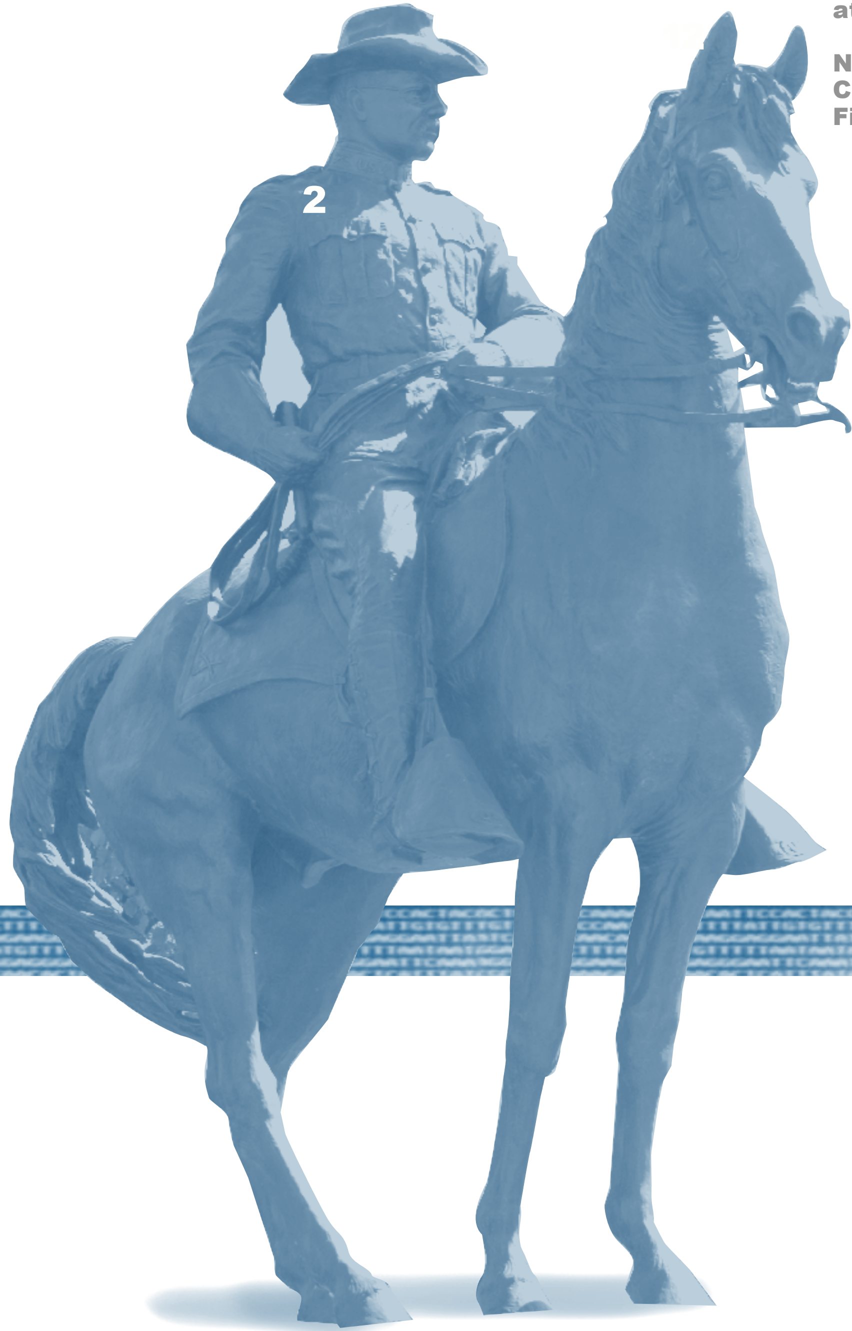
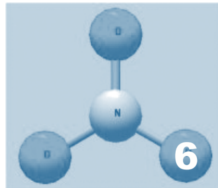
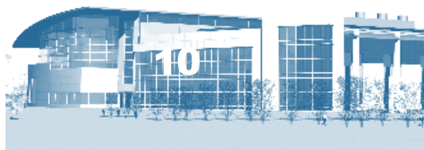
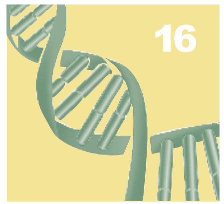
Summer 2006





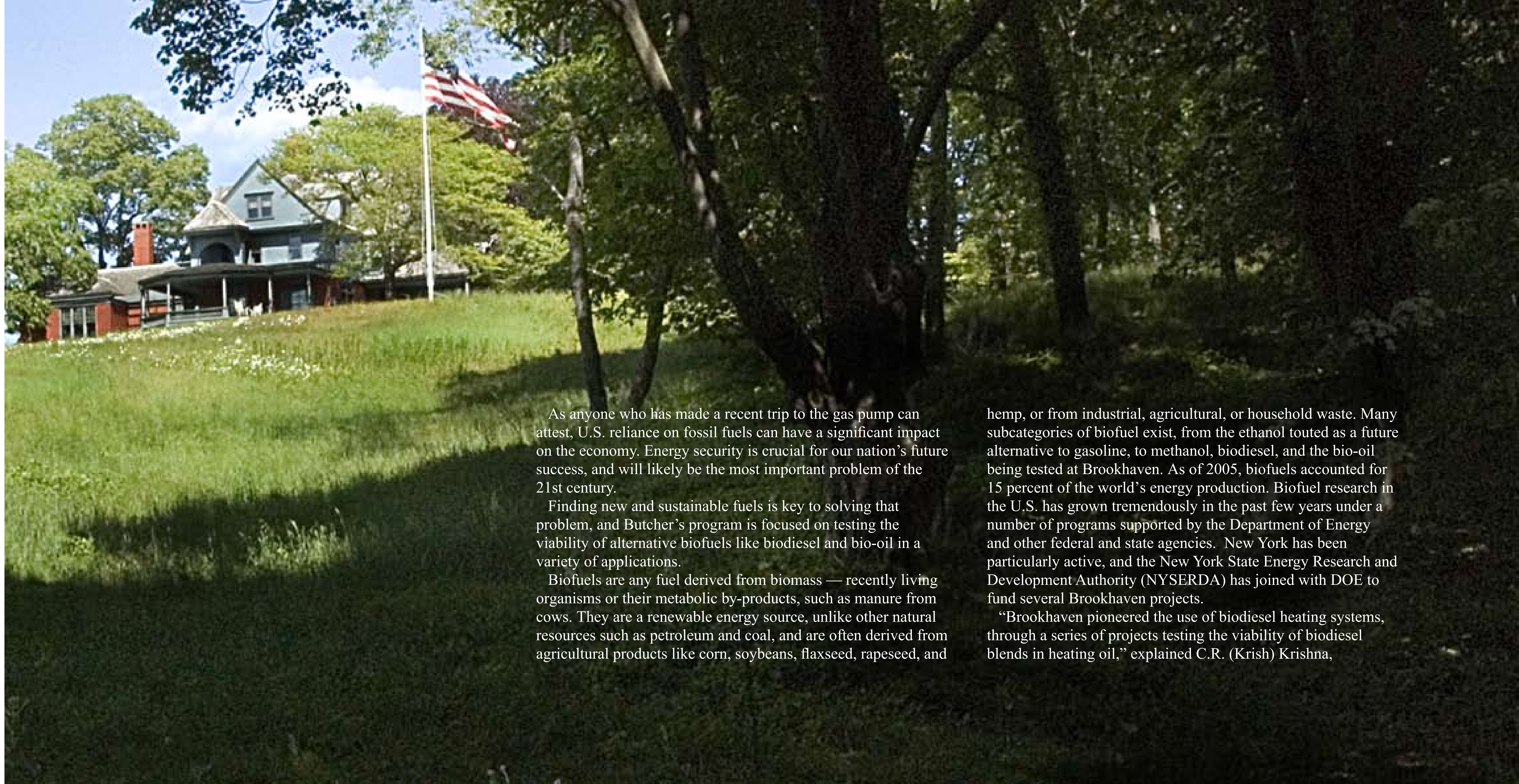




BIOFUEL RESEARCH *at* BROOKHAVEN

Brookhaven's biofuel projects — like one under way at Teddy Roosevelt's former home at Sagamore Hill — demonstrate the role these fuels can play in our future energy portfolio.

