Profiles in Environmental Research
2009

The Environmental Institute
University of Massachusetts Amherst

Facilitating and Supporting Environmental Research and Education

The Environmental Institute (TEI), an office of the Vice Chancellor for Research and Engagement, connects, facilitates and supports interdisciplinary environmental research and education across campus and and serves as a gateway for public, non-profit, and private groups to tap into the University's environmental expertise. The Institute supports these connections through a number of initiatives including working groups, the TEI Environmental Lecture Series, seminar series, conferences and workshops, and special projects. The Institute serves as an environmental information portal for the campus and maintains a number of environmental databases on the TEI website. TEI partners with public agencies, non-profit groups, and industry. Collaborators include the Environmental Protection Agency, Fish and Wildlife Service, Geological Survey, Department of Energy, Massachusetts Department of Environmental Protection, Massachusetts cities and towns, and volunteer water monitoring groups. TEI also houses the Massachusetts Water Resources Research Center, the Environmental Analysis Laboratory, and the Earth Sciences Information Office.

The **Water Resources Research Center** (WRRC) supports research, education, and outreach on water resources issues of state, regional, and national importance as one of 54 Water Centers nationwide belonging to the National Institutes for Water Resources.

The **Environmental Analysis Laboratory** (EAL), in partnership with the Chemistry Department, provides a range of inorganic analyses of water as well as sediments, tissue samples, and microbes for environmental research and monitoring activities.

The **Earth Sciences Information Office** (ESIO) distributes maps and other cartographic information, including aerial photographs and space images from federal, state, and local governmental agencies, and private sources.

Profiles inEnvironmental Research 2009 showcases a small selection of the wide-ranging environmental research underway at the University of Massachusetts Amherst. Research projects address climate change impacts, water resources protection, energy needs, and human and environmental health impacts. Research stories feature projects in nine academic departments, from groundbreaking research in the Amazon to perfecting biofuel conversion and other energy alternatives that will impact the global green economy. For more information about environmental research at UMass Amherst, please visit the TEI website or call at 545-2842.

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- Center for Fueling the Future
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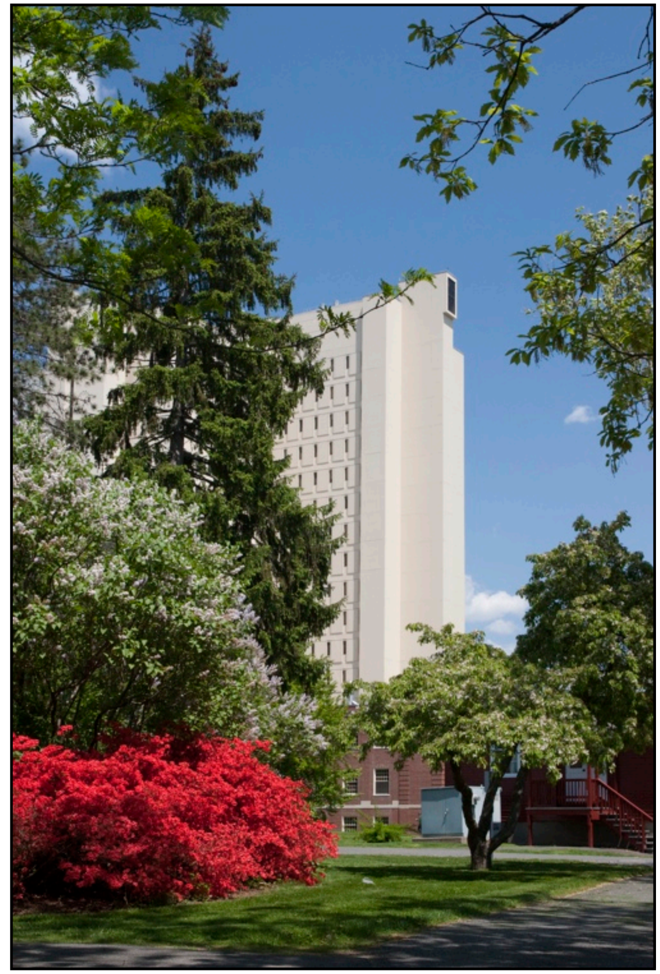

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Writers: **Stephanie McPherson** ('10) and **Ted Rogers** ('10)
Editor: **Sharon Tracey,** TEI Associate Director
Design: **Richard Newton**, TEI IT Manager and **Stephanie McPherson** ('10)

September 2009

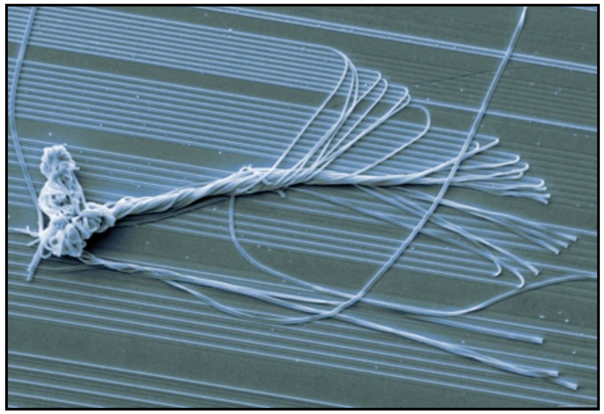
Nanostructuring Organic Photovoltaics

Dhandapani Venkataraman, Chemistry

In the not-so-distant future, it could be possible to harvest electricity not from power plants, but from house paint or walking outside in a winter jacket. Associate Professor of Chemistry Dhandapani Venkataraman is working to make it happen through his research on organic solar cells. The flexible nature of these cells could change the way we use electricity. "There are people who dream about making roof shingles based on organic photovoltaics," he says. "I could make a bag which is covered with [them] and you can charge your iPod. I could make a window screen or window curtain that has organic solar cells on one side."

To make this a reality, Venkataraman draws from his expertise in the organization of molecules. Organic photovoltaics are comprised of two main components, both organic semiconductors – one material to stimulate electrons to a higher energy level and one to transport them in their excited state. If the electron is properly transported through the cell while in a higher energy state, that excess energy is released as power. The trick is keeping the electron excited, as it will quickly settle to its original state unless something prevents it from doing so. Organic cells already in existence use conjugated polymers like polythiphene to absorb sunlight and fullerene-based molecules to grab the electron from the polymer and keep it excited. The fullerene molecule then needs to pass the electron to other fullerene molecules. The electron travels through the chain and its energy is eventually released as electricity. The fullerene and polythiophene molecules have to be no more than 10 nanometers apart or the electron will be unable to make the jump. "Here's the funny part of the problem," Venkataraman says. "Either the semiconductors don't want to be at 10 nanometers or they want to mix. They don't want to actually sit separated. So what we're working on now is how [to] trick the molecules to get the structures you need for organic photovoltaic cells that are stable."

To achieve an acceptable distance apart a film containing the polymer and fullerene is heated slowly, which gradually generates the desired distance. This method is not sufficiently stable, however, since heating the structure too



Nano-scaffolding produced for creating efficient hybrid solar cells

much will destroy the solar cell. Venkataraman is working to structure close, continuous paths through which electrons can travel. Non-modified molecules of fullerene and polythipene tend to mix. Venkataraman is engineering molecules to assemble themselves in separate stacks set appropriate distances from each other. To prevent them from randomly assorting, he synthesizes tails onto the different molecules. One set receives a tail made from a hydrocarbon, similar to oil. The other tail consists of anything that repels oil, namely anything water based or fluorocarbons, similar to Teflon.

After the tails are attached to the molecules, Venkataraman probes the stacks with one of a suite of techniques to make sure the tails are adequate to prevent mixing. The typical method is X-ray crystallography, though electron microscopy, atomic force microscopy and UV visible spectroscopy are also used. After he determines whether or not the tails work, he tests them in a solar cell to see if there is increased efficiency. Organic solar cells produced in laboratories currently run at around four percent efficiency. To make them cost effective, the cells must reach at least 10 percent efficiency.

Organic solar cells have far reaching implications. The materials with which they are made are flexible enough to allow for a myriad of applications – from window panes to backpacks to military uniforms. But organic solar cells have a long way to go before they are commercially viable. Aside from the efficiency problem, the lifetime of the organic compounds is fairly short due to extended sun exposure. "When you stand in the sun, you get tanned. When they stand in the sun, they degrade," Venkataraman says. Erin Baker, Associate Professor of Mechanical and Industrial Engineering, has calculated the cost effectiveness of organic photovoltaics and the outcome is promising, if the self-assembly and longevity problems can be solved.

Venkataraman is also working on the development of hybrid solar cells, combining organic and inorganic molecules in one cell. These types of cells could be used in places where organic cells would degrade too quickly. The polymer molecules in these structures must also be only 10 nanometers apart but instead of trying to mix, they are like two magnets of the same poles. Venkataraman is pushing the limits of nanotechnology by structuring nano-scaffolding in attempts to force the stacks of molecules together, but has yet to push them within 10 nanometers of each other. The nano-wires that make up the scaffolding are made of an inorganic semiconductor, cadmium selenide.

