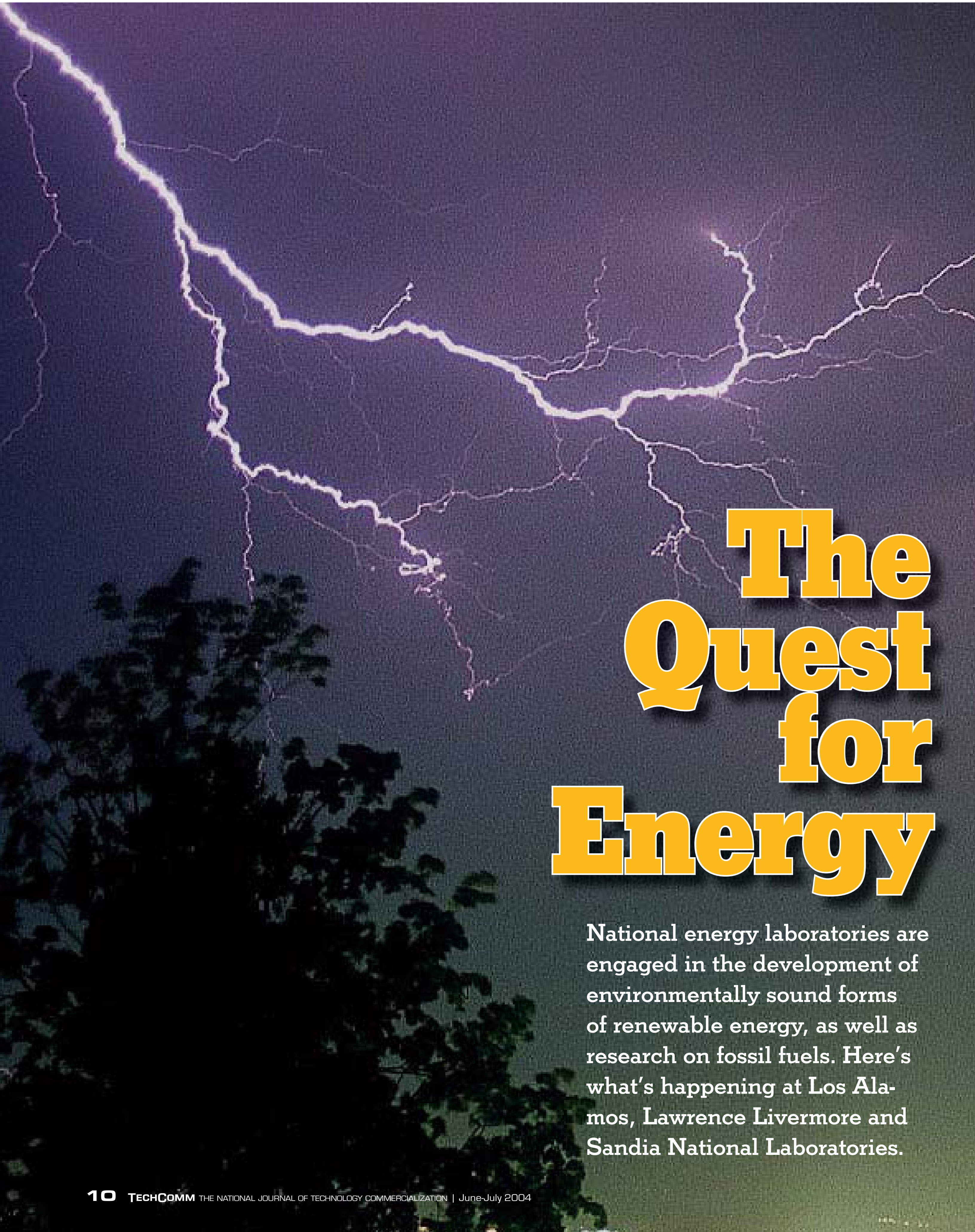

The Quest for Energy

National energy laboratories are engaged in the development of environmentally sound forms of renewable energy, as well as research on fossil fuels. Here's what's happening at Los Alamos, Lawrence Livermore and Sandia National Laboratories.