by Peter Genzer



The first thing that strikes a visitor to Brookhaven's biofuel research lab is that one key to the United States' future energy independence may very well smell something like a cross between a ripe French brie and heavy crude oil. That's because the biofuel being tested here — flowing from a 55-gallon drum through a maze of shiny copper piping to a standard industrial boiler in the corner — is a truly recycled natural product, with its origins in, of all things, turkey waste. It's all part of collaborative research project involving Brookhaven Lab and KeySpan Energy, and is emblematic of Brookhaven's focus on renewable energy and alternative fuel research.

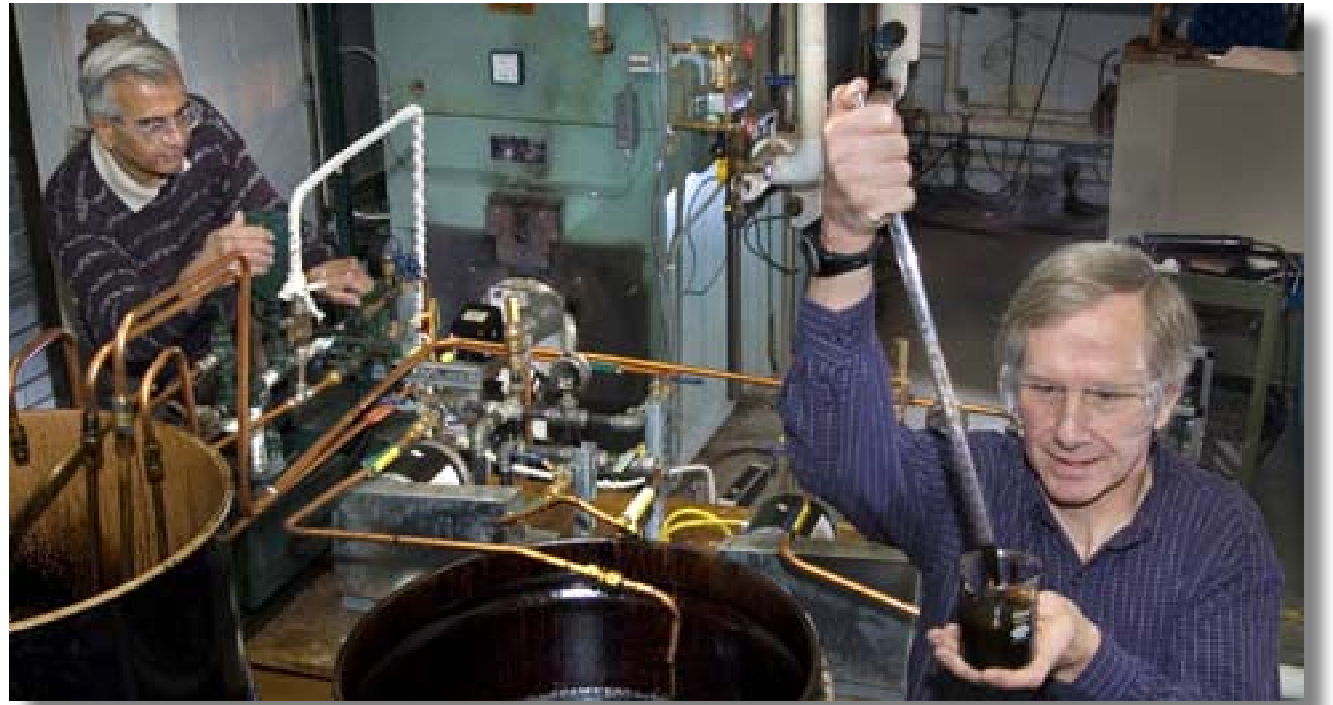
"What we're burning here are three different blends of bio-oil, derived from turkey waste, and #6 home heating oil," said Tom Butcher, head of the Energy Research Division in BNL's Energy Sciences & Technology Department. "This particular biofuel shows a lot of promise, but we need to determine how well it burns, what emissions are generated, and which blends are optimal for industrial use."

As anyone who has made a recent trip to the gas pump can attest, U.S. reliance on fossil fuels can have a significant impact on the economy. Energy security is crucial for our nation's future success, and will likely be the most important problem of the 21st century.

Finding new and sustainable fuels is key to solving that problem, and Butcher's program is focused on testing the viability of alternative biofuels like biodiesel and bio-oil in a variety of applications.

Biofuels are any fuel derived from biomass — recently living organisms or their metabolic by-products, such as manure from cows. They are a renewable energy source, unlike other natural resources such as petroleum and coal, and are often derived from agricultural products like corn, soybeans, flaxseed, rapeseed, and hemp, or from industrial, agricultural, or household waste. Many subcategories of biofuel exist, from the ethanol touted as a future alternative to gasoline, to methanol, biodiesel, and the bio-oil being tested at Brookhaven. As of 2005, biofuels accounted for 15 percent of the world's energy production. Biofuel research in the U.S. has grown tremendously in the past few years under a number of programs supported by the Department of Energy and other federal and state agencies. New York has been particularly active, and the New York State Energy Research and Development Authority (NYSERDA) has joined with DOE to fund several Brookhaven projects.

"Brookhaven pioneered the use of biodiesel heating systems, through a series of projects testing the viability of biodiesel blends in heating oil," explained C.R. (Krish) Krishna,



C.R. Krishna and Tom Butcher

> “ Brookhaven pioneered the use of biodiesel heating systems ”

mechanical engineer and Brookhaven’s lead biodiesel researcher. “Biodiesel has been proven effective as a fuel for combustion engines, but we wanted to show that it could be used successfully in other applications as well.”

Krishna led a biodiesel project in upstate N.Y. from 2003 to 2005 where about 100 homes were switched over to “B-20,” a blend of 20 percent soy-based biodiesel and 80 percent low-sulphur heating oil. No burner modifications were necessary to burn the biodiesel blend, and the results were quite positive. “The heating efficiency was about the same, and we saw a significant decrease in sulphur dioxide and nitrogen oxide emissions,” said Krishna. “We also think we will see some long-term benefits in terms of maintenance costs.”

The primary obstruction to the widespread use of biodiesel is the price. “It tends to be more expensive than your typical heating oil, but that’s because there isn’t yet a strong market for it,” said Krishna. “Over time, as production and use expands, the price should come down to a competitive level.”

Other Brookhaven projects currently under way include one in New York City, where biodiesel blends will be tested in large industrial apartment building boilers, and another at the Sagamore Hill national historic site in Oyster Bay on Long Island (see sidebar).

