

Tiny Dreams for the Future of Transmission Capacity

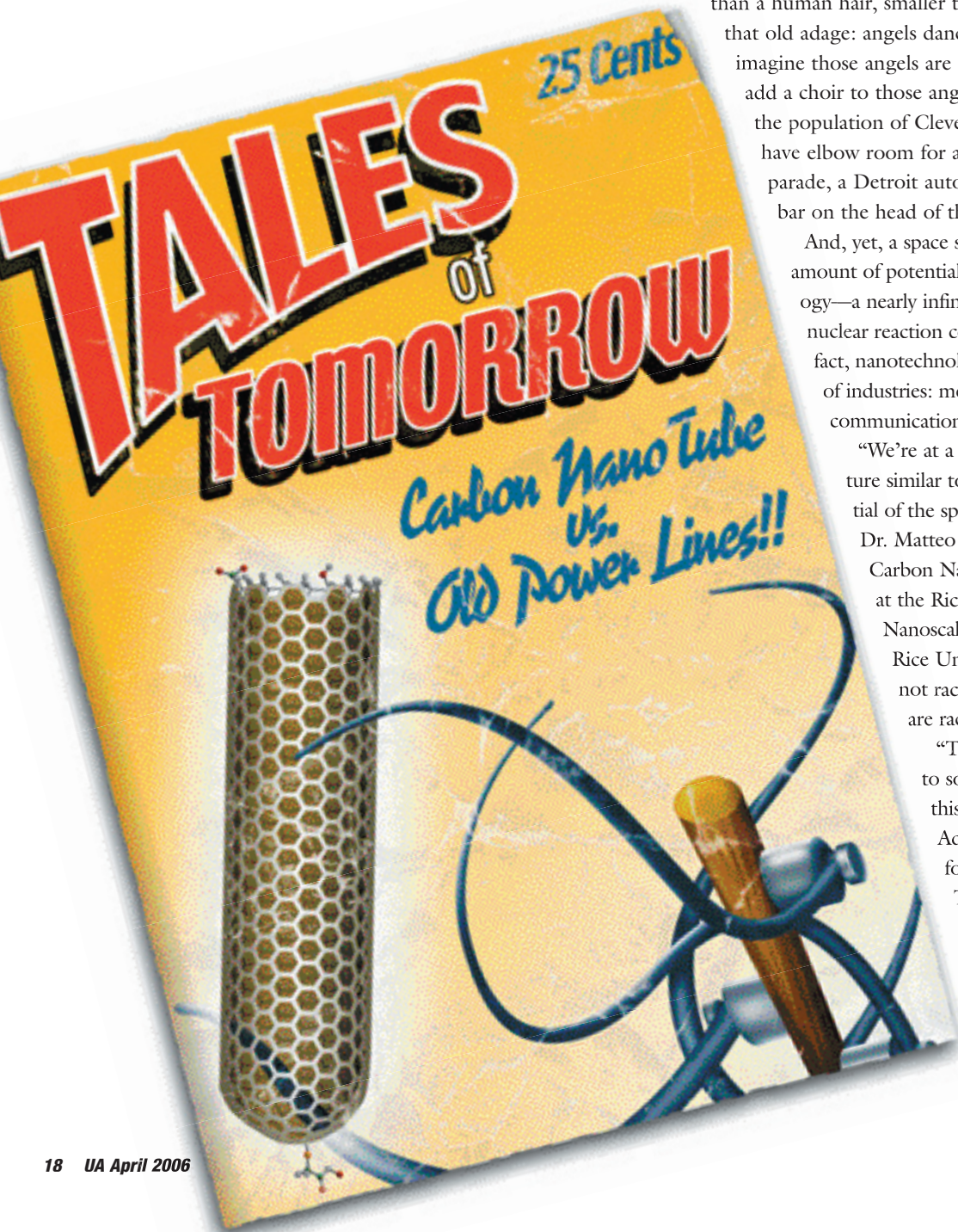
By Kathleen Davis, associate editor

It's a concept difficult to grasp: the nanometer. A billionth of a meter. A measure of space so small it doesn't seem to take up any space at all. It's smaller than a breadbox, smaller than a human hair, smaller than a blood cell. Think about that old adage: angels dancing on the head of a pin. Now, imagine those angels are a single nanometer high. Then add a choir to those angels. And a congregation. And the population of Cleveland, Ohio. And, we'll still have elbow room for a band, a New Orleans funeral parade, a Detroit auto show and a full-service cash bar on the head of that tiny sliver of metal.

