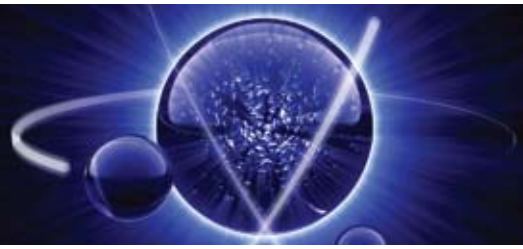
Advances in Nanotechnology



In just the last few years, the number of products on the market that incorporate nanoparticles has exploded. According to the Project on Emerging Nanotechnologies, more than a thousand nano-based consumer products are now available, compared to only 212 in March, 2006. Lux Research predicts that nanotechnology will generate $2.5 trillion in 2015. And both university and corporate researchers in Florida and around the world see this as the tip of the iceberg: projects are underway to take advantage of the properties of a variety of nanoscale particles in fields such as the life sciences, clean technology, and the aerospace and defense sectors.

Specks of Gold

Gold, prepared to the nanoscale, has properties that attract scientists hoping to diagnose and treat diseases. Qun Huo, a chemist at the University of Central Florida, first turned her sights on using gold to create an inexpensive test for prostate cancer. In 2009, according to the American Cancer Society, there were almost 200,000 new diagnoses of prostate cancer, the most common form of cancer among American men and the second leading cause of cancer death. ACS estimates that more than 2 million men are living with prostate cancer in the U.S.

What intrigued Huo, she says, are gold's optical properties at the nanoscale. Gold becomes a dark burgundy color, and it absorbs and scatters light well. Huo was particularly interested in scattering. She describes an early experiment, in which a laser shining through water remained invisible, while water with gold nanoparticles scattered the light of the laser and displayed a clear red beam.

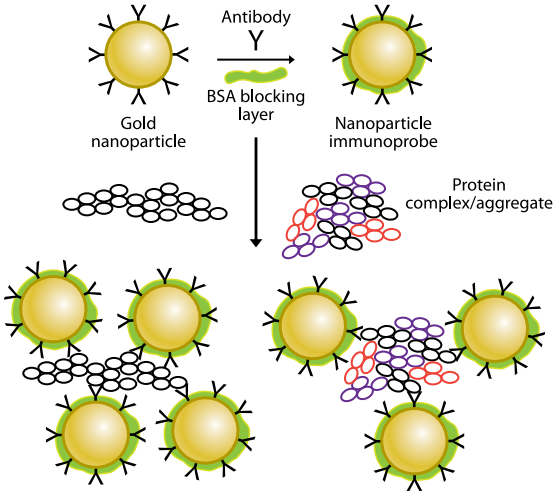
Huo partnered with researchers at the M.D. Anderson Cancer Center in Orlando to develop a new test for prostate cancer detection based on these principles. The team coated gold nanoparticles with antibody molecules. (These recognize and bind with specific target proteins in the sample and thus increase the particle size). With a dynamic light-scattering instrument, Huo can search for the enlarged proteins in small samples such as a drop of blood. While today prostate-specific antigen (PSA) tests are used to detect prostate cancer, this new test is intended to increase the accuracy of early detection.

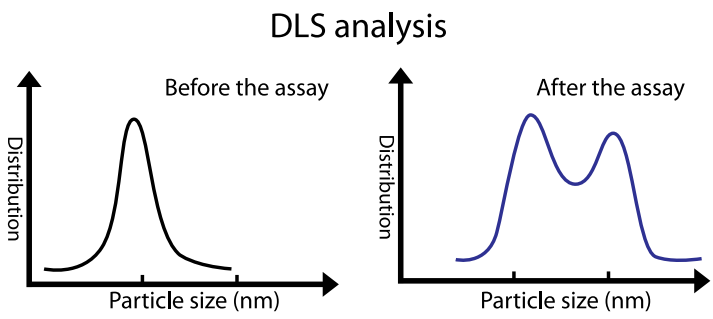
"Basically, these nanoparticles are a hook," says Huo. "When you're fishing, you can feel it get heavy. And in my case, I'm able to see that the nanoparticle becomes bigger, that it caught something." She believes this test could be generally available within a few years.

One of the challenges with PSA tests is that current tests can't distinguish between markers that signify cancer, and ones that represent a condition called benign prostate hyperplasia. Huo says she is developing a promising technique, based on her original research, which can distinguish between the two different conditions. She's also investigating whether there might be protein markers associated with ovarian cancer that this test could identify.