The bio-oil collaboration between Brookhaven, KeySpan Energy, and a company called Changing World Technologies (which manufactures the oil) might be the most interesting project to date. KeySpan hopes to eventually use a bio-oil blend in one or more of its large power plants. “We have a genuine interest in clean fuel technologies and renewable fuels, and this is a great business opportunity for us,” said Steve Eber, project manager and principal investigator for KeySpan. “Brookhaven is an important asset for us in that Krish and his colleagues have the ability to address our technical concerns and help us move to the next step.”

Eber said KeySpan hopes to complete the project by this fall, and then make the results public through NYSERDA so they can be shared with other industries across the state.

MEET C.R. KRISHNA AND TOM BUTCHER

At first glance, biofuel might appear to be just a pitch-black, viscous, foul-smelling liquid with no redeeming value, but Brookhaven researchers Tom Butcher and C.R. Krishna see something akin to liquid gold – a renewable resource that could solve many of our nation’s energy problems.

“It is important for the United States to have an alternative fuel option – we need to have a Plan-B energy source that we can turn to in the future,” says Krishna, who has worked in what is now Brookhaven’s Energy Sciences & Technology Department since 1975. “It makes a lot of sense to look at these kinds of renewable fuels because we can reduce our dependence on foreign oil and also help the environment.”

Krishna and Butcher’s interest in biofuels is tied to the fact that while organic materials take millions of years to transform into fossil fuels, biofuel feedstocks can be grown in just a few months and are biodegradable, nontoxic, and, most importantly, renewable. In addition, the plants themselves consume carbon dioxide, helping to counterbalance what is produced when the fuels are burned.

“Another benefit is that these biofuels burn much more cleanly than fuel oil, with reduced nitrogen oxide emissions,” says Butcher, who started at Brookhaven in 1978 and currently heads BNL’s Energy Resources Division. “In addition, if we can further develop biodiesel, we would likely see a significant economic benefit due to an increase in the agricultural production of biofuel feedstock in upstate New York and elsewhere in the U.S.”

Butcher’s division has a long history of successful projects tied to the conservation of fossil fuels used for heating and electricity generation. Brookhaven’s research to improve oil burner efficiency, for example, has saved approximately $6 billion in the past decade for the 10 million Americans who heat their homes and businesses with oil. The current focus on biofuels has the potential for an even greater impact on the nation.

“We have seen again and again how interdisciplinary research is very productive and often yields unexpected benefits for society,” said Krishna. “Biofuels are right at the interdisciplinary nexus of biology and engineering, and we believe they hold great promise.”

C.R. Krishna grew up in Bangalore, India and received his M.S from the Institute of Science, Bangalore in 1961. He received his Ph.D in mechanical engineering from Stony Brook University in 1974, and came to Brookhaven as a postdoctoral student in 1975.

Since joining the Lab in 1978, Butcher has been involved with a wide range of research projects related to energy and fuels. Butcher is originally from Long Island. He received B.S. in Marine Engineering from the U.S. Merchant Marine Academy in 1975, his M.S. from Stevens Institute of Technology in 1978 and received his Ph.D. in mechanical engineering from Stony Brook University in 1987.

SAGAMORE HILL

Back in 2004, Brookhaven researchers contacted the National Parks Service (NPS) with an interesting request — let us test a biodiesel blend at one of your Long Island sites so we can determine its effectiveness. After some discussion, the NPS agreed to participate in a pilot program at its Sagamore Hill National Historic Site, on the scenic North Shore of Long Island in Oyster Bay.

Sagamore Hill was the home of Theodore Roosevelt, the 26th President of the United States, from 1886 until his death in 1919. In 1880, at the age of 22, Roosevelt purchased 155 acres of land on Cove Neck, a small peninsula roughly 2 miles northeast of the village, and shortly after hired the New York architectural firm Lamb & Rich to design a shingle-style, Queen Anne home for the property.

The house and its surrounding farmland became the primary residence of Theodore and Edith Roosevelt for the rest of their lives. It became known as the “Summer White House” during the seven summers (1902-1908) Roosevelt spent there while President. Roosevelt died at Sagamore Hill in January 1919 and was buried in the small Youngs Memorial Cemetery, just one mile from his home.

The Sagamore Hill National Historic Site was established by Congress in 1962, and has since hosted thousands of visitors per year who come to see the main house, which still contains many of its original furnishings, and the Teddy Roosevelt museum. The complex includes several outbuildings, and three of these, including the site superintendent’s residence, were selected for the pilot program. In 2004, each of the three buildings was switched over to “B-20,” a blend of low-sulphur heating oil and 20-percent soy biodiesel, and the BNL researchers studied burner performance, emissions, maintenance, and tank status over the next two years.

According to Krishna, the results have been extremely positive. “We see no changes in terms of heating efficiency, no maintenance issues, and substantial reductions in sulphur dioxide emissions,” he said. “The Parks Service has been extremely happy with the project — in fact, the maintenance supervisor wants to start using biodiesel in his upstate residence.”

This may be the time to switch. Governor Pataki recently signed into law legislation that provides a residential bioheat tax credit for home and business owners who use a biodiesel blend in their heating systems. The credit is based on the percentage of biodiesel in the blend, up to 20 cents per gallon for B-20, and, when combined with an existing federal tax credit, should bring the net cost of residential bioheat below the market price for conventional number 2 oil.

Nitric Oxide Chemistry Contributes To Cystic Fibrosis Research

Scientists believe that a common chemical used to cure meat may hold the key to promising new therapies for a genetic disorder deadly to children and young adults.

By Kay Cordtz

There may be new hope for improved treatments and longer life for cystic fibrosis patients, thanks to a recent discovery by a team of researchers including Brookhaven National Laboratory chemist Sergei Lymar. Led by University of Cincinnati microbiologist Daniel Hassett, the team has discovered what might be the "Achilles heel" of a dangerous organism that lives in the lungs of cystic fibrosis patients—a fatal flaw that leaves the organism vulnerable to destruction by a common food preservative.

"Treatment for cystic fibrosis consists of clearing the patient's lungs of mucus, a stagnant medium where opportunistic bacteria thrive," Lymar said. "It is difficult to reach the bacteria there with antibiotics, but nitric oxide may be the key to an important new therapy."

Cystic fibrosis, which affects about 30,000 people in the United States, is an inherited disease caused by a defect in a single gene in a chromosome of both parents. Affecting the lungs and many other vital organs, cystic fibrosis is chronic, progressive, and ultimately fatal, mostly as a result of serious lung infections that breed in the thick and sticky mucus caused by the abnormal gene. Until the 1980s, most deaths from cystic fibrosis occurred in children and teenagers. Today, thanks to improved treatments, people with cystic fibrosis live an average of 35 years.

It has been known for some time that an opportunistic pathogen, *Pseudomonas aeruginosa*, a common inhabitant of soil and water, invades the lung-clogging mucus found in the airways of cystic fibrosis patients and significantly weakens them. In the lungs, *Pseudomonas* mutates to form a dense, resistant biofilm that leads to lung destruction. The new study suggests that this mutation harbors a fatal flaw that could help physicians clear the characteristic "goop" from the lungs of advanced cystic fibrosis patients. The same genetic change that turns the organism into an antibiotic- and immune-system resistant killer also leaves it susceptible to destruction by slightly acidified sodium nitrite, a common chemical that is widely used in the curing of lunch meat, sausages, and bacon.