And, yet, a space so small contains an enormous amount of potential in the area of nanotechnology—a nearly infinite amount, the power of a nuclear reaction contained in the infinitesimal. In fact, nanotechnology could revolutionize a bevy of industries: medicine, construction, aerospace, communications—even the power industry.

"We're at a time in our scientific culture similar to the excitement and potential of the space race in the 1960s," said Dr. Matteo Pasquali, co-director of the Carbon Nanotechnology Laboratory at the Richard E. Smalley Institute for Nanoscale Science and Technology at Rice University. "Only, today, we are not racing toward the very large. We are racing toward the very small."

"This is the way we're going to solve the energy problems for this century," added Dr. Wade Adams, director, Smalley Institute for Nanoscale Science and Technology. "In this area, the United States could be ahead in creating the energy system of the future."



Carbon Nanotubes 101

Nanotechnology began simply: with a discovery. In 1985, Dr. Richard Smalley and his coworkers at Rice University stumbled across a form of pure carbon that, at microscopic levels, resembled a soccer ball. Why was this so unusual? Well, until then, scientists only knew carbon—at its basic building blocks—as either diamond or graphite. This third option was entirely new and unexpected, as well as being incredibly, almost unnaturally, stable. In 1996, Smalley won a Nobel in chemistry for this discovery, a discovery that was the tinder for a scientific fire: namely, the research into nanotechnology. It seems that tiny carbon soccer ball or C_{60} —nicknamed the buckyball—opened a whole new aspect of science and an incred-

ible universe of tiny, but powerful, opportunities.

Once scientists knew what to look for, they found fullerenes—the general family of molecules to which the buckyballs belong—everywhere, in a variety of shapes and configurations. Buckyballs in an elongated hollow form were first observed in the early 1990s: carbon nanotubes. Individually, these tubes are hundreds of nanometers (or more) long and about a single nanometer in diameter. There are single-walled and multi-walled tubes, a variety. (For a good visual, imagine that roll of chicken wire you just bought at Lowe's.) And, some of these carbon nanotubes show amazing properties: strong, resilient and incredibly electrically conductive. It's that last one that catches

the imagination of those of us in the power industry. Technology many times more conductive than steel or copper could mean pushing a lot more power through the same or fewer lines. In an industry where transmission capacity and congestion are the bane, this could be the great carbon hope.

“Specific defect-free carbon nanotubes have been shown to have remarkable current-carrying capacity,” stated Altaf Carim, a physical scientist with the Scientific User Facilities Division of the Department of Energy (DOE), a government agency with its own nano program, the National Nanotechnology Initiative (NNI). He added that individual carbon nanotubes sometimes behave as “one-dimensional ballistic conductors,” which may mean great things for electric transmission—“if such properties can be achieved in large-scale cables,” he added.

And, the full potential of a carbon-nanotube wire product (called “armchair quantum wire” for the type of nanotube best suited for the process) is staggering. Replacing current wires with armchair quantum would make a grid with, perhaps, a million times the capacity that we have right now (assuming a current centimeter-diameter aluminum cable carrying about 1,000-2,000 amps).

“But, let's say that's all just theory. In fact, a mere million amps would be a practical, even conservative, estimate,” Dr. Adams stated.

“To get to those million amps, we only have to get 0.1 percent of the most conservative theoretical estimate. Not 90 percent. 0.1 percent,” Dr. Pasquali added.

To say the least, that's impressive. A definite “wow” factor.

But, throw hurdles in the works for them. They don't mind. Say estimates

are way off, processes are way more difficult. Say they can only manage to double the current capacity; there are still other factors. Armchair quantum wire will cut the weight of current wires by a factor of six, and you've done it with a self-supporting cable.

So, conductivity isn't the only positive of carbon nanotube technology for transmission. Additionally, wire made from this technology would have less (or no) loss, as the electrons are forced lengthwise through the tube and can't escape out at other angles: Think no resistance. None. You could truck in power from the wilds of Canada to the beaches of Key West. And, it wouldn't be impacted by heat, keeping sag to a minimum (or non-existent). Essentially, armchair quantum wire would release the T&D side of the industry from temperature constraints, which are already adding to the bottlenecking of capacity.

"With respect to the power industry, the benefits of having single-walled carbon nanotube cabling are numerous," said Stephane Robert, president and CEO of Raymor Industries, a Montreal, Quebec-based company already specializing in various carbon nanotube applications, citing the same list as the doctors at Rice and Carim at the DOE.

"So, what's the problem?" you ask. It's a million times more conductive. It doesn't sag. It won't have loss. Professor Smalley himself (who passed away last October after a long battle with leukemia) envisioned armchair quantum wire enabling a robust electric grid. It was one of his dreams for carbon nanotubes. "What's the catch?"