In another project, Venkataraman is working with the Center for Fueling the Future on the production of proton transport membranes for hydrogen fuel cells. These cells strip hydrogen apart and send electrons and protons through membranes providing power. The only byproduct of hydrogen fuel cells is water, making it preferable to current transportation fuel emissions. The problem is protons move much slower than electrons, making the fuel cell's efficiency less than ideal. A special membrane is needed to enhance the proton's speed, allowing it to catch up with the electron. Currently, a material called Nafion is used. The Nafion membrane forms pores filled with water, which protons can speed through. Unfortunately, when the fuel cell heats up in a car, the water vaporizes and the Nafion membrane cracks. Venkataraman and the Fueling the Future team are trying to find a non-water based membrane to allow fast proton movement. They are also analyzing the controlling factor in proton movement to improve all aspects of transport. "Fundamentally, what is it that actually allows it to move from one to another?" Venkataraman asks. "Can you make a system where the proton can actually move from one end to another without any problem?" Now, they are testing the viability of imidazole and triazole, two nitrogen-based substances, to replace Nafion in hydrogen fuel cells. "It's been an exciting time in energy, looking at a very fundamental problem and its application," he says. These fundamental problems could prove integral to creating a clean energy future.

Phytoremediation of Toxic Pollutants

Om Parkash, Plant, Soil and Insect Sciences

Growing up on a farm in India, Om Parkash took note of a large plant never harvested for food and ignored by grazing animals and insects. Years later, as Assistant Professor of Plant, Soil and Insect Sciences, he is making use of a high biomass, fast growing sibling of that same plant through the process of phytoremdiation. Using *Crambe abyssinica*, commonly known as Abyssinian mustard or Abyssinian kale, Parkash is trying to rid the environment of toxins, particularly the toxic metalloid arsenic. “We’re building the pathway in non-food plants for arsenic uptake, detoxification and hyperaccumulation so we can harvest and recycle the arsenic,” Parkash says.

Arsenic poisoning is a problem found across the world, particularly across Southeast Asia. Toxic metals like arsenic are not biodegradable, so they can remain in the soil and water indefinitely, unless they are removed by human technologies. The dangers of arsenic contamination arise when food crops use the compromised soil to gather nutrients, sucking up the poisonous metal as well. When the food crop is harvested and eaten, the poison affects the human body. This problem is particularly prevalent in Southeast Asia where rice is a major crop which is known to accumulate higher levels of arsenic in seeds and straw. “It’s a catastrophe. The biggest environmental disaster of the century – that’s what the World Health Organization have dubbed this,” says Parkash. “It’s a mass poisoning.” Millions of arsenic poisoning cases are reported around the world, and exposures can eventually cause cancer, diabetes and other life-threatening health problems.

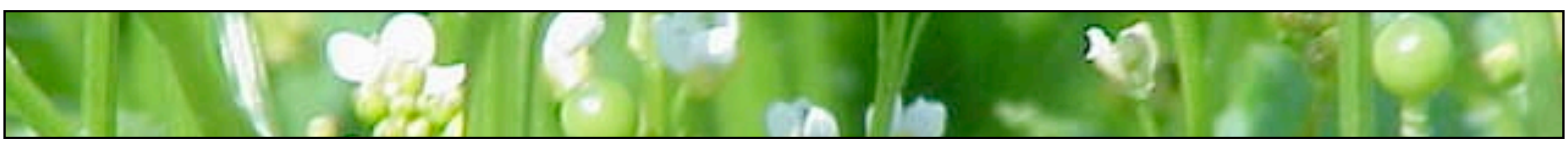
To address this growing global issue, scientists are using bioremediation, the process of using living material to absorb toxic metals. Parkash focuses on phytoremediation, where plants are sown on the affected soil to absorb toxins from the ground. When that biomass is harvested, the land is successfully cleared of contaminants. This cycle can be replicated as quickly as biomass can be regrown. The *Crambe* plant from Parkash’s childhood has all the criteria needed to be a successful phytoremediation crop. It is non-food crop and grows quickly – in only 45 days, it reaches maximum leafy biomass before flowering. In one year, multiple crops can be grown and harvested. It is also never used as food crop, so there is no danger of accidental consumption.

Crambe naturally has ideal phytoremediation properties, but Parkash also employs genetic engineering to create a plant that will soak up a maximum amount of toxins with minimum amount of damage to the plant. To do this, he is identifying and isolating certain genes in arsenic tolerant bacteria and yeast. He is also exploring the genome of the plant to determine which naturally occurring gene will provide arsenic tolerance. The expression of the gene depends on environmental conditions. Parkash is trying to activate arsenic tolerant genes in *Crambe*, which already has some biologically resistance. “All these plants have the same genes,” he says. “Some plants have more capacity to uptake; some plants have less capacity to uptake.”

After *Crambe* cleans the soil and is harvested, scientists are left with toxic biomass and few options. They could incinerate the leftover leafy matter and bury it in a landfill, which would simply relocate the arsenic problem. After incineration, they could also recycle and sell the metal to industries. The current green economy, however, has supplied Parkash with a new option – converting the biomass into biofuels. As long as the arsenic does not travel into the plants’ seeds, they could be converted into diesel fuel. Parkash is working on genetically engineering both clean and arsenic-exposed *Crambe* plants to be more resistant to environmental stresses like drought and high salinity so they can be grown on marginal lands. “We have isolated genes that can provide tolerance to multiple stresses,” he says. He is trying to determine which genes will produce the best results. Parkash, along with Professor Stephen Herbert and Randal Prostak, are working on a farm biofuel production grant funded by the Massachusetts Department of Agricultural Resources and Massachusetts Technology council to evaluate *Crambe* and switchgrass as bioenergy crops. The team is analyzing the growth performance of *Crambe* and switchgrass varieties on marginal and prime agricultural lands including the University of Massachusetts Amherst Agronomy Research farm in South Hadley and seven other farms throughout Western Massachusetts. Parkash also served as an advisor to the Hilltown Farmers Biodiesel Cooperative, a group of Western Massachusetts farmers who purchased a portable means of biodiesel production. They plan to use canola, sunflower and some *Crambe* to produce fuel for their tractors. This project is one of the first in-situ practices of biodiesel production in the northeastern United States.

In another project, Parkash is trying to engineer food-crops to avoid arsenic uptake – the opposite of phytoremediation. “We are engineering rice with genes that can resist arsenic,” he says. “That can provide tolerance to plants, so plants don’t suck up the toxins and we have safer foods.” He is examining genes from yeast, bacteria and plants and combining them under different systems, trying to determine which genes open pathways for arsenic uptake and how they can be blocked. Parkash is trying different combinations of genes and their promoters, which are biological remotes responsible for turning gene processes on and off, like a light switch. When using certain resistant genes from Arabidopsis, the first plant whose genome was sequenced, the rice accumulated two to three times less arsenic in the seeds and in the above ground biomass tissues.

Parkash is now trying to better understand the mechanisms of arsenic uptake to improve the blocking process. Recently two genes that cause the uptake and accumulation of silicon in rice are shown to co-transport arsenic. He and other scientists are concerned that while blocking some of arsenic’s pathways, the important element silicon is barred entry as well. Silicon is a major component of plant strength and disease resistance. “The plant’s health will be compromised,” Parkash says. “Plants will not be able to stand because silicon provides the mechanical strength, and those rice lines will be susceptible to disease and pests.” Parkash may have found a solution – he and his research team has identified and cloned a family of genes that may block the uptake of arsenic without preventing uptake of silicon.



‘Green’ Water Cleanup

David Reckhow, Civil and Environmental Engineering

David Reckhow, Professor of Civil and Environmental Engineering, works to ensure the safety of drinking water supplies across the country. “I’m involved with a lot of aspects of water treatment [...] the purification of what we call raw drinking waters,” Reckhow says. Water contamination comes in many forms and Reckhow’s laboratory work determines the most efficient ways to clean the compromised water.

Organic compounds such as polysaccharides and proteins are harmless products of terrestrial and aquatic plants. But when they interact with disinfecting agents, they are converted to compounds that have deleterious effects. These disinfection byproducts are associated with cancer, particularly of the bladder. Reckhow’s group examines exactly what these harmful compounds are and how to control them. They begin as nontoxic, normal organic materials released from both aquatic and terrestrial plants. As they flow downstream and into water treatment plants, they interact with bacteria and chlorine to create dangerous carcinogens. “We’re concerned about the nature of the organic material and how it changes from the well water or the lake in its pristine form,” says Reckhow. “[We want] to minimize the risk to people.”