Because of Lymar's expertise in inorganic nitrogen chemistry, Hassett's team sought his assistance in their observation of the bactericidal action of sodium nitrite on the mucoid forms of *Pseudomonas aeruginosa*.

"I felt that they were up to something potentially very important," Lymar said. "It has quickly become clear that the species toxic to these bacteria is not the nitrite itself, but one of the downstream products of its decomposition in a slightly acidic environment. This chemistry is complex, including a peculiar mix of very rapid and slow reactions and a number of products and intermediates, so we had to resort to computer simulations to understand what is happening on the relatively long time scales typical of bactericidal assays."

The project was quite a change of pace for Lymar, who is used to dealing with reactions occurring in microseconds. In this case, computations revealed that the reactions take hours and days to unfold. His modeling clearly pointed to nitric oxide as the most probable toxic species and also helped to design experiments that could test this and other model predictions.

"We knew from experience, that this kind of experiment is very susceptible to artifacts," Lymar said. "One needs to work cleanly, quantitatively, with the right mixtures of gases -- and completely eliminate contact with air. When all that was done, the model predictions checked out beautifully."

Both simulations and experiments showed highly desirable properties of acidified sodium nitrite as a time-release capsule drug-delivery system. In a matter of hours, it elevated the nitric oxide content of cell cultures and then maintained these levels over days, constantly exposing bacteria to this active ingredient and killing them. Similar rates of killing were observed in a series of experiments designed to produce the same nitric oxide (NO) levels either by various combinations of nitrite concentration and acidity or by applying nitric oxide-argon gas mixtures in the absence of nitrite. Another remarkable feature of the acidified nitrite chemistry is a built-in "feedback mechanism" where the system will increase the rate of nitric oxide production in response to an attempt by bacteria to get rid of NO.

"Although we are convinced that the bactericidal action of acidic nitrite is due to nitric oxide that it generates, we are less certain about the molecular mechanism of its toxicity," Lymar said.

One important clue might be in the dramatic decline of the bacterial population upon exposure to NO. One day after treatment, the organism population decreased by roughly 90 percent; the next day, 90 percent of what remained was eliminated.

"This means that treatment wouldn't need to be long-term," Lymar said. "But what it also tells us is that nitric oxide might act as a trigger of bacterial death. An organism that has survived to any given time appears "to have no idea" that it has spent a day or two in a toxic environment until something hits it. It is difficult to reconcile such behavior with slowly accumulating damage to a microbe; it rather suggests that only a small number of reactive events, or perhaps even a single event, trigger the bacterial death."

"This pattern is consistent with a well recognized role of nitric oxide as a regulator in biology. It can trigger biochemical processes, but doesn't necessarily participate directly in them. For the mucoid bacteria, nitric oxide can be a messenger of death."

The research was funded by the National Institutes of Health and the Cystic Fibrosis Foundation and Lymar's work on nitrogen oxides is supported by the U.S. Department of Energy.

MEET SERGEI LYMAR

Chemist Sergei Lymar wasn't too surprised last year when his daughter Dasha, then a graduate student at the Massachusetts Institute of Technology, called to tell him that her inorganic chemistry textbook made reference to his work on reactive nitrogen oxides. Lymar has made a career of studying the small inorganic nitrogen-oxygen compounds that are involved in everything from human health to radioactive waste management.

For the past decade, Lymar has been using electron accelerators at the Brookhaven Chemistry Department's Center for Radiation Chemistry Research (CRCR) to generate reactive nitrogen oxides and observe their reactions.

"These reactions are important in biology where they can be both harmful, contributing to a number of diseases, and beneficial, participating in combating microbial infection," Lymar said.

The reactive nitrogen oxides are also central in environmental chemistry and in the chemistry occurring within nuclear waste storage tanks. Soon after coming to Brookhaven in 1997, Lymar won a six-year grant from the Department of Energy's Environmental Management Science Program to study the implications of inorganic nitrogen chemistry for waste management and remediation.

"The molecules we are studying contain less than half a dozen atoms – only nitrogen, oxygen, and hydrogen --but there is little that's simple about their chemistry," Lymar said. "For one thing, these species often have only a fleeting existence, reacting in microseconds, so we must generate them faster than that to actually observe them."

This is best done with the pulse radiolysis technique available at Brookhaven's CRCR, where researchers pass short bunches of electrons from an accelerator through sample solutions. In its wake, each electron leaves thousands of broken water molecules and these extremely reactive fragments are used for making the nitrogen oxide species. Brookhaven is one of only three U.S. facilities where the pulse radiolysis technique is available.

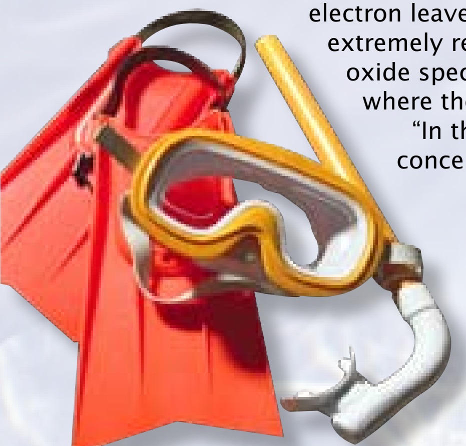
"In the waste management project, we were mainly concerned with the radiation-induced accumulation and reactivity of a particular, high-energy nitrogen oxide that can present a safety concern," Lymar said. "We also have explored the application of the strong oxidizing power of this species in waste remediation technologies. This information is essential for making more informed decisions concerning the waste disposal options."

Sergei Lymar

Part of DOE's Hydrogen Fuel Initiative relates to the conversion of solar energy by splitting water into hydrogen and oxygen. Lymar is also involved in the application of radiation chemistry techniques to this project.

Born in the Ukraine, Lymar received his B.S. and M.S. degrees from the Moscow Institute of Physics and Technology, and his Ph.D. from the Institute of Catalysis of the Russian Academy of Sciences in Novosibirsk. He worked as a senior research associate at the Institute of Catalysis before joining the Oregon Graduate Institute of Science and Technology as a visiting scientist in 1991.

Lymar's wife Elena is an assistant biochemist at Brookhaven, working on the application of gold nanoparticles for labeling proteins and protein complexes. Their busy lives allow little time for leisure activities, but Lymar, a paramilitary-trained scuba diver, enjoys diving and windsurfing in the Caribbean when he can manage a vacation.



NO KNOCKS OUT OTHER GERMS

Nitric oxide's reputation as a vital biological molecule has been bolstered by other recent work conducted at Brookhaven.

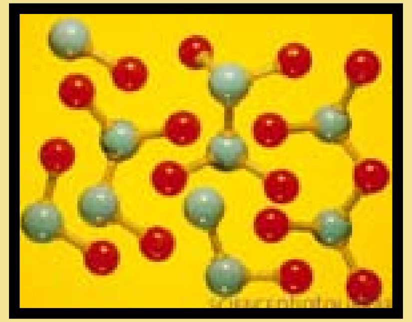
In collaboration with The Johns Hopkins University, a Brookhaven team led by biologist Walter Mangel has shown that human adenovirus treated with nitric oxide (NO) showed a dramatic decrease in infectivity.

Human adenovirus causes viral pink eye and epidemics of colds among military recruits. It can also cause blindness and, in the third world, diarrhea, killing many children. It participates in opportunistic infections, killing many AIDS patients.

"There are more than 37 human types of adenovirus," Mangel said, "so the prospect of a universal vaccine is unlikely. What is needed is an antiviral agent."