While gold nanoparticles hold great promise for the

Protein Complex/Aggregate Detection





- Average particle size will increase upon detection
- Non-uniformly sized protein complexes/aggregates leads to a very broad size distribution
- Measurement-to-measurement variation may be large

Source: Qun Huo , University of Central Florida

original application—detecting prostate cancer—Huo believes her technique of dynamic light scattering coupled with gold nanoparticles is a potentially powerful analytic tool for biomolecular research. She's started a company to create a dynamic light-scattering system, which is specifically geared to this type of application and could handle many samples in rapid succession, then interpret their results. "I'd like other chemists and biologists to be able to use this very easily; it should be accessible to everyone who needs it," says Huo.

Also taking advantage of nanoparticles and illumination, scientists at the University of Florida's Particle Engineering Research Center (PERC) are helping doctors and surgeons identify whether tissue is diseased or healthy.

PERC and University of Florida (UF) cancer researchers are collaborating with biomarker experts at the H. Lee Moffitt Cancer Center & Research Institute in Tampa. The Moffitt researchers are identifying biomarkers that will latch onto certain components in diseased tissue, while PERC scientists are devising nanoparticles and coatings to facilitate easy identification of them, using magnetic resonance imaging (MRI), fluorescence, or photoacoustic imaging. PERC's location near the UF cancer research facilities guarantees immediate feedback on the performance of the coated nanoparticles. "They'll test our particles, then in the evening we'll chat for a few hours to discuss what they observed, and what we should be doing next," says Brij Moudgil, PERC's director. "This type of feedback has been extremely beneficial."

There are a number of challenges in developing nanoscale technologies, explains Alan Brothers, senior materials engineer at Rockledge-based Mainstream Engineering: "Conceptually it comes down to the fact that materials and systems at the nanoscale generally don't follow our intuitions, which were of course developed through experience with the macroscopic world." This means, he continues, that characterization of materials is a crucial step. "You need very sophisticated characterization techniques, such [as] very sensitive electron imaging, if you want to be able to look at a product and how it works."

Sarasota-based DTI is attempting to address this challenge by offering high-precision devices for companies and researcher centers. DTI has designed an ultrasonic

piezomotor to manipulate and position objects at the nanoscale. It functions by means of a special ceramic ring that pulses at ultrasonic speed in response to pulses of electricity, causing precise rotation of the motor.

This polymer—unlike the microporous membranes used in reverse-osmosis water filtration for desalination—transfers molecules through the otherwise solid material molecule by molecule, selecting for more than just particle size.

The result is a device that is faster than a conventional electromagnetic motor and offers resolution more than a thousand times greater.

Says DTI's CEO Mark Broderick, "We're enabling our customers to manipulate a sample or procedure at the submicron level, so the applications are very broad." One of the tools, a piezoelectric nanomanipulator, can be controlled by a joystick or a computer. A push of the joystick allows researchers to penetrate the cell membrane without damaging the cell.

Cleaning to the Billionth

The need for clean, safe drinking water concerns governments and individuals, not only in the developing world, but here in the U.S. as well. Increased awareness of drugs and other residues in drinking water, and of the impact of discharged wastewater on streams, rivers, and other water ecosystems, has prompted the Environmental Protection Agency to consider stricter regulations for water purity. At the same time, communities around the country experience restrictions to their water use because of drought and water shortages.

In Pasco County, Florida, Tim Tangredi believes his company, Dais Analytic, has a solution to both these problems: a solid film with interconnected nanostructures that can filter waste out of water down to a few parts per billion and provide safe, clean drinking water. The process requires only about half the energy of current treatment technologies.

This polymer—unlike the microporous membranes used in reverse-osmosis water filtration for desalination—transfers molecules through the otherwise solid material molecule by molecule, selecting for more than just particle size. For water filtration, the system works like this: a salty stream of water runs on one side of the polymer, while on the other side flows clean, cooler water. The temperature difference creates a driving force, and different chemistries along the strands of polymers create charges that attract only water molecules. So the water is transported from the warmer to the cooler stream, leaving its impurities, such as drugs, viruses, and salt, behind. "The size restriction and polarity knock out just about everything," says Tim Tangredi, Dais's CEO.

This material is already in use today in the company's air filtration system, known as ConSERV. The same properties it uses to filter water are applied to purifying air: the polymer is impermeable to oxygen, nitrogen or argon in air, but permeable to water. So air can be dehumidified and cooled before it ever reaches a building's heating and cooling system. And the Dais Analytic cooling system uses no fluorocarbons.