To address the problem Reckhow first collects water samples from water treatment plants around the country and conducts laboratory analyses. With newly-developed analytical instruments such as liquid chromatrographs and mass spectrometers (LC/MS) he can identify the exact compounds present in the water. Next, he determines the optimal methods for removal and mitigation. Most treatment plants around the country use conventional removal methods. Some put coagulants in the water to form particles, which draw contaminants out. Some use media filtration – the process of running water over sand or activated carbon, which sifts out unwanted organics. Some treatment plants also continue to use chlorine disinfection. The town of Amherst is on the cutting edge of water purification treatment, using ozone as a chemical to partially oxidize the contaminant, making it easier to break down and dispose of through other methods. Reckhow is perfecting this method, using beneficial bacteria to rid the water of the oxidized organics leaving only carbon dioxide and water. “That’s the beauty of the synergy,” he says. “If you do that right, then it’s a great one two punch for contaminants.”

Reckhow’s research also focuses on another group of contaminants affecting water supplies - pharmaceuticals and personal care products, also known as PPCPs. Everyday products like pain medication, perfume and shampoo flow down the drain and, without proper filtration, enter the water system. This problem is particularly prevalent downstream from major cities, and in the Southwest, which is perpetually effected by water shortages. “They absolutely need to reuse the water that someone from an upstream community used already,” says Reckhow.

Through funding from the Water Research Foundation, Reckhow also is testing the effectiveness of 15 city treatment plants around the country. In his lab, PPCP contaminated water runs through pilot scale models of each plant. The water is measured before and after a run using a specialized LC/MS instrument dubbed “Betsy.” With this newly-developed hybrid instrument, his group is able to analyze PPCPs in smaller samples (20 mL) in a fraction of the time required by conventional methods. They compare the results pre- and post-filtration to determine just how much contaminant is removed. If the result is unsatisfactory, Reckhow tests various advanced methods until the outcome is desirable. After the tests are complete, the necessary adjustments to improve treatment are communicated to the water treatment practitioners.

Another project focuses on the Merrimack River, running from New Hampshire through Massachusetts. Towns along the river are concerned about wastewater flowing downstream. Reckhow is collaborating with faculty at the University of New Hampshire and the U.S. Geological Survey to understand the nature of the PPCPs present along the watershed. Once the state of the river is determined, they will begin to install a new pilot-scale system using riverbank filtration – a method successfully carried out in Europe. Instead of pumping the water directly out of the river, the water is pumped from a well approximately 100 feet away from the bank. “It sucks water down out of river through the ground and into the well so the water travels in the subsurface and, in the process, it gets purified by natural bacteria,” Reckhow says. “It’s extremely low tech, but really green.” The team could even apply ozone to the water before it travels through the ground, enhancing the biodegradation processes.

This method, while environmentally friendly due to the use of natural bacteria, requires more energy than pumping straight from the river. The water would need to be siphoned up a pipe resting far below the bank’s height. While digging a well also incurs costs, riverbank filtration may be more cost-effective than traditional methods. Some issues still need to be addressed, as the method has not been widely tested in the United States. “Engineers are inherently conservative,” Reckhow says. “You want to build something you know is going to work for a long time, and [with] these you can’t always be sure.” The only way to find out, he says, is to jump right in and try.

Reckhow and graduate research assistant Jing Lin look at the column effluent of an ozone-biofiltration pilot in a constant temperature room

Microbial Wonders

Klaus Nüsslein, Microbiology

Microscopic organisms make up more than half the biomass on Earth, and Klaus Nüsslein, Associate Professor of Microbiology, is investigating how they work. "They own this planet. There is more biomass in microbes than there is in plants," says Nüsslein. The hundreds of thousands of microbe species live and work together. It is near impossible to find one species living on its own. "They live together in the amount of a billion in [a gram of] soil. So how is that possible?" Nüsslein is focusing on three major areas of study to understand how microbes function in their various ecosystems, with emphasis on stressful environments.

The first area of research focus is the deep underground layers of organically rich sediments such as shale and coal, used for the production of energy. Currently, companies drill wells and extract the materials using less than environmentally ideal processes. Nüsslein is interested in using microbes to produce methane gas from the wells without removing sediment. Since food sources are scarce in this deep subsurface, microbes found here have been forced to evolve alternate methods of energy intake. They have developed a way of eating organic materials in the rock and, in the process, emitting methane gas. "Instead of surfacing this rock, you could surface the gas," Nüsslein says. "And this country sits on huge reserves of this kind of organic matter. Again, it's fossil fuel, but microbes would help transfer this unreachable fuel from this type of rock into a gas we can use."

The major question to be answered is how the microbes are able to live off these materials. To date, no one has figured out the exact process through which microbes metabolize the rock. "A microbe is tiny. It sits in front of these long chains of carbon. What scissors do they use to cut out a piece?" Nüsslein asks. He is trying to determine which microbes are doing the work, and exactly how the process occurs. He is examining the chain of reactions within the microbe communities to see the steps taken from coal to gas. He is also examining different sizes of coal, big chunks to pulverized bits, to determine whether or not surface area effects methane production. Nüsslein also is analyzing the presence of lipids in the rocks to see if microbes are living off the fatty molecules.

In another project co-funded by the National Science Foundation and the U.S. Department of Agriculture, Nüsslein is studying microbial diversity in the Amazon Rainforest to determine if it mirrors the biological diversity of rainforest plants and animals. Nüsslein and his collaborators at the University of Oregon, Michigan State University, University of Texas, and University of Sao Paulo are asking if, when a rainforest is cleared for farmland, the microbial diversity decreases. They also plan to monitor whether or not the diversity returns when the farmland is no longer in production and evolves into a secondary rainforest. "Does it ever come back to the same functions?" Nüsslein asks. "Will it be an active, healthy ecosystem? Will it be as strong as it was before, or will it never be the same?"

The team is taking soil samples from a farm in Rondônia, Brazil to determine what microbes reside in the soil samples. Because of the immense microbial diversity, identifying all species present would be difficult. Instead, they are analyzing 400,000 DNA samples at a time for identification purposes, focusing on two strands of microbes dominant in a range of soils whose functions are widely known. One microbe thrives in nutrient limiting conditions while the other has a large genome, which allows it to thrive in environments rich in nutrients. The team will analyze the genomes to see if any beneficial shifts occur from rainforest to farmland ecology. Nüsslein hopes the data gathered will indicate the stress levels occurring within the changing environments.

Another field of research interest is bioremediation, the practice of using biomass to reduce toxins in the environment. One project pairs Nüsslein with researchers in Civil and Environmental Engineering to develop a more efficient means of removing the toxin perchlorate from ground water. Perchlorate is a chemical used to deliver oxygen during reactions and can be found in explosives such as roadside flares, fireworks and military weapons. When consumed in drinking water, it can block the human thyroid gland and is particularly dangerous for pregnant women and newborns, where it can cause serious problems in neurodevelopment.

The Massachusetts Military Reservation in Bourne, Massachusetts is currently dealing with perchlorate contamination by pumping water from the ground and passing it through filters filled with resin. This method cleans effectively, but creates other problems. "You have this resin, this granulated chemical substrate that is loaded with perchlorate," Nüsslein says. "Where do you put it?" It is usually dumped in a landfill, but that does not really solve anything. It's also costly, in monetary and energy terms, requiring the removal of large tanks full of resin. Nüsslein knows certain microbes use perchlorate for energy, so he wants to employ the microscopic communities to remediate the problem. Nüsslein and his team have created a small, trash can-sized test filter in which microbes are placed along with elemental sulfur. As the water flows through the reactor, the microbes feed on the sulfur and use the perchlorate, effectively reducing the contaminants present in the water. "We tell the engineers what the microbes really like and the engineers build systems and test them out to optimize them, and together we develop this project," says Nüsslein. He says the project is already seeing success and could be commercially viable in several years.

Another bioremediation project has Nüsslein working on acid mine drainage at Davis Mine in Rowe, Massachusetts. After its collapse, groundwater in the mine began to leak as acid streams, but further downstream the acid was neutralized and the water became clear. With hydrologists, engineers and geologists, Nüsslein examined the water to determine the cause of the self-cleaning. Eventually, the team recognized a large group of microbes called sulfate-loving bacteria able to "breathe" the sulfate which, when combined with the water, was creating sulfuric acid. By removing the sulfate, the microbes removed the acid. The stream was also rich with heavy metals, with which the microbes formed a strong bond and fell to the bottom of the river as sediment. A member of Nüsslein's research group has been working on ways to support these acid-loving microbes. By understanding how the tiny organisms work, they hope to make the filter process more efficient and applicable to other similar sites around the world. "Engineers say we harness the power of the microbes," Nüsslein says. "We say we harness the knowledge of the microbes, because we try to understand what the microbes are doing. We don't just use them as tools."