The catch? Well, right now, it's all theoretical.

From Theory to Manufacturing

One basic economic rule keeps all those groceries on the store shelf, all those different tires available for your Ford F-150, all those different meters as viable options for your distribution

system: The manufacturing process of the product is cheap enough for the company to make money from available demand.

Do we have the demand? Do we want armchair quantum wire curled

up on the shelf of every utility in the country? Of course. But, then, there's the price.

And, from a company perspective, the final hurdle is cost, as the experts as Raymor pointed out. It could be that all of these issues with carbon nanotubes (good and bad and theoretical) will be reduced down to just one: money.

"It's a great new material, but dollar and cents is what matters to the end-user," said Tom Whitton, Raymor's business development manager. "The economics have to change."

With the research being conducted and the process involved, right now, the experts at the Rice Smalley Institute put carbon nanotube products in a category more precious than gold or platinum, at about \$200,000 a pound. That's an impossible dream for the average American utility that can't raise rates a penny without getting the approval stamp of a regulatory body—a fundamental issue for implementation.

It seems there are a number of fundamental issues with carbon nanotubes. All the basic journalism questions, in fact—who, what, when, where, why and how—are still pretty much in the air.

"In keeping with the current state of understanding, DOE and NNI activities in this area largely involve addressing these kinds of fairly fundamental questions," stated Carim.

"Further challenges that need to be addressed before it makes sense to begin talking about implementation of carbon nanotechnology-based materials include the consistent production of carbon nanotubes with controlled and desirable conduction properties, and the understanding of transport across tube junctions," he added.

Yes, even the government is rooting around in the possibilities of

nanotechnology (to an extent). After establishing the NNI six years ago, it continues to be at the forefront of funding—something rather unusual given the many drains on government coffers these days. In fact, the 2007 President's budget provides more than \$1.2 billion for the program, bringing the total investment since the NNI was established to more than \$6.5 billion and nearly tripling the annual investment of the Initiative's first year.

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Pasquali, however, disputes this funding as a sign the government is really getting behind nano research. "NNI is not a new agency; it's a cross-agency initiative," he stated. "In fact, there is very little new money. Most of the \$1.2 billion was just rerouted internally in the agencies and came from money that used to fund other research."

Pasquali believes funding (real, non-rerouted, unique cash) is one of the major areas that needs to be addressed to really get carbon nanotube studies on track. The money is important, and a good research lab always needs more money. Rice has scaled the program up to nearly \$3 million a year, but they believe it needs to double.

"We're looking for more agency funding and more industrial funding,"

Dr. Adams said. "In order to make our goal of pulling this off in the next five years, we definitely need more money."

And, in the discussion of funding, the power industry isn't exactly at the forefront in "cutting edge" technology. Money tends to go toward more practical and proven innovations, and mostly within product-based, revenue-driven companies. Adams question: Given armchair quantum wire's potential, should that change?

"Is the industry going to start funding this kind of work, or should the government take the lead because it's still high risk?" Dr. Adams asked. Industry analysts may point a finger at the Administration, but there is a drawback: That government funding is fickle. NASA had been covering "the gap" in Rice's research budget for development of the armchair quantum wire (think lighter wire for all those bright buttons and whistles on the shuttle) but yanked funding to put cash into the more immediate goal of a moon mission.

It seems that carbon nanotube research suffers from the stigma of being "long-term," and no one wants to look at the future until the future is breathing hot and hard on the backs of their necks—until the technology of the future becomes practical in the now.

Practical is key. And, Dr. Adams truly believes that a real breakthrough in methodology is in the works, within two to four years. Additionally, he says, we could be looking at commercial viability within a decade. He foresees armchair quantum wire following quickly on the heels of superconductivity cable. In fact, he postulates that superconductivity cable might be

“chased” by armchair quantum wire.

“It could come faster; it could take a little longer,” Dr. Adams said. “But, we’re not talking 25 years, by any means. This is going to happen faster, and, when it does, it will be revolutionary.”

He added, “Rick Smalley used to call carbon nanotubes the perfect engineering material and the strongest material we’ll ever have available to us in the universe. I used to think that was an arrogant, if not crazy, statement. Now, I think he was right.”

The Business of Wires

Smalley may have been right about many things, in fact, not the least of which was the business angle for his discovery. He always believed in the practical side of nanotechnology (sometimes causing a bit of a ruckus in some of the more “pie in the sky” nanotechnology circles), and his coworkers at Rice have followed that lead. In fact, Rice is working with a company in the Houston area with the capacity to manufacture carbon nanotube products. Additionally, there is a proposal with the state of Texas to look at the practical issues of growing the process itself, the infrastructure required to take that scientific breakthrough and inject it into the economy. It will be a two-year effort to companion the science aspect with a more business-oriented one.