LOS ALAMOS NATIONAL LABORATORY

A More Efficient Energy Delivery System

BY ANTHONY MANCINO

WHILE THE NATION is preoccupied with hostile threats from abroad, it is easy to forget that other, less-publicized issues threaten to undermine our national security and well-being. Chief among these are the intertwined issues of energy production and the environment. The nation's security and economic stability rely on sufficient energy supplies and environmentally sound energy production and use. Parts of the U.S. have already experienced shortages as demand for electricity increases far more rapidly than new generating capacity; 52 percent of the nation's primary transportation fuel source is imported from an unstable foreign market (projections show those imports at 70 percent by 2020).

Furthermore, increases in atmospheric carbon caused by energy production and use threaten to change the climate. The potentially disastrous implications of such change are little understood at present. These factors could erode the nation's economy, security, and quality of life. But the story is not all bleak. These trends can be reversed with the nation’s vast scientific and technological resources, many of which reside at Los Alamos National Laboratory.

Los Alamos is applying its multidisciplinary expertise to national problems in energy security, such as:

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LAWRENCE LIVERMORE NATIONAL LABORATORY

Magnetic Fields to Tap Fusion Energy

BY CHARLES OSOLIN

ANYONE WHO’S EVER BEEN INTRIGUED by the seemingly magical properties of magnets should meet Dick Post. Sitting in his office surrounded by a wall-to-wall clutter of books, research papers, reports and gadgets of various shapes and sizes, Post can barely contain his enthusiasm over the latest news about his favorite scientific tool.

“Here, take a look at this,” he exults, turning to his computer and calling up a paper reporting on computer simulations of what Post calls a “new wrinkle” in using magnetic fields to tap the fusion energy that powers the sun.

“A few years ago, Dmitri Ryutov of Novosibirsk (Russia) came up with a way to stabilize an axisymmetric (cylindrical magnetic fusion) system,” Post says. “It’s very elegant, but also very simple. And we now have a real chance to do realistic simulations showing that it works.”

While his colleagues at Lawrence Livermore National Laboratory (LLNL) and around the world experiment with high-powered lasers and ponder exotic zero-point energy fields, Post is putting his money on the old-fashioned magnet to help solve the energy needs of the future.

A veteran particle physicist at LLNL, Post has devoted a lifetime to studying magnets in virtually all their forms and applications – from generating all-but-limitless energy via controlled nuclear fusion to providing energy-efficient-

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SANDIA NATIONAL LABORATORIES

Expanding Safe Nuclear Energy

BY MARGARET LOVELL

AMERICA’S ATTITUDE about what we once called atomic energy has shifted from gratitude for the resolution to warfare and presumed protection that our weapons brought us, through appreciation for the, again presumed, blessings of clean and abundant energy that would power our ever-expanding worldwide economic hegemony, to fear and anger that even atoms for peace were not as fail-safe as we had imagined.

We are again at the decision point of investing our national will and wealth in nuclear energy for peace and prosperity. Over the past six decades, though, the game and the players have changed. Now, to move forward with a new nuclear energy policy, we need to assure ourselves, our friends and our enemies that we can manage the present and future outcomes of nuclear reactors and their fuel in a manner that assures their protection and secure disposition.

The energy policy currently advanced by the White House recommends an expansion of nuclear energy in this country to enhance energy security. Studies by DOE/NNSA also recommend growth in nuclear power. The consensus is that to achieve this goal, the U.S. scientific community must demonstrate technical options to

- Expand the use of nuclear energy worldwide
- Manage radioactive waste
- Reduce the threat of nuclear material misuse

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• Ensuring a stable, non-polluting supply of energy

• Modeling and understanding climate variability

• Preventing carbon emissions from entering or remaining in the atmosphere

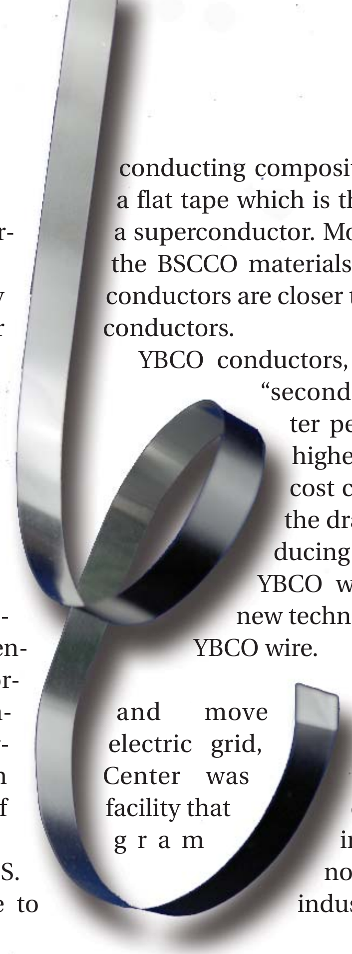
• Increasing the safety and viability of nuclear energy production