Environmental Pollutants and Gene Expression

Kathleen Arcaro, Veterinary and Animal Sciences

While at first glance breast milk and fish may seem to have little in common, Associate Professor of Veterinary and Animal Sciences Kathleen Arcaro sees a relationship in these seemingly disparate areas of study. For the past six years, Arcaro and her team have been studying the effects of environmental pollutants on gene expression in fish and the health of cells present in human breast milk. “Fish serve as sentinels for water quality, while the breast milk and cells present in the milk provide biomarkers of human exposure and effect. In both cases we’re particularly interested in those pollutants that have hormonal activity,” Arcaro says.

Arcaro has several projects underway with the Japanese Medaka, a small freshwater fish. She has teamed with Professor of Civil and Environmental Engineering David Reckhow to monitor the effects of aquatic pollutants with a particular focus on personal care products and pharmaceuticals in water. Reckhow gathers samples from water treatment plants from across the nation and prepares extracts. Then Arcaro places the fish in fresh water with the extracts and studies the effectiveness of the water treatment processes. “Does their treatment remove any compounds that might have hormonal activity, like an estrogen that causes cells to grow and divide?” Arcaro asks. After the fish have been exposed to the water, Arcaro checks certain tissues, particularly the liver, for unusual changes. For example, if a male fish is exposed to estrogen he will start to produce the protein vitellogenin, which is the precursor to forming eggs.

Arcaro’s research is valuable for detecting classes of contaminants with a known effect, rather than for identifying the contaminant. “I couldn’t tell you what was in the water, but I could tell you that it had this effect,” she says. It is a good method of determining whether or not a full chemical screening is necessary. “If you screen very quickly the 20 water samples [with the fish] and they have no effect, then you don’t want to go on and do the more expensive chemical analysis. But if you screen one and it has an effect, then you better go find out what’s there,” she says.

In another related line of research involving fish studies, Arcaro and several of her colleagues at UMass Amherst,

Japanese Medaka, the fish examined by Arcaro to study the effect contaminants in the environment have on individual gene expression

Professors of Chemistry Vincent Rotello, Richard Vachet and Julian Tyson, and Professor of Sociology Douglas Anderton, are cooperating on a study in which Arcaro is exposing fish to monolayer-protected gold nanoparticles in an effort to understand the fate, transport, and bioavailability of nanoparticles in the environment. The widespread use of nanoparticles in all types of products assures that they will be released into the environment, yet little is known about how and where nanoparticles will accumulate and their effects on the health of wildlife and humans.

“The first step is just to see where these nanoparticles go,” says Arcaro. “They’re in the water, so they can potentially be taken up by the fish and spread through the body.” After 24 to 48 hours of exposure, the team harvests a variety of tissues including the gills, intestine, liver, gonads, brain and muscles. “It looks as if the nanoparticles accumulate first in the intestines and gills and then slowly pass to the gonads and liver,” Arcaro says. Then, through the same methods used for the analysis of vitellogenin, the team looks closely to see if nanoparticles affect the performance of the tissues.

Arcaro adds the human element to her research with her studies of breast milk. “Many of the pollutants in our environment, including pesticides, plasticizers, and flame retardants are lipophilic, ‘fat loving,’ and so accumulate in fatty tissue while other compounds from our diet or environment are present in the liquid portion of milk,” says Arcaro. Breast milk can give us information about a lifetime of exposure as well as what a woman ate for dinner. Arcaro and her colleagues have assessed the levels of various pollutants in milk from women living in western Massachusetts. The good news is that levels of some pollutants such as the banned polychlorinated biphenyls have greatly decreased in the last 20 years. Unfortunately the levels of other compounds, such the flame retardants and synthetic musks, are slowly increasing.

As we produce and release more and more chemicals into the environment we need to monitor breast milk, not because we know that the chemicals get into the breast milk and cause harm, but rather because we don’t know where the chemicals end up. Arcaro states, “I think it’s so important to study breast milk because infants are at the very top of the food chain.”

Arcaro has ongoing studies that will examine levels of pollutants in breast milk donated from women across the country. In addition, the cells from these breast milk samples will be utilized as a potential screen for changes in DNA indicative of breast cancer risk. Breast milk can be used as a tool to measure pollutant load, and may one day be used as a noninvasive method to detect breast cancer risk.

Environmental Justice and the Hungarian Roma

Krista Harper, Anthropology

Krista Harper, Assistant Professor of Anthropology, shuffles through large stiff printouts of photographs taken of Sajószentpèter, a predominantly Hungarian Roma village in northern Hungary. There is a lush river bank covered with plastic containers. A photo of a wood stove a Roma family uses for heat, despite its poor ventilation. A young boy stands in front of the family outhouse, used in lieu of an indoor bathroom. These photos were taken in a neighborhood that is a five minute walk from the mayor's office. "Somehow, the town has never managed to install sewerage or indoor water," says Harper.

As part of *Across the Bridge: Environment, Health and Individuality in a Hungarian Roma Community,* these photos portray what Harper has been studying for the past few years – environmental injustices in the Roma community. "Environmental inequalities are rampant," Harper says. "This research in many ways opens up a conversation."

It's a conversation that needs to take place. Since its transition in 1989 from state-socialism to a free market, Hungary has made advances in its environmental policies, but there have also been set-backs, Harper says. "One the one hand, there are new environmental laws and regulations that are up to the standards of the U.S. and many Western European countries," she says. "The state does have more of an ability to regulate firms as an outside watchdog."

The transformation from state-socialism also opened the door for a number of new environmental groups, from clean air to environmental education. However, the new free market economy has not been all positive. Rapid privatizing and clearing of land led to deforestation. The highly efficient recycling systems developed under state-socialism disappeared. Sajószentpèter was home to a glass packaging factory, which provided a number of jobs in addition to environmentally friendly food packaging. In the early '90s, after the fall of state-socialism, the factory was shut down. "One of the things that was incredibly hard for people in the neighborhood to see was pictures of their neighborhood drowning in plastic food packaging, right there in the shadow of what had been a factory that provided jobs and recyclable or reusable glass packaging," says Harper.

The people most affected by the factory's closing were the Hungarian Roma, the largest ethnic minority in the country. The Roma, formerly known as Gypsies, have been a settled part of Hungarian society for more than 100 years. During the 1970s and 80s, Roma had a high work force participation, but were the first to lose their jobs after 1989. "It was a truly humanitarian disaster," Harper says.

Now, Harper has noticed that predominantly Roma neighborhoods are more likely to be located near landfills, flood plains and other environmentally unsound places. "Hundreds of neighborhoods that are comprised mostly of Roma residents do not have access to public sewerage infrastructure or water lines, when non-Roma neighborhoods across town have access to this public infrastructure," she says. The Roma also have a ten year shorter life expectancy than other Hungarian citizens. While this is partly due to lifestyle and access to health care, biological factors and environmental health play a huge role.

The *Across the Bridge* project is working to catapult the Hungarian Roma's situation into the public eye. The photo project, worked on by Harper in conjunction with the Sajó River Association for Environment and Community Development, was presented to the United Nations Committee on Economic, Social and Cultural Rights in Geneva in 2007. The photos were displayed in October 2008 in the UMass Campus Center. "It's exciting because it's a visual way of putting environmental justice issues on the agenda," Harper says. The photos don't only focus on the environmental disasters of the area. "It's a region with many natural wonders to conserve such as the Sajó River and the Aggtelek cave systems," Harper says.

A Hungarian Roma boy stands in front of an outhouse, used in his village in lieu of a septic system

In a related effort, Harper's 2006 book, *Wild Capitalism: Environmental Activists and Post-Socialist Political Ecology in Hungary* portrays the transformation of the environmental movement from state-socialism to democracy. She discusses one of the largest displays of Hungarian environmental activism: the plan to dam the Danube River. After decades of negotiations between Czechoslovakia and Hungary to dam the Danube River, the Hungarian National Water Conservancy Office ordered a report on the project in 1983. When word was released that the findings were less than favorable, a group of activists convened to form the Danube Circle and supported years of underground protesting, eventually leading a march of an estimated 40,000 people on the Parliament Building.

After the fall of state-socialism, the Danube movement was left by the wayside. "The Danube movement, already diversified by that time into a variety of camps, splintered as activists turned their attentions to forming political parties and NGOs geared to the new political system," Harper writes in *Wild Capitalism*. "Its concern with democratic processes and public access to information, however, continues to characterize the contemporary Hungarian environmental movement." The final chapter of *Wild Capitalism* hints at Harper's later research, what now focuses on the Hungarian Roma. "A variety of different activists articulated suspicions that specific groups might suffer disproportionately from environmental pollution: low- and middle-income people living in cities, the rural poor, and Romani (Gypsy) communities in Hungary's post-socialist Rust Belt," she wrote. "Such suspicions rarely resulted, however, in organized political actions to address specific problems or to build new environmentalist constituencies and coalitions." It is Harper's hope that her work with Roma communities will open up a dialogue about these environmental injustices, and improve the quality of life for the people living in these all but forgotten neighborhoods. "I've wanted to see a society in change, and I've been able to do that," Harper says.