Additionally, with breakthroughs in the science and a scale-up of manufacturing, it’s only logical that the price of carbon nanotube-based wire will fall sharply. After all, carbon isn’t exactly a rare and unusual substance. And, rampant availability usually means one thing economically: It’s going to be cheap. Peter Hartley, a policy analyst with Rice University and their “electricity scholar in residence” agrees.

“My understanding is that eventually the industrial process might resemble something like making artificial fibers (such as those used in clothing or carpets); so that, in principle, it ought to be amenable to a cheap mass production process,” he said.

And, Rice isn’t alone in the idea that carbon nanotubes could mean big business. Raymor is already sending out feelers in aerospace, polymer and military applications for carbon nanotube products. In the future, they see openings in the power industry as well.

“We at Raymor are trying to position ourselves as the major player in the carbon nanotube area,” stated Whitton. “There aren’t a lot of players yet in this arena, and no one is really working on a large scale just yet. But, it’s certainly on the horizon.”

“We’re already in discussion with companies about the benefits of this technology,” Robert added. “And, ultimately, a single-walled carbon nanotube will be the technology platform for a multitude of applications spanning a number of industries, including electricity.”

Right now, Raymor has taken a passive approach to the power industry and is focusing more on polymers and composites, more immediate military and aerospace applications. But, any company would salivate over the high volume demand that an expansive industry like power would generate.

“We certainly feel that expanding into the world of power delivery could be very fruitful for us,” Whitton said. Raymor feels that a transmission wire product will be commercially available in the “not too distant future.”

“In 10-15 years, carbon nanotubes will be in place in many of the products around us. So, carbon nanotubes are a

good business,” Robert stated.

Whitton added, “Ultimately, we’re here to make money. We wouldn’t be in the single-walled carbon nanotube business if we didn’t think there was a great opportunity there.”

Even the government is guardedly optimistic. The DOE’s Carim stated, “While promoting carbon nanotubes to electric utility companies in the near term would be premature, we certainly hope that the promise of such materials for power transmission can be realized in the future.”

And, the promise is there. But, not everyone is quite ready to board the bus to Nano City—not everyone believes that promise leads easily, or directly, to potential and production. From simply urging a more cautious “brakes-on” approach to postulating we’re on entirely the wrong road, nanotechnology is not without its naysayers.

Hold the Bus

“There are major fundamental challenges to be solved before use of nanotubes in overhead power lines can become a reality,” stated American Superconductor’s chief technical officer, Alex Malozemoff. (American Superconductor is a manufacturer of superconductor wire: the technology Dr. Adams sees armchair quantum wire “chasing,” if you recall.) Carim, for one, agrees.

“There are important caveats,” Carim said. “All nanotubes are not created equal. Some are metallic, but others are semiconducting. High-yield selective production of desired nanotubes is a very active area of current research and interest.”

Malozemoff also pointed out that only one of “about 50” different

nanotubes are metallic (and, therefore, conductive) and that how to separate and replicate that one type is a problem without a specific solution at this point (a fact that Raymor Industries and even Dr. Pasquali and Dr. Adams admit to).

“We’ll get there with nanotubes, it’s just a matter of time, people, and funding,” Pasquali added. Raymor would like to believe that as well; although, right now, they also admit to a bit of a hurdle in separating metallic and non-metallic tubes. But, as of yet, no single-walled nanotube provider “has been able to demonstrate their ability to supply the material in large volumes with reasonable pricing,” Raymor’s Robert stated.

Malozemoff added. “When nanotubes are synthesized, all these different configurations appear. Until a good solution for this problem is found for large volume manufacturing, the impact of nanotubes on power line usage is hypothetical.”

But, Adams and Pasquali don’t see “hypothetical” as a major hurdle. After all, all science begins at the hypothetical. They believe in carbon nanotubes and the possibility of armchair quantum wire as both good science and good business.

“Even if we’re way off on the numbers for the potential of carbon nanotubes,” Dr. Adams said. “There will still be a huge increase in current carrying capacity with the development of armchair quantum wire. Plus, all the other benefits. And, the vision that we follow here at Rice is Rick Smalley’s vision: That the most important problem facing humanity is energy, and, for worldwide peace and prosperity, we have to find a way to provide energy that’s widespread, green and cheap. And, this is a way to do that.”◀◀