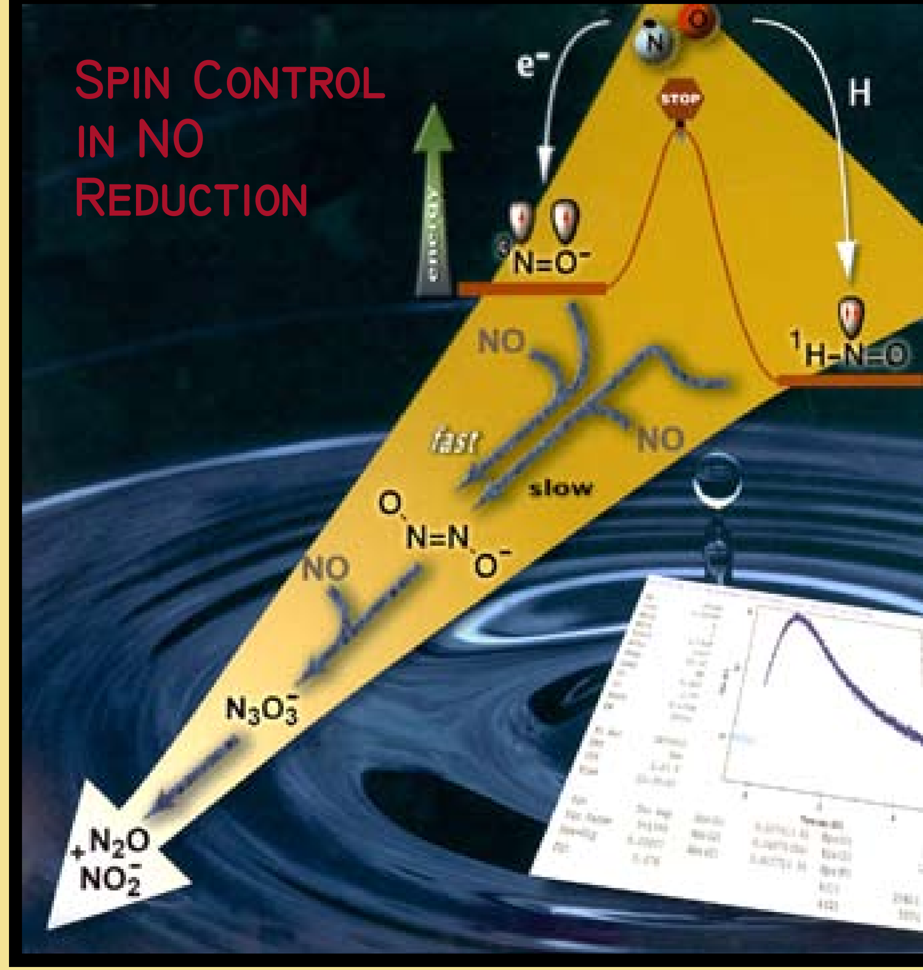
An essential component of adenovirus, as in HIV, is its protease, an enzyme that cleaves proteins to help virus particles mature. The team hypothesized that NO would inhibit the adenovirus protease because NO modulates the biological activity of many proteins. If the enzyme is inhibited from cleaving certain viral proteins, the virus particle can't become infectious and the infection is aborted.

Mangel's team is now trying to find a way of selectively inducing the synthesis of NO only in cells infected by adenovirus. If they succeed, they might have a novel way of not only aborting an adenovirus infection but also infections by other viruses with proteases similar to that of adenovirus, like the virus that causes SARS.



Nitric oxide also plays a role in the body's own defense against bacteria. It's one of the compounds immune system cells known as macrophages produce to kill or disable these germs. The current hypothesis is that compounds derived from NO and oxygen work by damaging or destroying proteins, and the accumulated damaged proteins kill the cells.

But some infectious bacteria have evolved ways to clear the damaged proteins by chopping them up in a structure called a proteosome. Brookhaven biophysicist Huilin Li and collaborators at Cornell University, the Max Planck Institute of Biochemistry, Cold Spring Harbor Laboratory, and Millennium Pharmaceuticals have just uncovered structural and biochemical details of the proteosome in Mycobacterium tuberculosis – the microbe that causes TB.



Nitrogen oxide molecules, like the ones shown at left, are long known to be involved in environmental problems, such as acid rain, global warming, and urban smog, but other important biological roles have only recently been recognized. These roles depend on chemistry. The diagram above illustrates an over three-decade-old chemical puzzle Lymar and coworkers have unraveled about what happens when nitric oxide receives an electron or a hydrogen atom to become nitroxyl, a molecule of emerging biological significance.

"This proteosome is, in effect, the bacterium's own defense against damaging effects caused by nitric oxide," said Li. "Our structural and biochemical studies may help us find a way to inhibit the proteosome and to develop a new, effective treatment for TB. Such a treatment might even eradicate TB microbes from infected individuals who show no signs of infection."

Julian Baumert and Michael Lefenfeld.

Through research, the circuits that make electronic devices work have become smaller and more efficient, leading to better products. At Brookhaven Lab, scientists are engaging in studies and experiments aimed at taking this miniaturization trend to the extreme.

Structure of a Molecular-Scale Circuit Component

By Laura Mgrdichian

As technology becomes more and more advanced, many electronic gadgets that define the modern world have become steadily smaller and more powerful. Digital music players, computers, cellular phones — all have become more compact and better performing as researchers learn to make tinier, faster circuits. Now, many scientists, including a team of researchers at Brookhaven, are beginning to learn how to make remarkably small molecular-scale circuit components.

The BNL team has determined the molecular structure of an experimental, organic compound-based circuit component that is only a few nanometers (billionths of a meter) in dimension. Their work may help scientists understand how the structure of these components, known as "molecular electronic junctions," relates to their performance and function. Moreover, in the longer term, this work may help incorporate these and other molecular-scale devices into a new generation of electronics-based technologies.

A NEW FRONTIER

"Molecular electronics is a very exciting developing field, since these extremely small circuits, based on organic molecules rather than metal, have a potentially greater circuit density than conventional silicon-based technology. This means that more circuits could fit on one circuit board, leading to electronic devices that are much smaller than those currently produced," said one of the study's lead scientists, Brookhaven physicist Julian Baumert. "We're interested in the structure of the junction — how the molecules are oriented and packed together — because it is linked to the function and performance of the circuit."

In conventional circuits, junctions are commonly made of two different types of silicon that, when layered together, allow electric current to flow in one direction only. Here, the junction under study consists of two very thin layers of two different organic compounds — "alkyl-thiol" and "alkyl-silane." They are sandwiched on one side by a layer of solid silicon and on the other side by a layer of liquid mercury, which serve as electrodes. Alkyl-thiol and alkyl-silane molecules have simple structures (making them fairly easy to study) and the potential to be good insulating materials (a desirable property in many junctions).

The scientists created the junctions by filling a small container with a drop of liquid mercury and depositing a very small amount of alkyl-thiol onto the mercury surface. They then topped the alkyl-thiol layer with an alkyl-silane-coated silicon wafer. This method yielded a junction with just a five-nanometer-thick gap between the two electrodes.

"This technique is not limited to simple alkane molecules," said Columbia University graduate student Michael Lefenfeld, the study's second lead scientist. "Many other types of organic molecules could be used, such as semi-conducting and conducting molecules. These materials also have a structure and packing density that plays a large role in their electrical performance."