Watershed Management and Conservation

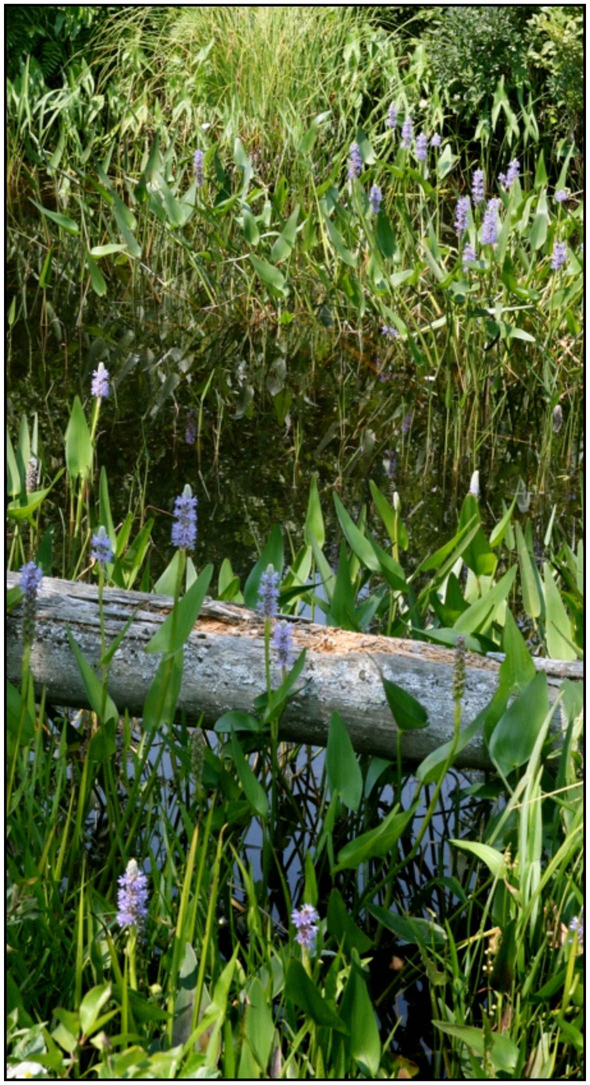
Timothy Randhir, Natural Resources Conservation

Timothy Randhir, Associate Professor in the Department of Natural Resources Conservation, works with the most important molecule known to earth- H2O. From the amoeba to ourselves, everything needs water, and watersheds are the source of it. Watersheds, as Randhir will tell you, are not only bodies of water, but also "any mass of land that drains into the point itself." The sheer scope of watersheds has contributed to Randhir's wide-ranging research interests, which include watershed science, climate change impacts, ecological economics, and water quality and policies.

Close to home, Randhir has made a study of the effects that urbanization is having on the watershed on Westfield River Watershed. Because watersheds play such an important role in terms of recreation, natural resources, and biodiversity, research needs to cross many disciplinary boundaries. In the Westfield River Watershed study, Randhir and Paul Ekness, also of the Department of Natural Resources Conservation, studied the detrimental impacts of urbanization on the flora and fauna of the watershed and developed policy suggestions on how to minimize these effects. The study estimates how far urban areas can go before breaching a threshold in animal populations. Another finding is that suburbs can cause more damage to wetlands than cities, as, "suburbs sprawl across watersheds; breaking up the land and creating a need for a more widely spread water supply system."

Due to the need to have both watersheds and humans exist together, Randhir says, "Conservation policy approaches need to be based on science, as well as people's needs, " and also be "flexible, in that they need to find a balance between a communities' objectives and the preservation of watersheds." He describes how a single objective would be a poor way to manage watersheds. "Regulations are needed, but there are other ways to reduce problems like sedimentation and pollution, such as incentives and education," he says. Randhir and UMass graduate student Olga Tsvetkova have designed a few tradeoffs that would allow continued development in the Blackstone River Watershed in Massachusetts and Rhode Island with minimal impact to the watershed itself. Suggestions include adding vegetation cover and storm water buffers to mitigate the damage. As with most of Randhir's recommendations, these are not meant to be enforced by law, but rather encouraged through the creation of incentives.

Watershed problems are not created equally. Basins down stream are far more vulnerable to pollution and sedimentation, and developing countries, especially in South America, Africa, and Southeast Asia suffer from serious water quality issues. In a project based in Honduras, Randhir has worked to improve the water quality by suggesting that a coffee plantation take specific actions to reduce runoff carried downstream. Randhir is also conducting research on the Rift Valleys in Africa, coined "hot spots of biodiversity. " Future international projects that Randhir has in mind include researching different locales in Africa, South America, and the Ganges river basin, to assess how climate change variations might affect local communities without much fresh drinking water.



One of the major water quality issues in the Third World is the prevalence of arsenic in drinking water, such as found in Bangladesh. Arsenic itself is a poisonous element that can cause various gastrointestinal problems, tremors, and death. It can be found in watersheds by pollution or naturally occurring deposits. "Many are exposed to a small amount of arsenic through the water supply on a daily basis," Randhir explains, "By the time that the symptoms of arsenic poisoning are seen, it is already too late." Due to the fact that the arsenic can occur naturally, there is no chance of curbing the problem at its source. "We cannot build a large-scale treatment plant to get rid of arsenic in a country as impoverished as Bangladesh," Randhir states. "To do something, we need solutions that would take place at the consumer level, and education is key."

Perhaps the most topical of Randhir's studies is research on how climate change, brought about by global warming, may affect the stability of watersheds. The research available shows a disturbing trend for the future if greenhouse gasses are not contained. In Randhir's study of the Connecticut River Watershed, likely outcomes include, "significant affects on stream flow, sediment loading, and nutrient loading in the watershed. Climate change also influences the timing and magnitude of runoff and sediment loads." If global warming continues, the Connecticut River Valley may face, "water shortages during peak season, disruption of fish migration, and increased pollution."

In the future, Randhir also will be investigating ways to mitigate water shortage stress in drought prone areas, develop watershed adaptations in the face of hurricanes in Florida, and closer to home, assess how climate change will likely impact effect the local maple syrup industry.

Detecting Contaminants in the Environment

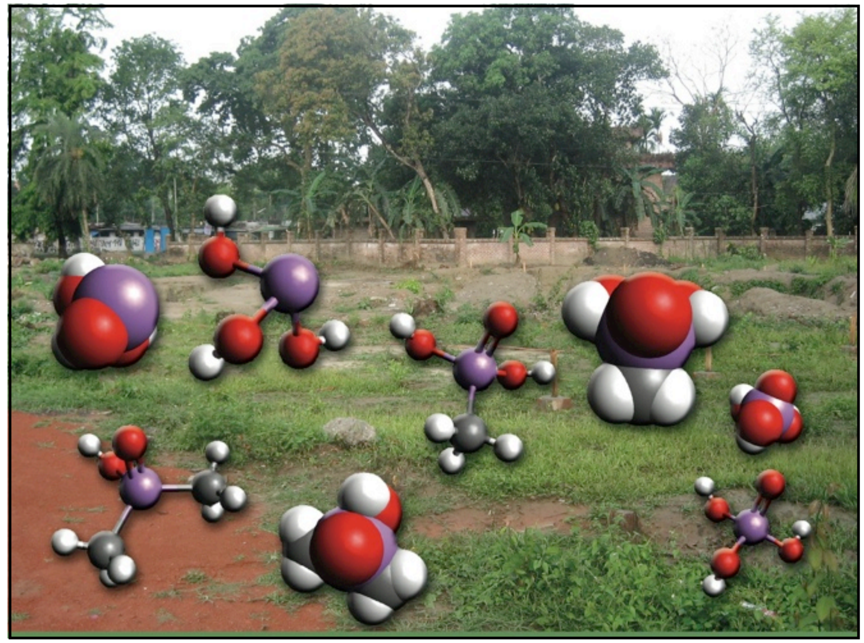
Julian Tyson, Chemistry

Bring a sample of soil from a playground or water from a well and Julian Tyson, Professor of Chemistry, can tell you if it is toxic. "In the broadest sense, a lot of what we do is answering 'is it safe,' and 'it' can be all kinds of things," Tyson says. "We're monitoring the safety of the immediate environment." Tyson is working to develop more efficient methods of detecting toxic elements in the environment. "You can go to a standard textbook and look up a method for measuring the total arsenic concentration in soil," Tyson says, but reading about a method detailing how to find the levels of specific compounds of arsenic is impossible. "That method doesn't exist," he says.

Right now, the majority of Tyson's work deals with the detection and removal of arsenic, mainly overseas. "We're interested in helping countries that have arsenic in the groundwater by coming up with some simple procedure that is portable," Tyson says. "Somebody can actually go to the village where all these wells are and, right at the side of the well, can measure the amount of arsenic that's in the water without having to take the sample back to the lab."