• Ensuring an abundant and clean supply of water

• Modernizing and increasing the efficiency of the nation's energy infrastructure

Advances in infrastructure efficiency alone would greatly reduce the consumption of fuels used to generate electricity and the resultant emissions of greenhouse gases. One technology that will spur an enormous leap in infrastructure efficiency is high-temperature superconductivity, and Los Alamos's international leadership in superconductivity research and development is accelerating the deployment of this promising technology.

Ten percent of electricity generated in the U.S. each year (300 million kilowatt hours) is lost due to resistance of the copper and aluminum wiring currently used to transmit power across the nation's electrical grid. The energy lost is enough to supply the combined energy needs of New Mexico, Arizona, California and Oregon. Superconductors, materials that have no electrical resistance when cooled with liquid nitrogen, can carry up to 100 times the electricity of ordinary copper or aluminum wires of the same size. Superconducting tape developed at Los Alamos can carry 200 times the capacity of copper. These materials can be used in many electric power applications, such as transmission lines, industrial motors and generators, fault-current limiters, and transformers. Superconductivity will have a dramatic economic impact. The electricity saved by superconductor cables could equal $4 billion per year.



LANL-developed superconducting tape can carry 200 times the capacity of copper.

UNTIL VERY RECENTLY, superconducting materials were not advanced enough to be commercially viable. Low-temperature superconductors proved uneconomical since they required expensive, liquid helium cryogenics to reach zero resistance. But high-temperature superconductors, discovered in 1986, operate in the relatively warmer, and much cheaper, environment of liquid nitrogen. The key to applying superconductivity to energy security is developing a strong and flexible high-temperature superconducting wire capable of carrying large currents in magnetic fields. At Los Alamos, this objective has led to two parallel efforts that focus on two different superconducting compounds known as BSSCO and YBCO.

The first technique to yield good superconducting wire was the oxide-powder-in-tube method in which oxide powders of BSSCO are loaded into silver or sliver alloy tubes, sealed, and then drawn or extruded into round wire. The round wire is then thermally processed to form a superconducting composite, or it is further rolled to produce a flat tape which is then thermally processed to produce a superconductor. Most of the conductors produced with the BSCCO materials are made in the tape form. These conductors are closer to commercialization than the YBCO conductors.

YBCO conductors, known as "coated conductors" or "second generation" wires, promise better performance in high magnetic fields, higher temperature operation, and lower cost compared to BSCCO wires. However, the drawing and rolling technique for producing BSCCO wire does not work well for YBCO wire, so Los Alamos has developed new techniques to produce practical lengths of YBCO wire.

TO ADVANCE THESE TECHNOLOGIES and move them quickly out of the lab to the electric grid, the Superconductivity Technology Center was established, a 10,000 sq. ft. research facility that coordinates a multidisciplinary program in research, development, and technology transfer in collaboration with industry, universities, and other national laboratories. Research areas include wire and system development, powder synthesis, processing of tapes and coils, deposition of thin and thick films, characterization of micro-structural and superconducting properties, power cryogenic engineering, and fabrication of prototype devices.

In comparison to conventional technologies, superconductivity power equipment will typically be half the size and have half the energy losses. The Department of Energy estimates that about 2,200 miles of existing underground cables are rapidly becoming outdated and could potentially be replaced with high-temperature superconductive lines. However, implementation will be an expensive undertaking because the cost of superconductor cable can be four times the cost of conventional copper cable. Because utility companies are primarily concerned with cost recovery, the price of superconducting cable must drop considerably before the technology becomes more widespread.

Some experts believe that commercialization could start in as soon as three to five years as more money is invested, newer prototypes are developed, and the technology gains new economies of scale to decrease the cost. The main focus of DOE's superconductivity program is to address barriers to widespread implementation of the technology, including cost. Now that reliability of the nation's transmission grid is at the forefront of national security policy, superconductivity could soon be adopted into mainstream applications. High-temperature superconductors will dramatically enhance the nation's energy security by increasing the efficiency and reliability of the electrical power grid.