In September, 2009, Dais Analytic struck a deal with Genertec America, a subsidiary of a state-owned Chinese company, for distribution of its low-energy air filtration and cooling systems and water purification technologies in China. The company is hiring and rapidly expanding its production capabilities in Florida to meet the needs of the Chinese market.

Following the announcement of the China deal, Pasco County in Florida offered Dais Analytic the use of an abandoned waste sewage treatment facility to allow it to ramp up its water treatment abilities and test its filtration system in a pilot plant. The company will be taking already treated wastewater—now destined for use in irrigating lawns and golf courses—and remove the chlorine, nitrogen, and phosphorous that concern the EPA.

"We [can] offer amazingly clean water from almost any source," says Scott Ehrenberg, Dais's chief technology officer. "Many places in the world, including in the U.S., don't have sufficient water for the future. This technology opens up the possibility that you can take effluent water of any quality and return it as potable and close the loop."

Sanford-based Argonide is also committed to finding solutions to the world's filtration needs. CEO Fred Tepper, by background a materials scientist and chemist, started the company by pouring his retirement money into research and hiring scientists to assist him. The end result is a pleated paper-like filter, whose active component is an aluminum hydroxide nanofiber attached to a scaffold of microglass and cellulose. In the presence of water and solvents such as alcohol, the filter will attract and retain undesirable particles.

The small, home-scale device can arrest the movement of bacteria, viruses, and other unwanted materials. It could be used for pre-treatment for reverse-osmosis desalination filters, which can be ruined by just the types of small particles that Argonide's filter can extract. The EPA has also demonstrated interest in this filter, as a means of entrapping viruses to analyze water quality. The University of Florida tested the filter to evaluate its ability to remove viruses from air, and found that the Argonide filter was 3 thousand times more effective than current hospital-standard equipment.

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The photocatalytic paints of Port Richey-based Bio Shield, Inc. serve to clean the air by oxidizing and exploding pollutants. The paint is applied in two layers, a base-coat primer and an active top coat. The top coat contains nanoscale particles of titanium dioxide that produce oxidants in the presence of light. The oxidants split apart and destroy air pollutants such as viruses, bacteria, and odors, and also break up volatile organic compounds spewing from automobile and truck tailpipes. These paints will protect buildings from mildew, mold, and air pollution, and clean outdoor air that passes over the surface.

CEO Frank Forman sees hospitals as one of the main markets for the nine-year-old Bio Shield technology. Hospitals today are reeling from bacterial infections that can't be treated with today's antibiotics and may infect patients who come in for unrelated

procedures. "You no longer need toxic or caustic cleaners," says Forman. "This paint creates hygienic surfaces that also purify the air."

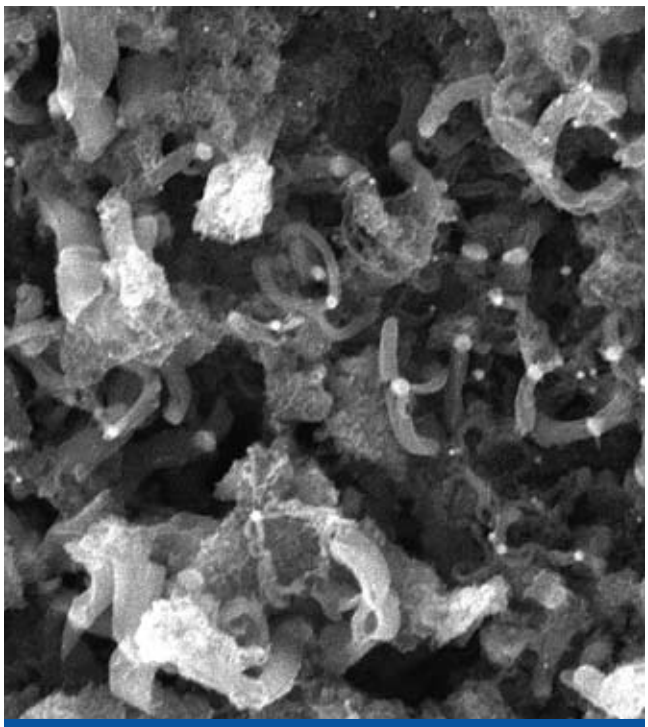
In the Field and in the Air

In the renewable energy field, Mainstream Engineering is building on more than two decades of experience providing solutions to NASA, the Department of Energy, the Department of Defense, and others. The company has developed a method for growing carbon nanotubes directly on a metal surface, without the usual need of a special catalyst layer.