One option is a technique called "naked-eye" detection. As a result of a water test, a color is produced, which is then compared with a predetermined range of calibration colors to "see" the concentration of arsenic. To make the results even more reliable, Tyson and his colleagues are trying to develop a portable digital image analysis using scanners or digital cameras. The electronics could be carried to the side of the well then plugged into a car battery to analyze the colors.

Phytoremediation, the use of plants to absorb toxins, is another area of research. Tyson is working to develop new methods to use plants to absorb metal contaminants in the environment. "The beauty of phytoremediation is if you can concentrate the toxic chemical into the above ground or above surface biomass, then you can harvest it and allow it to regrow. That's, I think, the ideal," says Tyson. It hasn't happened yet, as most plants absorb and store toxins in their roots, but Tyson says it's a goal. The practical applications for this research are many and Tyson and his team have ties to the Bangladesh Agricultural University at Mymensingh to work on this area of research.



The cover of the April 2009 Journal of Analytical Atomic Spectroscopy, on which an illustration of Tyson's work was featured

In another area of research, Tyson is examining mercury levels in fish. "People who are concerned about the environmental impact of mercury want to know how much inorganic mercury there is which is not so toxic, and how much methylated mercury there is, which is very toxic," Tyson says. So far, he and his collaborators have published a number of papers detailing potential methods of separation and detection of these two types of mercury.

With funding from the Center for Hierarchical Manufacturing at UMass Amherst, Tyson is also working on the occurrence of manufactured nanoparticles in the environment, particularly gold, which is a byproduct of manufacturing processes, and titanium dioxide, which is found in sunscreen. For humans, these compounds are not so toxic, but "the implications for the health of organisms in the environment are perhaps much more severe," Tyson says. "So [there is the potential that] whole ecosystems could be disrupted." The gold nanoparticles could be used to transport drugs to tumors, so he is now working on a method to determine its toxicity to humans. Tyson is also currently working with the Water Resources Research Center's Environmental Analysis Laboratory at The Environmental Institute, providing an analysis of a number of materials for researchers, including water and soil.

With all of his work, Tyson makes a point to remember the students and involve them in invaluable research experiences. "We're interested in integrating our research with teaching and learning," he says. Each semester, Tyson teaches a course that puts first year students in a real-life research situation, assigning them the task of creating new techniques to detect arsenic in soil and water. "I construct the course as though it was an authentic research activity," Tyson says. Students try to take commonplace items that could be viewed as trash and create a water filter to remove deadly arsenic. "Almost every semester, we have students come up with something that works," says Tyson, citing successes such as moldy, used coffee grounds, steel wool and bacon fat. "The students have been very ingenious in terms of what they've tried," he says. Though they are successful in the laboratory, these ideas do not necessarily translate well into the real world. There are all sorts of logistics to contend with, including project scale-up.

Tyson also works with middle school students in Springfield to gather soil and water from schoolyards to test for arsenic that has come from pressure-treated wood. Tyson used grant funding to provide the classrooms with elementary testing kits for this purpose. Though the grant has run out, Tyson and his graduate students still run the program with middle school teachers out of Springfield and Easthampton, Massachusetts. "[I have] a not-so-hidden agenda to get kids interested in science," he says.

Watershed Hydrogeology

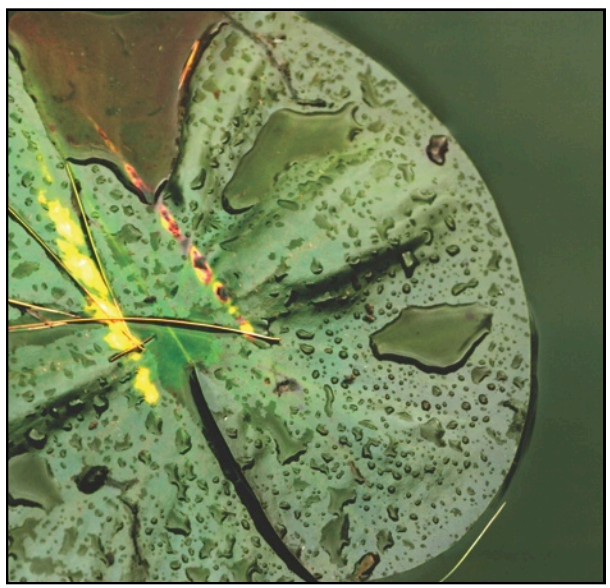
David Boutt, Geosciences

David Boutt, Assistant Professor of Hydrogeology in the Department of Geosciences knows a thing or two about subsurface liquids. "All my work involves fluids of some sort, whether in the shallow or the deeper crusts," says Boutt. His extensive research in subterranean fluids allows him to assess a situation and determine the best course of action, whatever the scenario. Boutt has been working on a number of water related projects, and is also studying the effects of carbon sequestration on the natural rocky make-up of aquifers.

One research project places Boutt on the Deerfield River Watershed. The Fife Brook hydroelectric dam is a potential cause for concern, as the timed release of water from the dam is altering natural patterns of stream water mixing with ground water, which could eventually affect aquifers. "We're trying to understand implications of managed surface water," Boutt says, referring to the dam. To determine just how much water is being transferred from stream to ground, Boutt is using small disks the size of three or four pennies, called the iButton. These mini sensors are self-contained temperature loggers. While the average temperature of ground water is five degrees Fahrenheit, the temperature of surface water changes with the seasons. The underground iButtons detect and record the temperature changes when surface water is pushed into the ground. "We can back calculate how much water must be moving through the ground," Boutt says. From this, Boutt can determine how the dam-released pulses of water disperse contaminants as compared to natural conditions. "This fluctuation has a significant effect on how much contaminant in the stream gets into the aquifer," Boutt says. "Temperature data helps tell us how much interaction there is."

Boutt also examines the geology of the watershed area, analyzing how the changes in the nature of sediments influence the amount of interaction of stream and ground water. This information can be used to improve stream management and protection. For example, raising the level of a stream may in some ways be beneficial, but can also force more contaminants into the ground, having detrimental effects in the long run.

Boutt is also looking at the types of rock that make up Massachusetts aquifers, subsurface reservoirs of water. The more porous the rock, the more potential water an aquifer can hold. Most rocks in Massachusetts are made of less porous but fractured rock, and can hold less water than aquifers elsewhere around the country. Boutt uses a process called borehole geophysics to figure out how much water is actually being stored, and how much contaminant is making its way through. By mapping the fracture network in detail, Boutt measures the hydraulic properties of the well. This analysis will show just how sustainable fractured bedrock wells are in Massachusetts. "So far, it shows a pretty alarming trend," Boutt says. "Almost all the flow into the well is in the upper hundred meters." His research on a number of wells throughout the state show that the deeper the hole, the less fractures in the rock, which means there is less water available. Of the 4000 fractures measured in various wells throughout the state, only four percent are actively involved in contributing water to the well. Also, subsurface temperature measurements of ground water below 100 meters remains generally unchanged, suggesting that there is less movement in these deeper regions. All these factors combine to paint a picture of water scarcity, even in seemly water-rich states like Massachusetts. "I'm not necessarily trying to scare people," Boutt said. "But at the same time … it's only going to get worse with global environmental change and population growth. At some point, sacrifices have to be made to be able to accommodate those changes." Boutt is currently working with Office of the Massachusetts State Geologist, and the U.S. Geological Survey to continue studying aquifer systems in fractured bedrock around the state.



Boutt's is also working with the Department of Energy on carbon sequestration, the process of removing carbon dioxide from the atmosphere and storing it in subsurface aquifers. Boutt is investigating the implications of CO_2 injections into deep aquifers and spent oil/gas reservoirs. CO_2 can react with certain types of rocks, so the effects of sequestration could be dangerous. "How would a reaction change both mechanical properties and hydraulic properties of the material?" Boutt asks. So far, Boutt has determined that the hydraulic dangers outweigh the mechanical concerns, and has directed his research focus there. The CO_2 could change the permeability of the rocks and precipitate different cements and new minerals into the aquifer. It could also change the pathways for various liquids or displace other subsurface fluids. Another danger of carbon sequestration is the possibility of fracturing rocks. Since carbon dioxide wants to rise, the rocks that are a natural barrier to flow could crack under the upwards pressure. "We're trying to understand the physics, and at what pressure the fractures will propagate."

Besides his research work, Boutt is helping to plan for the Deep Underground Science and Engineering Laboratory, also known as Homestake DUSEL. This National Science Foundation South Dakota mine-turned-lab has been in the works for five years and would comply with the underground needs of a range of sciences, from physics to biology to the geosciences. Boutt is representing the interests of the geoscientists during these planning stages, and he hopes, when the lab is up and running, to study the relationship between deep subsurface fluid movement and the subsurface biosphere. It is known that two thirds of all the biomass on Earth is found deep underground. "One of the things we don't know is where does that extend? Where does it end?" Boutt asks. This is an interdisciplinary question, as the answer, whatever it may be, has implications for possible life on other planets. "What is the relationship between fluid movement, Earth's ambient stress state, and life?" Boutt asks. "What controls the distribution of subsurface life?"