ANTHONY MANCINO IS WITH THE OFFICE OF ENERGY AND ENVIRONMENT INITIATIVES, LOS ALAMOS NATIONAL LABORATORY.

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transportation.

Post, who joined Livermore when the lab was established in the early 1950s, retired in 1992 but quickly realized he still had "unfinished business." At 85, he puts in four full days a week in his office and has no intention of slowing down.

Holder of more than 30 patents and celebrated as the "father of the modern flywheel," Post could easily sit back and rest on his scientific laurels. But he continues to work on magnetic confinement fusion, determined to have the last laugh on skeptics who love to joke that fusion energy is 30 years away and always will be.

Post concedes that the path to fusion energy has been less than smooth. The technical challenges involved in attempting to harness the thermonuclear energy released by hydrogen bombs and the stars have been formidable and political support for fusion research has been fickle.

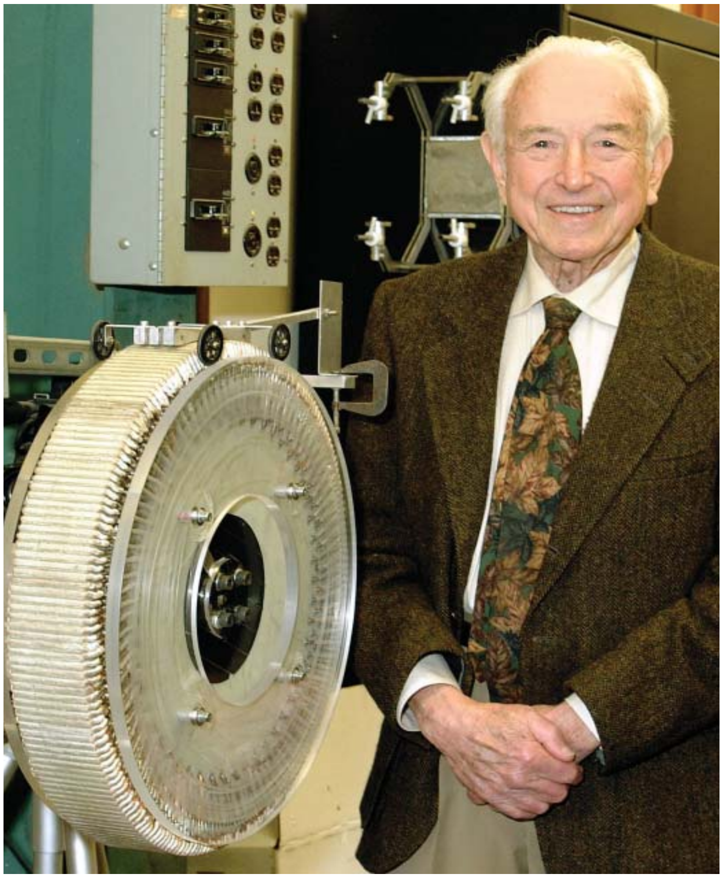
By the mid-1980s, Post and his colleagues were making good progress in demonstrating the viability of the "open," or "magnetic mirror" approach to fusion. Cylindrical magnetic fields, pinched at their ends like a party popper, were used to confine superheated plasma, a gas consisting of electrons and positively charged hydrogen ions. The goal was to apply enough heat and pressure to allow the hydrogen nuclei to fuse and release more energy than the amount required to heat the plasma.

Government funding dried up, however, and the project was mothballed. Support for fusion research focused on another approach, using huge doughnut-shaped "closed" fusion reactors known as tokamaks. Magnetic mirrors, which were prone to plasma drift and leakage, slipped to the back burner.

But Post and his colleagues persevered, hoping to find a way to achieve controlled fusion that would be smaller and less expensive than tokamaks by sidestepping their chief drawback—turbulence.

"In magnetic fusion, you're faced with a turbulent regime," Post says. "You can deal with it either by making the reactor big enough so you can live with the turbulence, which is the tokamak approach, or by finding geometries that have shown low turbulence and making them into a practical fusion system."

LLNL



Dick Post with some of the components of his maglev system.