ILLUMINATING THE DETAILS

The research group studied the junction at Brookhaven's National Synchrotron Light Source, a facility that produces x-ray, ultraviolet, and infrared light for research. They aimed high-energy x-rays — energetic enough to penetrate the silicon wafer — at the junction from several incident angles and measured how the rays scattered off the organic molecules. Next, they attached electric contacts to the silicon and mercury electrodes and, for several different applied voltages, measured both the reflected x-ray signal and the electric current through the junction.

By analyzing the x-ray scattering data, the researchers discovered that the organic molecules are densely packed together, with most of the molecules positioned vertically. Further, the combination of the electric-current and x-ray measurements revealed that the current does not deform that structure, even when the applied voltage was very high. This implies that the molecular structure is quite stable.

"These are important details to know in order to fully understand the electronic properties of molecular-scale junctions," said Brookhaven Physicist Benjamin Ocko, one of the study's senior researchers. "These investigation methods should be able to provide us with a better understanding of many other molecular junctions."

This research was supported by the Office of Basic Energy Sciences within the U.S. Department of Energy's Office of Science, the National Science Foundation, the New York State Office of Science, Technology, and Academic Research, and the German-Israeli Foundation.

EDITOR'S NOTE: In June 2006, Brookhaven scientist Julian Baumert died of melanoma at the age of 31.

SYNERGISTIC USER COMMUNITIES MEET AT BROOKHAVEN

Sam Aronson

Pat Dehmer

Steve Dierker

As science moves into the realm of the ultra-small, a rosy future was forecast for Brookhaven's user facilities at the first-ever joint meeting, this spring, of the user communities for the National Synchrotron Light Source (NSLS) and the Center for Functional Nanomaterials (CFN).

Officials from the Laboratory, the Department of Energy's (DOE) Office of Science and the New York State congressional delegation painted an optimistic picture for an audience of several hundred current and prospective users of Brookhaven's cutting-edge science facilities — those that are currently in operation, planned and under construction or eagerly anticipated.

The Laboratory's interim director, Sam Aronson, outlined Brookhaven's "extremely strong science agenda" in terms of ongoing research and new facilities that will maintain Brookhaven as a leader in world science. He said that the Laboratory's highest priority is the design and construction of the National Synchrotron Light Source II (NSLS-II), which along with the CFN will give Brookhaven a powerful combination of cutting-edge research tools. These new capabilities will enable exciting new studies to be undertaken at Brookhaven and will enhance many current projects, such as the molecular electronics work being done by Baumert, Lefenfeld and Ocko.

Last fall, DOE granted "Critical Decision Zero" (CD-0) status to NSLS-II, the planned world-leading successor to the NSLS. Later, Critical Decision One (CD-1) will approve a construction plan and a definite site decision will be made.

"The NSLS-II will allow our science to continue to flourish and expand, and keep the United States in the forefront of light source science," Aronson said. Citing Brookhaven's expected contribution to energy research, Aronson said that work here "will be vital to that effort for the U.S. economy and energy security." He said that the DOE's forward-looking investments in user facilities "will eventually change the face of the Laboratory. The completion and operation of the CFN and NSLS-II will profoundly change the balance of research here."

Focusing on the rollout of the American Competitiveness Initiative (ACI) which she called "great news for the physical sciences," Pat Dehmer, director of DOE's Office of Basic Energy Sciences, explained that the ACI would double funding for DOE's Office of Science over the next 10 years. One of the ACI's focus areas is the tools of science, described as "unique, expensive, large-scale tools beyond the means of a single organization."

Projected funding for the Office of Basic Energy Sciences has increased by 25 percent, in large part because the office's work "aligns almost 100 percent with the ACI goals."

Steve Dierker, who is leading Brookhaven's effort to bring the NSLS-II facility here, noted that "the CFN will be producing materials that will be crying out to be characterized." He said that development of nanoscale materials will be critical for the development of future energy technologies.

"NSLS-II will be brighter than any existing light source. None of today's light sources was designed to probe materials with one nanometer spatial resolution and 0.1 meV energy resolution," he said. "The changes that NSLS-II brings will be transformative."

Dierker briefly described plans for the Joint Photon Sciences Institute (JPSI), intended to foster development of new techniques and capabilities.

"JPSI will serve as an intellectual center for development and application of the photon sciences and as a gateway for NSLS-II users," he said.

"The NSLS-II will be essential for energy security, and important for U.S. industry, " he concluded. "It will enable 'grand challenge' science in many diverse fields."

The Challenge of Keeping Up With the Data

Year-round, RHIC/ATLAS Computing Facility staff are working 24 hours a day, seven days a week, providing support to users.

by Karen McNulty Walsh

The immense amount of data emerging from the Relativistic Heavy Ion Collider (RHIC) gives the staff at the RHIC/ATLAS Computing Facility (RCF/ACF) plenty of work to do. In five years of running, the four RHIC experiments have taken digitized "snapshots" of billions of particle interactions – data-dense "pictures" that may reveal details about the early structure of the universe and the fundamental properties of matter.

During RHIC's 2005 run, for example, the experiments collected a total of 675 terabytes of data — enough to fill roughly one million compact discs. As the ions were colliding, the RCF received data from the experiments at rates in excess of 200 megabytes (MB) per second — equivalent to transferring the contents of a CD in a mere three seconds. All those terabytes were stored on robotically manipulated tapes for later analysis.

The 2006 RHIC run is now complete. The data is being stored in a new robotic tape storage system which has the theoretical capability of recording data at rates in excess of 1000 MB per second and has a data storage capacity of over 2.4 petabytes.

Now, the 3,300 processors making up the RCF's RHIC Linux Farm are crunching the numbers. Year-round, the RCF/ACF staff are working 24 hours a day, seven days a week, providing both hardware and software support for users.

"When needed, they repair, replace, or upgrade facility hardware and deploy and upgrade system software," said Bruce Gibbard of the Physics Department, who heads the facility. "The staff also uses sophisticated software to monitor computer system usage, performance, and status, and make sure data back-up, e-mail, and web services are working smoothly."

To speed up the RHIC data analysis, RCF processors will at times be augmented by computing resources from collaborating sites around the world using the latest rendition of large-scale computer networking, known as the Grid. The Grid keeps track of all the networked computers, and distributes jobs among them.

During the 2005 RHIC run, the PHENIX experiment used Grid technology to transfer nearly 270 terabytes of data to the RIKEN Institute in Japan using Grid-aware software tools at an average rate of 100 MB per second. This is equivalent to transferring the entire contents of a CD halfway around the world every seven seconds. During the 2006 RHIC run, the bulk of the PHENIX share (250 terabytes) of the new data recorded has again been transferred via network to RIKEN.

This year's transfer is making use of a newly upgraded Wide Area Network connection which increases the possible transfer rate in and out of Brookhaven by a factor of eight from approximately 300 MB per second to 2.4 gigabytes (GB) per second. This very high data transfer capability is required to avoid interference between RHIC data transfers and data transfers being done for another large-scale high-energy physics experiment: ATLAS.

SHOULDERING ATLAS DATA

ATLAS is one of the detectors located at the Large Hadron Collider (LHC), a new accelerator complex now under construction at the European Center for Nuclear Research (CERN). It was designed to analyze the thousands of particles streaming from proton-proton or heavy-ion collisions, some with as much as 30 times the energy as the collisions occurring at RHIC. ATLAS is being built by a large international collaboration and is due to come online in 2007.