Building Green

Paul FIsette, Natural Resources and Conservation

Paul Fisette, Professor and Department Head of Natural Resources and Conservation, first realized the importance of energy efficient building during the energy crisis of the 1970s. As a general contractor, Fisette saw many homes with leaking window seals or water damaged foundation systems. "That really had an impact on me," says Fisette. Since that time more than 30 years ago, Fisette has been a magazine editor and professor, has worked on numerous papers and projects and taught countless students about building houses in more environmentally durable ways.

While it is obvious that heating and electricity play a huge role in the amount of energy a household uses in its lifetime, a large percentage of a household's energy is used before it is even occupied. The whole building process, including the extraction and harvesting of the building materials, transportation and installation, uses a large amount of resources. The energy required to deliver a home that is ready for occupation is called embodied energy. When totaled it rivals the amount of energy used to maintain a home while occupied. "If you look at the amount of energy that goes into all the materials used in [constructing] the house, it's about one third of the energy that is required during the lifetime of a home," says Fisette. "It's a significant amount, and it's a part that people ignore."

As a house ages, damages occur – some of the worst due to water damage. Fisette's main focus has been how to improve durability of building systems and maintain the integrity of the original structure. This reduces the frequency of maintenance and repairs, reduces the required embodied energy, lowers cost, and avoids the need to harvest or extract additional building materials, which further depletes the environment of valuable resources. "If I had to identify one primary focus [over my career], it has been studying the performance and durability of structures and how to construct homes so they last for a very long time," says Fisette.

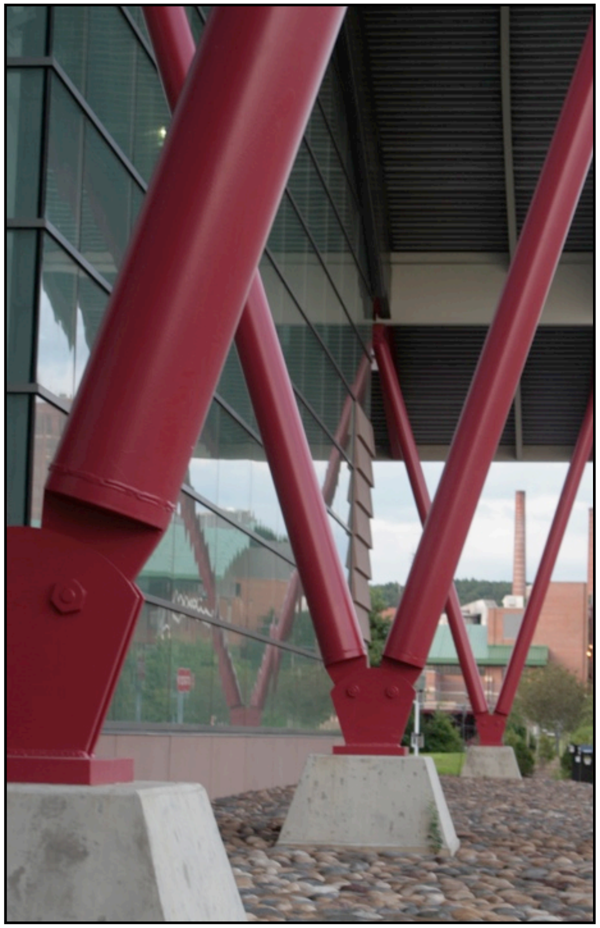
Along with a team of scientists, Fisette recently completed a two year study on green schools for the National Academy of Sciences. The book, titled *Green Schools: Attributes for Health and Learning*, looks at specific criteria that make a school environmentally friendly. "There's not a clear definition of 'green,'" says Fisette. "There are guidelines that talk about 'green,' such as if you used recycled materials and if you have bike racks, if there is no mold or mildew, if you use natural products and natural daylight, and natural ventilation. So there's a whole string of these things that people consider as 'green' attributes." Fisette and the team of experts examined each aspect of an actual "green" school to determine effects on the health and productivity of the students and faculty.

One of the goals of a green school as specified in the report falls in line with the traditional notion of "green" – "to have positive environmental and community attributes." The other, as the title suggests, focuses on how "green" attributes affect the health and productivity of all students and faculty. Findings and recommendations include the benefits of high quality air ventilation and the efficient use of natural light to enhance a safe and healthy learning experience. The findings also noted there was a definite relationship between excess moisture in buildings and poor health and structural damage. According to the recommendations, "green" school guidelines must be revised to include specifications regarding an appropriate and safe amount of moisture in a building. Currently, such guidelines are non-existent. The report also recommended future research into the effect of moisture on health and learning in schools.

In the future, Fisette hopes to join his colleagues working on a project with the housing authority in Springfield, Massachusetts. Assistant Professors Simi Hoque, of Natural Resources Conservation, and Christine Rogers, of Public Health, are working to determine energy efficiency and indoor air quality of public housing. Good air quality reduces allergies and illnesses, and ensuring that the homes are energy efficient would allow families to save money on heating costs. "That's what interests me," Fisette says. "Looking at how houses work, how they are sustainable and healthy places for people."

This attitude is reflected in the Department's new Professional Masters in Green Building Program, which is aimed at educating students in a holistic approach to the essentials of the environmentally safe building process and sustainable living. The program is run by departmental colleague Associate Professor Peggi Clouston. The two-year program draws from a number of different departments to provide students with a broad understanding of what it takes to build "green." It also gives students hands-on experience with home energy audits - assessing the energy efficiency of house - and evaluating city green building codes.

When Fisette discusses sustainability, he does not mean simply ensuring that what we do today will not hinder the progress of the next generation, which is the traditional definition. "It's not that if you take a tree, one tree will be grown in its place, or if you do something, that the same capacity will be there later," he says. "It's 'can we do things smarter so that we can actually improve the capacity of the Earth to provide fresh water and clean air, and provide us with the resources we need to live better?'"



V-shaped beams support the roof of UMass' 'green' central heating plant

Mitigating Atmospheric Toxins

William Manning, Plant, Soil and Insect Sciences

For the past thirty years, William Manning, Professor in the Department of Soil and Insect Sciences, has been examining the interaction of greenhouse gases and plant matter. "I'm just a natural scientist who wants to know what's going on out there," he says. "What does it mean?" Right now, by looking at injury and absorption, Manning is trying to decipher which plants are the best to cleanse the air or act as pollution markers. "If Tree A is better at taking up CO_2 than Tree B, let's use tree A if we can. If Tree Z is better at taking up NO_2 than Tree Y, then we should use Z, but those criteria are not used," Manning says. "So I'm trying to convince people that trees should really do something for us other than just be attractive."

According to a number of computer models, NO_2, a precursor to the air pollutant ozone, should be used by trees as a source of nutrients. If this is true, it would mean the trees are acting as a natural air filter, a useful fact in cities where air pollution from combustion engines is high. Manning and graduate student Tanner Harris, however, are not content to assume the simulations' validity. Their field work in Springfield deals with monitoring the NO_2 uptake of Red Maple and London Pine trees. "We really would like to demonstrate in Springfield whether or not trees are taking up NO_2 from the air and, if so, how much?" Manning says. Their focus is Liberty Street - flanked by Routes 291 and 91 and a railroad, it is a prime spot for combustion engine emissions. Manning and Harris use a number of small, inexpensive devices called passive samplers – what looks like a PVC pipe cap hung with the open side down – on each tree they monitor. Clipped inside the plastic is a container with a small piece of filter paper soaked in a nitric form of nitrogen. The NO_2 in the air flows across the filter causing the nitrogen to change from the nitric to the nitrate form. By determining how much has changed, they can figure out how much nitrogen dioxide is present in the air.

Through these methods, they observed that NO_2 levels are higher within the canopy of the trees than outside and, true to the models, leaves are absorbing some NO_2. These observations are confirmed by laboratory analysis through detection of the stable isotope N^{15}. "It just happens that the stable isotope form is very characteristic of NO_2 from combustion, so it's almost like a marker, which is really neat," Manning says. But while they see some NO_2 absorption, they don't know whether or not it is enough. "It's not clear whether the uptake is really significant, in terms of what's in the air. I mean, it's true this may happen, but is it really a way to reduce pollution?" he asks. Manning hopes to extend this research to a wider variety of trees, to see if there are more efficient NO_2 absorbers.