That's where the exciting "new wrinkle" devised by Post's Russian colleague Dmitri Ryutov, now at Livermore, comes in. Post believes Ryutov's solution to stabilizing and containing the plasma in an open system – by "anchoring" it in place using small amounts of plasma on the outside of the magnetic field – has the potential to revive magnetic mirror fusion "in a form that would make it much more attractive for a fusion power system. The mirror machine could become the answer that fusion has been waiting for."

While fusion energy remains tantalizingly out of reach for now, many of the other uses for magnets that Post has invented and patented are beginning to find their way into a variety of practical applications. One of the most promising is a simple and efficient way to use permanent magnets to levitate the trains in a mass transit system and eliminate most of the power drain caused by friction. Livermore's "maglev" system uses a special arrangement of powerful magnets known as a Halbach Array to elevate the train above a guideway embedded with close-packed coils of insulated copper wire. Such trains are smooth, quiet, energy efficient, and capable of speeds of more than 300 kilometers an hour.

PHYSICIST KLAUS HALBACH of Lawrence Berkeley National Laboratory developed Halbach arrays for use in particle accelerators. Arranging magnets so they create a periodic magnetic field that is alternately vertical and horizontal concentrates the field on one side while canceling it on the opposite side. A Halbach Array can levitate a weight 50 times heavier than its magnets.

Post said the maglev system, recently licensed by General Atomics of San Diego using the trade name Inductrack, is moving toward a large-scale demonstration. He said Inductrack is "nowhere near as complex" as the maglev systems currently being tested in Germany and Japan.

Inductrack requires neither the costly cryogenic cooling systems needed by the superconducting magnets in the Japanese system, nor the complicated sensors and feedback circuits of the German system. What's more,

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• Enhance national security

Sandia National Laboratories is following these recommendations by advancing a concept it calls the Global Nuclear Future. This model envisions a world that has an abundant, sustainable and environmentally friendly supply of nuclear energy produced in ways that keep nuclear materials out of the hands of terrorists or rogue states. Robert J. Egan, Sandia's senior vice president for special projects, says, "The time is right for America to revisit nuclear energy — only now with a new expanded sense of what it means in light of September 11 and looming economic and environmental developments in the world." Eagan notes that President Bush and Vice President Cheney have expressed support for pragmatic approaches to solving these problems. "I think there's a high probability we'll get a favorable hearing on the Global Nuclear Future concept."

Sandia's Global Nuclear Future logo.

Seven DOE/NNSA laboratories are investing in this Global Nuclear Future, with Sandia both performing research and acting as a system integrator. Sandia is joining with Argonne, Idaho National Engineering and Environmental, Oak Ridge, Pacific Northwest, Lawrence Livermore and Los Alamos national laboratories to reinvigorate nuclear power in the 21st century. "Sandia has offered to the rest of the labs our experience and expertise as 'system integrators' for this effort," says Sandia President C. Paul Robinson. Each lab in the partnership has expertise in particular areas of nuclear technology that it will bring to the table, Robinson adds, "but we thought that what was most needed was an impartial system integrator that could serve as the honest broker to build the pieces — only as appropriate — into a system solution."

The technology vision for this partnership outlines three major goals necessary to achieve the vision of global expansion of nuclear energy systems.

• Reduce air pollution and improve global climate by increasing the use of nuclear power. Among the objectives are 50 percent of U.S. electricity produced by nuclear power and 25 percent of U.S. transportation fuels produced by hydrogen by 2050.

• Achieve a 90 percent reduction of reactor waste requiring repository disposal by 2050. Objectives include demonstration of a "closed" (more efficient) fuel cycle system by 2020 in a pilot facility and use of the new fuel system with an advanced reactor.

• Reduce the threat of nuclear weapons proliferation while expanding nuclear technology worldwide. To achieve this, the plan calls for demonstration of affordable technologies and safeguard systems to minimize proliferation risk.

To achieve these goals, DOE and its labs will have to reach some near-term objectives that include demonstrating an advanced Generation IV (Gen IV) reactor to support both electrical generation and hydrogen production and accelerating the initiative to develop a closed fuel cycle that will be economically, socially and politically sustainable.

Within the Gen IV reactor development program, the Next Generation Nuclear Plant project will demonstrate high-temperature reactor technology and the capability of this technology to power the affordable production of hydrogen and electricity. The Gen IV program will also invest in the development of new reactor technologies that hold significant promise for advancing sustainability goals and reducing nuclear waste generation.

