacts with other components, how they can reduce the catalyst for a new type of membrane, or how they can make another important component called the catalyst layer.

Ph.D. student [illegible] studies hydrogen fuel cell dynamics

Along with advanced *in situ* diagnostic methods, another area of strength is their materials fabrication facility. "In other words," says Wang, "if you give me a membrane and a catalyst, how should I put them together to make a high performing membrane electrode assembly? That requires special manufacturing processing techniques."

Grad student Puh Chang Lim is working on Direct Ethanol Fuel Cells for lap tops

World's smallest fuel cell-powered laptop

One example of this is Panasonic's latest direct methanol fuel cell laptop, unveiled at the consumer electronics show in Las Vegas in 2006. Panasonic announced that the fuel cell stack, the world's smallest to date, used the membrane-electrode assembly technology developed at Penn State. This prototype fuel cell is the same size as a battery pack in a laptop but can run for 20 hours at a time. When replacing a battery with a fuel cell, you can expect a 2-5 times increase in run times, according to Wang.

"We have a number of technologies patented and used by major companies," Wang says. "Not all of those companies have made the Penn State connection public, as yet."

Wang predicts that fuel cell technology will allow automakers to rethink how they do business. This is because a fuel cell engine has no moving parts to wear out and theoretically should last much longer than an internal combustion engine. In addition, fuel cells are a clean technology, and the stack design makes it possible to add extra cells for more power, if necessary. "Solving the energy problem, the fossil fuel problem, is about freedom rather than cost," Wang concludes. "Don't worry so much about the price of the technology. When you generate innovations, that is the thing that keeps an economy growing."

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