"The computing needs of ATLAS will be enormous by today's standards," Gibbard

RBRC ADDS TO RHIC SUPERCOMPUTING TOOLS

Information being generated by the RHIC detectors demands a variety of computing facilities to process it all. The RIKEN BNL Research Center (RBRC) is another important piece of the RHIC supercomputing effort.

Dedicated to the study of strong interactions in physics through the nurturing of a new generation of young physicists, the RBRC was established in April 1997 at Brookhaven and funded by the Rikagaku Kenkyusho, or RIKEN, of Japan. A multidisciplinary lab like Brookhaven, RIKEN is located north of Tokyo and is supported by the Japanese Science & Technology Agency.

Hosting close to 30 scientists each year, including postdoctoral and five-year fellows and visiting scientists, the RBRC also houses state-of-the-art computers to aid their calculations. Its research focus began with theoretical physics but has expanded to include experimental studies.

RHIC's main purpose is to collide atomic nuclei such as gold at speeds approaching the speed of light in an attempt to produce a hot, dense state of matter that has not existed since shortly after the Big Bang. This so-called quark-gluon plasma is expected to be a "soup" of quarks and gluons set free from the protons and neutrons in the colliding nuclei. But RHIC took on an additional, complementary mission in 1995, when RIKEN agreed to contribute $20 million to equip RHIC for the study of the world's highest-energy spin-polarized protons. These experiments will help scientists understand the "spin" structure of protons.

"With RHIC and the RIKEN BNL Research Center both in our stable of world-class research facilities, Brookhaven has strengthened its position as a leading center of both experimental and theoretical physics, and will continue to foster the interplay between the two," said Nick Samios, director of the RBRC.

The recently dedicated $5 million RBRC supercomputer known as QCDOC, for quantum chromodynamics on a chip, has 10 teraflops of peak computing power and is capable of performing 10 trillion arithmetic calculations per second. This speed is necessary to perform the complex calculations of the theory that describes the interactions of quarks and gluons and the force that holds atomic nuclei together. Taking up only 100 square feet of floor space, the supercomputer, which took three years to design and build, is used for physics research for 90 percent of its operating time.

Said Larry McLerran who heads the RBRC theory group, "These are very exciting times for theoretical physics. The Brookhaven and RBRC groups are leading the efforts to understand the many new developments arising from both the RHIC accelerator and the new supercomputers."

The people and the machines they run will delve into the mysteries of matter.

said. ATLAS is expected to collect five to eight petabytes of data per year — the equivalent of 7.5 million CDs of data.

"Individual scientific laboratories do not have the human or computing resources required by this demand," Gibbard said. "That's why the international physics computing community worked together to develop the new computing tools of the Grid, as well as a highly distributed, Grid-based data-analysis infrastructure."

Hundreds of thousands of computers distributed worldwide with hundreds of petabytes of tape and disk-storage capacity and state-of-the-art networking will be linked to meet the demand. Resources currently available to ATLAS at Brookhaven include 200 terabytes of disk storage, 700 Linux Farm processors, and a second new 2.4 petabyte robotic tape storage system dedicated to ATLAS.

Besides providing a large portion of the overall computing resources for U.S. collaborators in ATLAS, Brookhaven is also the central hub for storing and distributing ATLAS experimental data among U.S. collaborators. A series of exercises to establish the capability of filling this data handling role have been ongoing in preparation for the start up of ATLAS. In the most recent of this series of exercises, referred to as Global Service Challenge 4, data was transferred from CERN in Switzerland to the ACF site at Brookhaven at rates as high as 300 MB per second, with an average over the two-week period of 200 MB/sec. The fact that this exercise was going on at the same time that PHENIX data was being transferred to Japan underscores the importance of the new very high Wide Area Network transfer capacity.

"The ACF staff will play an important role in developing the next generation ATLAS Grid production tools. They'll also operate a support center to assist U.S. collaborators in using Grid-based resources," Gibbard said.

Together, the people and the machines they run will delve into the mysteries of matter, perhaps uncovering that needle in a petabyte that offers new insight on the world around us.

MEET JANE LIU AND IRIS WU

Zhenping (Jane) Liu and Yingzi (Iris) Wu

Engineers Zhenping (Jane) Liu and Yingzi (Iris) Wu are helping to solve the data storage challenges at the RHIC/ATLAS Computing Facility. Together, they have built a large-scale grid-enabled storage element in the production system at Brookhaven. This system is designed to meet the requirements of ATLAS experiments to store and access very large amounts of data for local and Grid ATLAS users. The very large disk cache system known as dCache includes about 350 servers and 150 Terabytes of disk space.

"We've brought a level of practical reliability and functionality to the project, which is a real challenge" Liu said. "The system has been proved a great success during a series of Global Service Challenge activities. The system is expected to be expanded to petabyte scale, about 10 to 20 times its current size over the next two years."

Liu came to Brookhaven in 2004 from Virginia Tech, where she received her master's degree and is a Ph.D candidate in computer engineering. She received B.S. and M.S. degrees in electrical and computer engineering from the University of Science and Technology of China.

Wu came to Brookhaven from the University of Missouri where she is pursuing a master's in health care informatics. She received B.S. and M.S. degrees in electrical engineering from Central South University of Technology, China.

Liu and Wu both work on supporting the massive amounts of data collected by RHIC. They occasionally discuss other topics of mutual concern such as raising bilingual children and providing them with healthy meals when they ask for fast food. Liu's first daughter is due this summer. Wu has a 5-year-old son and a two-year-old daughter. "I want my children to keep their Chinese culture," Wu said. "The most challenging thing is language. We speak Chinese at home, but I worry that it will be hard for them at school."

When she has time, Liu loves to travel and enjoys both Chinese and American music. Wu has participated in Yamaha Music classes with her children, and likes to take them to the beach to build sand castles.

Learning to read the book of life

Genome signature tagging, a new method developed at Brookhaven National Laboratory, has enormous potential for helping scientists understand the language of life.

by Karen McNulty Walsh

Though scientists have decoded almost the entire human genome — not to mention the genomes of myriad other species — there's a long way to go to make sense of all the data. Which genes, for example, make brain cells different from blood cells? Are there quick genetic tests that can readily distinguish relatively harmless bacteria from close relatives that could be used as terror weapons? How can what we know about genes help us understand what goes awry in conditions like cancer?

A new technique developed and patented at Brookhaven National Laboratory with funding from the Office of Biological and Environmental Research within the U.S. Department of Energy's Office of Science holds enormous promise for answering such questions. Called "genome signature tagging," the technique relies on the tools of molecular biology — gene chopping and splicing — to break the problem of identifying genes into manageable pieces, and powerful computer algorithms to speed comparisons.

"We are just beginning to decipher the meaning of the series of

The tools of molecular biology have helped scientists translate the language of life encoded in our DNA.

nucleotide bases that make up the source code for running the machinery of cells," says Brookhaven biologist John Dunn. "It's as if we have in our hands a giant book of life, but we are barely beginning to learn how to read it. Our technique gives us a new way to index the code."

Of course, scientists have known since the mid 1950s that sequences of the nucleotide bases adenine, thymine, guanine, and cytosine (known by the code letters A, T, G, and C) direct living things to make proteins. In the 1960s, they worked out the specific sets of three sequential letters that code for each amino acid — the protein "building blocks" used by the cells' construction machinery.

But finding quick ways to sequence the code and tell which genes are at work within different types of cells, how turning genes on or off can trigger cancer, or where the differences are between closely related species has been a big challenge.