Closely coupled to the Gen IV program is the Nuclear Hydrogen Initiative (NHI). This program contributes to the overall goals by demonstrating hydrogen production technologies using nuclear energy. A commercial-scale demonstration plant could be coupled with a Gen IV demonstration facility in the middle of the next decade.

Reaching the Global Nuclear Future goals will also require the transition from the current once-through fuel cycle to an advanced fuel cycle. The Advanced Fuel Cycle Initiative (AFCI) is a focused R&D program that addresses types of fuel, fuel fabrication and separation techniques, and disposal technologies to reduce spent fuel volume, separate long-lived and highly radiotoxic elements, and reclaim spent fuel's valuable energy. The AFCI technologies will support both current and future nuclear energy systems.

In addition to satisfying a systems-integration role, Sandia is working with the AFCI team to establish technologies for limiting inappropriate or unsafe nuclear proliferation. This work presents a key opportunity for Sandia, says Tom Sanders, manager of Sandia's Global Nuclear Futures department. "By developing a smart fuel cycle, we can take advantage of advanced manufacturing, robotics, and automation to create additional data at a nuclear plant that can assess the intent of the facility in terms of uses of materials." To maximize this opportunity, Sandia is investing in projects to develop risk-informed proliferation assessments and transparency systems for fuel cycle components. This work includes efforts to develop systems that focus on verification of legitimate use and those that prevent the diversion of nuclear materials by removing humans from

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Inductrack trains would be inherently stable and safe: In the event of a power failure, they would coast smoothly to a stop and settle back on their auxiliary wheels. Post said they're also particularly well suited for low-speed urban mass transit systems, because they can accelerate rapidly and easily handle steep grades and tight turns.

The idea for magnetic levitation grew out of Post's research on electromechanical batteries, which use circular Halbach arrays, advanced flywheels, and nearly frictionless "passive" magnetic bearings (invented by Post, naturally) to store energy much more efficiently than conventional electrochemical batteries.

Flywheels first captured Post's attention "as a sidelight" in the early 1970s, when he and his son Stephen, an electric car buff, wrote a seminal article for *Scientific American* suggesting that flywheels made of composite materials instead of metal could be used to store energy in electric vehicles.

Post's flywheel battery technology was licensed to a San Francisco company in 1994, and is currently being developed for such applications as uninterruptible power supplies for computers and other sensitive electronic equipment, and to provide energy storage for wind and solar

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power systems.

The licensee has also received funding from the federal government to develop hybrid diesel-electric buses and trucks using flywheels in a program designed to reduce lung-damaging particulate emissions from diesel engines by 90 percent and cut diesel fuel consumption in half.

Manufacturers of hybrid automobiles, however, have yet to adopt flywheel batteries; both Toyota and Honda use electrochemical batteries in their popular gasoline-electric hybrid cars. Post remains convinced that flywheel batteries are a better idea.

"Somebody should really take the flywheel seriously for hybrid vehicles," he said. "Flywheel batteries are over 92 percent efficient in returning the energy put into them, versus 70 to 85 percent for an electrochemical cell.

"They should also have a very much longer life than an electrochemical battery.

"In fact, in terms of energy efficiency," Post said, his eyes twinkling, "a vehicle that uses hydrogen fuel cells and a flywheel battery would be an excellent combination…"

To someone like Dick Post, the appeal of saving that much energy can only be described as…well, magnetic.

CHARLES OSOLIN IS AN LLNL PUBLIC INFORMATION OFFICER.

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controls. As these and other projects advance along the research-to-application curve, commercial partners will have the opportunity to participate with Sandia and the other labs in cooperative and licensing agreements.

It is still uncertain if today's U.S. leaders and their constituents are ready to make the economic, social and political commitments to nuclear energy, but the nation's scientists and engineers are working on the technologies that will be needed when, or if, America welcomes in a new atomic age. What is certain is that to bring about the Global Nuclear Future Sandia has proposed, it and the other national laboratories are applying their decades of experience with nuclear materials, reactor engineering and construction, environmental stewardship, waste management, and safeguards and security to ensure that the nation will be ready for this future, which could be arriving sooner than was expected and, perhaps, just in time.

Margaret Lovell is a senior technical writer at Technically Write, assigned to Sandia National Laboratories.