Brothers says Mainstream is exploring how this technique might allow it to use carbon nanotubes as "little storage depots for lithium in a lithium ion battery. So the benefit of our technique is that, since the nanotubes are grown directly on the material, there's no resistance between the nanotubes and the metal of the battery," avoiding inefficiencies and losses. Energy storage is key for many applications today, from cell phones to electric vehicles, and for both military and civilian applications.

Mainstream Engineering paired up with the University of Washington to develop a more efficient material to store hydrogen, to assist soldiers in need of energy to run necessary equipment—GPS, radio, and other small electronics— without the need of heavy batteries. The army has expressed interest in this small fuel-cell technology. University scientists had developed a carbon material engineered to contain nano-sized pores, which could be loaded up with a hydrogen-containing material and heated to discharge the hydrogen. Mainstream Engineering was able to replicate their efforts much more cheaply and easily.

"Fuel cells are a fairly mature technology for that," says Brothers, "but what was missing was the hydrogen-storage material that could provide the fuel." The technology is still a few years away from commercialization, as researchers refine how the hydrogen is retained and released.

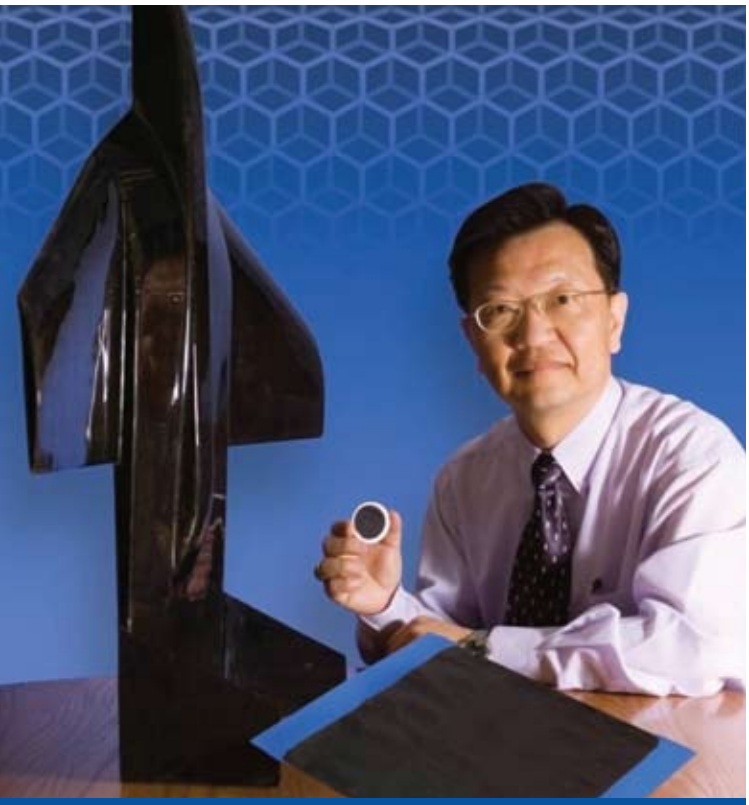


CNT Tin Anodes

Mainstream's carbon nanotube–Tin (CNT-Sn) composite anodes, pictured in this scanning electron microscope image, were used to create lithium ion batteries with increased energy storage capacity. Adding tin to Mainstream's low resistance CNT anodes further increases their capacity and could lead to much longer lasting batteries in everything from cell phones to hybrid cars.

Source: Mainstream Engineering

In another project for the armed services, the Navy required a new catalyst for its breathing systems and asked Mainstream Engineering to develop a solution. Occasionally carbon monoxide can leak into a breathing system, which could cause a pilot to lose consciousness and crash. Mainstream Engineering created a precious-metal nanoparticle on a



Dr. Ben Wang with buckypaper

Buckypaper uses carbon nanotubes to assist in the creation of high-strength materials for use in markets such as the aerospace sector. Dr. Wang is the Director of HPMI and serves as FSU's Assistant VP for Research in Engineering.

Source: High-Performance Materials Institute, Florida State University

metal oxide, at the range of 10 nanometers, which can convert carbon monoxide into carbon dioxide in the presence of oxygen, by latching an extra oxygen atom onto the carbon monoxide molecule. The catalyst is now being produced on a small scale. Meanwhile, Mainstream is working on cost efficiencies for larger-scale manufacturing.