BREAKING DOWN THE PROBLEM

The problem has been one of sheer magnitude: The human genome, for example, consists of some three billion nucleotides and many tens of thousands of genes. Sequencing entire genomes to find the subtle differences between, say, someone with cancer and someone without, while highly specific and informative, would be extremely labor-intensive and costly.

Even using genome sequencing to identify bacterial species, which have much smaller genomes, is a daunting task when you consider that thousands of species reside in a mere teaspoonful of soil.

So scientists have been searching for ways to identify key segments of genetic code that are short enough to sequence rapidly while yielding enough information about their research goals.

Genome signature tagging is one such method. Using "restriction" enzymes that recognize specific sequences in the genetic code, the scientists chop the genome into smaller segments that can be separated and used to differentiate species or traced back to the entire genome to identify important genes.

The segments, called "tags," contain roughly 20 nucleotide base pairs. "Because these tags are so short, we 'glue' 10 to 30 of them together to sequence all at one time, making this a highly efficient, cost-effective technique," says Daniel (Niels) van der Lelie, another Brookhaven biologist who is using the technique.

FINDING THE ON/OFF SWITCHES

In one recent example, John Dunn's group used genome signature tagging to rapidly identify more than 6,000 sites where a particular regulatory protein binds to human DNA.

They first chemically cross-linked the protein and DNA in living cells. Then they added antibodies specific for the regulatory protein to identify the pieces of DNA that had the protein attached. Then they washed away all the segments without the protein bound, and chopped the pieces of DNA with the protein into smaller tags they could sequence. Because they knew these tag segments were within a certain distance of where the regulatory proteins attached, they were able trace the sequenced tags back to the original genome to identify the regulatory proteins' binding sites.

Since the act of binding is thought to be a trigger for turning nearby genes on or off, "identifying the places where these regulators act — where these on/off switches are — should help us determine which genes are at work in different types of cells under different conditions," Dunn says. That one test study identified several genes that may play an important role in cancer as well as the gene responsible for Huntington's disease in mice, which is important for making advances in understanding Huntington's disease in humans.

"One test study identified several genes that may play an important role in cancer."

THE EMERGENCE OF BIOINFORMATICS

There was a time when biology happened mostly in dissection labs, test tubes, and under microscopes. But the discovery of DNA and the ability to sequence genomes changed all that. Biology evolved into molecular biology — the push to understand biological process at the level of chemistry encoded by the nucleotide bases of DNA.

Though biologists quickly developed methods to tag the four bases (A, T, G, and C), "manually" reading hundreds of sequences — each nearly a thousand base-pairs long — soon became inefficient, or impossible. The biologists needed help sifting through the volume of data.

Fortunately, Brookhaven Lab's resident physicists have plenty of experience dealing with enormous data sets. "In physics experiments, computer programs analyze millions of particle collision events, for example, to find those events that are interesting or significant," says Brookhaven's Sean McCorkle. McCorkle, now a bioinformaticist, moved to the Biology Department from Physics, where he had designed data-acquisition systems, when the need for computer-programming expertise in life sciences became apparent.

Bioinformaticists like McCorkle handle the nuts and bolts of data — maintaining databases and writing the software to "mine" that data for useful information. The biological information encoded in DNA is a natural for this kind of analysis, McCorkle says, because "DNA is an informational molecule, the computer program of the cell."

McCorkle also runs *"in silico"* experiments, or computer simulations. "Before we could do any of these gene-tagging experiments in reality, we ran simulations to prove that they would work," McCorkle says.

Data mining can also be applied to proteins, the molecules that carry out the work of cells. McCorkle recently collaborated with Brookhaven biochemist John Shanklin on a program designed to identify the parts of proteins most likely to control their functions. The program presents the data in a visually intuitive way.

"With more and more protein-sequence data available, computers become an important tool for sorting the informational 'wheat' from the 'chaff,'" Shanklin says.

Without programs like the ones McCorkle designs, efforts to identify and use relevant biological information would be enormously time-consuming — and expensive.

Brookhaven Laboratory bioinformaticist Sean McCorkle.

SORTING OUT MICROBES

In another example, van der Lelie's group used genome signature tagging to quickly catalog the many species of microorganisms living in an unknown "microbial community."

In this case the tags contained 16 nucleotide base pairs somewhat "upstream" from the beginning of a gene that is highly conserved among bacterial species. By sequencing these tags and comparing the sequenced code with databases of known bacterial genomes, the Brookhaven team determined that this specific 16-letter region contains enough unique genetic information to successfully identify all community members down to the genus level, and most to the species level as well.

This application has many potential uses — from assessing the microbes present in environmental samples and identifying species useful for cleaning up contamination, to identifying pathogens and distinguishing harmless bacteria from potential bioterror weapons.

Genome signature tagging "has no limits," says Brookhaven Biology Department Chair Carl Anderson. He plans to use the technique to study genes associated with cancer, while others have approached Dunn's group with ideas for using GST in studies of addiction, obesity, and diabetes.

As Dunn says, "it promises to be a really useful tool."

MEET JOHN DUNN

"I've had the good fortune of being in the right place at the right time throughout the 'golden age of molecular biology,'" says Brookhaven biologist John Dunn.

It may not sound that way from his humble beginnings washing urine bottles at a hospital lab to earn a few bucks while in high school. But it was there that Dunn first discovered the wonders of microbiology. After unknowingly washing the urine of a patient whose kidneys were infected with tuberculosis down the drain — setting off a mild panic about a potential public health crisis — Dunn learned a lot about the bacterium responsible for the disease.

His interest sparked, he got a job in a microbiology lab and worked his way through West Chester State, which was then a small teachers college in Pennsylvania. His initial plan was to become a biology teacher, but at the suggestion of an influential professor, he changed his major to focus on going to graduate school to study microbiology. "My parents were upset," he says. "They saw teaching as a more stable career."

From his graduate studies at Rutgers University to his postdoc days at the University of Heidelberg, and then at Brookhaven since 1972, Dunn has gone on to make a string of important contributions to the emerging field of molecular biology — enough to make his mentors, his employers, and his parents proud.

"When I was in grad school, no one knew how to sequence nucleic acids, the building blocks of DNA," Dunn recalls. His direct contributions to the developing molecular toolbox, many in collaboration with biologists at Brookhaven and elsewhere, include:

- Discovering how certain proteins tell transcription enzymes which genes to transcribe from DNA to make RNA, the chemical messenger needed to translate DNA into proteins
- Setting up the first RNA sequencing lab at Brookhaven
- Sequencing the DNA of the T7 bacteriophage, a virus that infects bacteria, with fellow Brookhaven biologist Bill Studier — which led to the discovery of many new T7 genes
- Helping develop T7 into a system for the rapid production of proteins and RNAs
- Synthesizing proteins that serve as antigens on the bacterium that causes Lyme disease, analyzing their structures, and contributing to the development of a new vaccine
- Developing a way to rapidly assess where regulatory proteins bind to DNA in living cells to affect gene expression
- Investigating the role of particular genes and chemical alterations of DNA on cancer

"The real joy at Brookhaven is the ability to do, do, do and go from one thing to another," Dunn says. When asked what he does when not at the lab, Dunn smiles and says, "I'm usually here."

Married to his college sweetheart and father to two daughters — one a biologist and the other an artist — he looks forward to spending time with his one granddaughter. He also admits to enjoying a good spy novel or medical thriller, and may even write one some day — based on his early-career tuberculosis scare.

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