At Florida State University's High Performance Materials Institute (HPMI), researchers are advancing a special film called buckypaper, which uses carbon nanotubes to assist in the creation of high-strength materials for use in markets such as the aerospace sector. The current generation of composites, made of plastics, are significantly lighter and stronger than traditional metal structures. But these composites don't conduct electricity well or offer protection from electromagnetic interference. To protect against a lightning strike in flight, for instance, the current material must be bonded with an additional material, usually a high-density copper mesh, which adds cost and weight.

HMPI engineers turned to carbon nanotubes, which offer great strength advantages and are highly conductive. Working with the nearby National High Magnetic Field Laboratory in Tallahassee, researchers were able to use high-power magnets to form buckypaper with aligned (rather than random) carbon nanotubes to create a film with advanced conductivity. They've since developed a material that serves as a source for use in other composites. In tests conducted by the Air Force Research Laboratory and with Orlando-based Lockheed Martin Missiles and Fire Control, the buckypaper-based composites have been shown to deflect lightning while retaining their strength and weight advantages.

Now that tests have demonstrated the material's advantages, HMPI is obtaining magnets to refine the technique in their labs and scaling up production of the buckypaper. The center is in talks with various companies about licensing and manufacturing the technology.

HPMI researchers are also working on other nanomaterial technologies, such as growing "a nanotube forest," as business director Amrita Kumar calls it, from which they can pull out thin sheets of translucent nanotube film. "If we can sandwich this nanotube film between two sheets of window material," Kumar notes, "we might be able to deflect some of the energy from a blast in the field and mitigate the effect."

Ensuring Safety

David Rejeski, director of the Project on Emerging Nanotechnologies, noted in a recent press release that the current inventory of products containing nanotechnology could reach 1,600 within the next two years, which "will provide significant oversight challenges for agencies such the Food and Drug Administration and Consumer Product Safety Commission, which often lack any mechanisms to identify nanotech products before they enter the marketplace."

Safety concerns scientists at PERC. PERC investigators synthesize, characterize, and conduct performance assessments on nanoparticles—both to investigate the properties of these particles and potential applications, and to evaluate their health and safety effects on people and the environment.

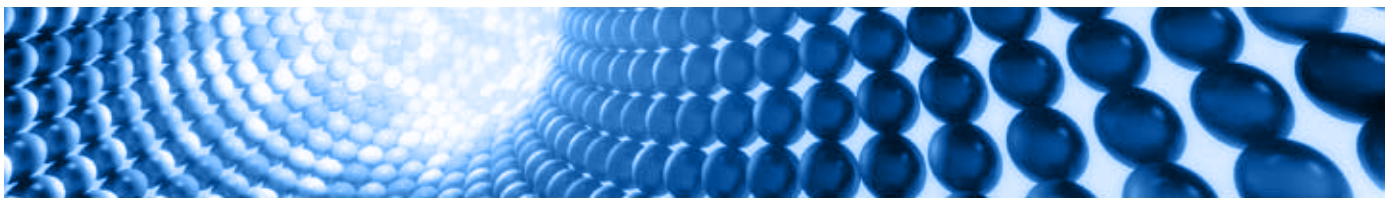
PERC's director Brij Moudgil relates that, when center researchers began studying applications of nanoparticles in biomedicine more than a decade ago, they kept returning to safety questions. "What happens to the particles in the body once they've done their job? What is their fate? This is what the doctors kept asking us as we were moving forward to design particles to their specifications," says Moudgil. "We realized that toxicity is going to be center stage."

The center has been developing the tools and protocols needed to know quickly, in the early stages of particle research, whether a particle will be toxic to cells or instigate a disease. Together with local and national companies, they've been developing ways to obtain reliable toxicity pathway information in a rapid, reliable manner; such tests today are time-consuming and expensive. "We don't want to spend one year to develop [a new particle] and then another nine months to find out whether it's toxic," says Moudgil.

The toxicity screening process involves bringing the particle close to a single cell and investigating how it affects cellular functions. This process can then be scaled up and used to test colonies of cells.

At the other end of the products life, eco-toxicity becomes a challenge. So PERC researchers are investigating the life cycles of these nanoparticles, and what might occur should they get picked up by plankton and work their way up through the food chain.

"We want to know how we can reduce costs and get reliable information early on," Moudgil adds. He believes that this effort will not only not detract from the promise of the new technology, but will actually help to speed up new research to bring the promise of nanotechnology to fruition.



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