Manning is also interested in the effects of daily levels of ozone on the bodies of plants. The more sensitive a plant is to ozone, the greater the injury to the leaves. Not much pollution is generated in the Valley itself, so most damaging compounds come on the wind from major southern cities. "When the wind blows from a southwesterly direction, which it often is, it's coming out of metropolitan New York and New Jersey," Manning says. "It's moving basically right up through the valley and it's bringing all the precursors and all the air pollutants with it." Manning is monitoring this phenomenon in collaboration with the Connecticut Agricultural Experiment Station in New Haven and Valley Laboratory in Windsor Locks. Each contributor grows 18 pots of a clover known to be ozone sensitive. Half the crop is treated with EDU, a compound to protect against ozone damage. The crops are examined throughout the summer to record their growth and reproduction while affected by ozone. Data from the three locations is then compared to identify which areas have the highest occurrence of pollutants. Current data suggests New Haven has the highest presence of ozone, Windsor Locks fares a little better, and Amherst has the clearest air of the three areas sampled.

In another line of research, graduate student Jennifer Albertine and Manning are working in greenhouses to mimic global warming conditions. "All these things are really tied together. You can't really only study part of the environment and ignore the rest of it," Manning says. As the world heats, there will be residual warmth overnight, which will then heat the ground and those things growing in it. They have found that plants growing in warmer soil germinate faster, but they also reach ozone sensitivity more quickly and the effects of ozone on the warmed plants are greater than the normally grown group. Albertine is taking this research outside to see how the findings hold up under more real-life circumstances.

Manning wants to give these findings a human application. He hopes to figure out a way to translate the ozone data from the plant experiments into something meaningful for human health. Simply monitoring the ozone through detectors is not enough. If there is no plant injury, there is likely no danger to humans. If the plants are damaged, however, there could be some implications for society. The problem is plants and humans respond differently to different stimuli, meaning what is harmful to a plant may not affect people. "Whether or not clover gets ozone injury is of very little concern to most people," Manning says. "But if the clover is injured and [the people] are injured, then they're really quite interested. What we need to pursue is the relationship between plants, pollutants and people. Right now, they're parallel lines."

Alternative Energy and Technology Policy

Erin Baker, Mechanical and Industrial Engineering

Since late Spring 2007, Erin Baker, Associate Professor of Mechanical and Industrial Engineering, has been working with groups of environmental activists towards bringing sustainability into the Pioneer Valley through the Sustainability Network, supported with EPA funding. "It's a pretty interesting project," Baker, says. The Pioneer Valley Sustainability Network was initiated by the University of Massachusetts Environmental Institute and Department of Mechanical and Industrial Engineering and the Pioneer Valley Planning Commission, and is now comprised of many individuals, groups and organizations working on sustainability in western Massachusetts.

Baker has been working with the group in a number of areas. "Part of it was to work with them to help them define what they thought were the fundamental values related to sustainability," Baker says. "Now we're trying to come up with a set of sustainability indicators […] things we can measure in the Pioneer Valley that will tell us if we're moving in the right direction towards sustainability." These indicators range from housing and transportation to land use and air quality.

Baker is also contributing a more specialized project to the network - a web-based program that will be free and available to the public that will allow any user to measure the cost-efficiency and other benefits of energy technologies that can be used to heat a house or run a business. "They can use this to evaluate different energy technologies based not just on cost, […] but also on some of these other kind of indicators that the Sustainability Network has developed," she says. "So we'll show people how their choices impact overall." All users have to do is plug in key information about their home or business, and the program will do the rest.

Baker uses a similar idea in a different branch of her research. She combines her math and engineering background to calculate the probabilities of success for potential alternative energy technologies. "I'm not trying to predict the future, but we try to quantify the uncertainty that we have about the future, so specifically, we put probabilities on things," Baker says. She then analyzes these probabilities against certain factors – for example, the potential for technological change, or the uncertainty about damages from climate change. "We then can roll that back and say, 'well what does that mean for the best near term decision?' Because a lot of time when you have uncertainties like that, what you want to do in the near term are things that preserve options and flexibility for the future," she says.

To determine the probabilities, Baker obtains the opinions of three to five experts in any given field of alternative energy, and then takes the average of those reported probabilities. For example, if the government wants to spend money on organic solar cells, what are the probabilities that someone will actually come up with a way to make it happen? Baker is using an National Science Foundation CAREER grant to analyze potential research and development portfolios based on her findings. "The idea of this project is to get insights about what the research and development portfolio should look like, say, for the United States, in the face of climate change," she says. "We know we're going to want to diversify [the portfolio], we know we don't want to put all of our eggs into one basket, but that's not enough to tell us how many eggs we want to put into each basket." She hopes these portfolios will add an element of science to policy decisions being made in Washington.

It may seem unusual that an undergraduate degree in Mathematics from the University of California Berkeley, and a Master's and Ph.D. in Engineering (Economic Systems and Operations Research) from Stanford University would lead to work in an environmental field, but Baker's two years in the Peace Corps in Ghana allowed her to witness disturbing sights. "The desertification could be observed," she says. The trees simply weren't coming back. "I was observing it first hand." Since then, Baker has examined a number of potential climate change solutions, and each one has its own pros and cons. "If there was a silver bullet for climate change, it would probably be carbon capture and sequestration," she says. This technology collects carbon dioxide and pumps it into aquifers, keeping it out of the atmosphere. While it's not a long term solution, it would give the world at least 50 years to make the switch from coal and other power plants to new, cleaner energy. Baker is intrigued by this idea and says she thinks it is worth pursuing further research into this technology.

Solar panels power lights at the UMass Mullins Center parking lot

Solar and wind energy, according to Baker, are simply limited, given today's technologies for the electricity grid. Unless we can develop new technologies for electricity storage or grid integration, "They will only provide a small level of what we need," she says. Wind and photovoltaic cells are dependent on the inconsistencies of nature. Nuclear energy is interesting because, according to Baker, "it's the technology we actually have right now." While many people are concerned about the ramifications of nuclear power and waste, Baker feels many of the worries are solvable. The problem that may be unsolvable is proliferation – the fact that with more nuclear power we are likely to get more nuclear weapons. It is possible, theoretically, to solve this technologically, but it requires many countries agreeing to accept less powerful nuclear plants. "Who wants to be the country that doesn't get the best technology?" Baker asks. It's a politically rocky situation, but Baker thinks it's worth investigation.

All of this work boils down to one main goal. "What I'm hoping is to have some influence on technology policy at the government level," Baker says. "I'd like to have some influence on these climate change bills before they really get fully implemented, so that based on our findings, […] we'll be able to say, 'well, these categories of technology are just really robust, that they should have a fairly high level of investment.'"

Fish Ecology, Evolution and Behavior

Francis Juanes, Natural Resources Conservation

The ocean is a living organism. It warms, it cools. Fish stocks migrate and sometimes disappear. With impending climate change and over-fishing, Francis Juanes, Professor in the Department of Natural Resources Conservation, studies fish species along the Atlantic coast. Juanes' research focuses on the ecology, evolution, and behavior of fishes and benthic crustaceans. Particular areas of interest include understanding the mechanisms leading to recruitment variability of marine fishes, the evolution of life history strategies, and behavioral ecology as it applies to prey size selection and spatial distribution of species.

"Dolphin fish rarely used to be found off Cape Cod," he starts, speaking of the Floridian game fish, "but fishermen have been pulling more and more up over the past decade; something that could be connected with global warming." Juanes has worked on many projects dealing with fish stocks, and to see the subtropical dorado move into Georges Bank foretells of major changes. One of these is the dramatic decline of Atlantic salmon all along its range, often attributed to changes in their freshwater habitats. Juanes and his colleagues have found that marine conditions strongly affect both the size and timing of adult salmon returning to freshwater to spawn. Over the last one hundred years, changes in ocean temperature also correlate with the decline in salmon abundance suggesting that future ocean warming could be fatal for the species.

Like the ocean itself, fish populations within it are all connected. As the dolphin fish population moves further north, stocks of the once common bluefish are nearing the breaking point. "All along the coast, people will sit on the beach and pull the juveniles out of the water as sport. Near the Cape, large party boats will spend a day out on the water taking the bigger specimens," Juanes says. One of his research projects is to understand how the decline of stocks of bluefish and other predatory fishes will affect the predator/prey dynamics on Georges Bank, a massive area of shallow sea on the American side of the North Atlantic. To do this, he and his students have used longterm databases collected by the National Marine Fisheries Service. One of the findings this work revealed was the increasing importance of squid in fish diets. Along with graduate student Michelle Staudinger and Roger Hanlon of the Marine Biological Laboratory in Woods Hole, Juanes used large tanks full of both benthic (bottom dwelling) and pelagic (open sea) predators and squid and prey fishes to observe their interactions. The results of these experiments will help scientists and resource managers as they move from single-species to multispecies ecosystem management.

In addition, Juanes studies predator and prey dynamics with the assistance of sport fishermen. After a fishing tournament concludes, Juanes will ask participating anglers for their catches' stomach contents. These catches include species such as bluefin tuna, dolphin fish and various sharks. Most recently he concluded a study of mako shark stomach contents collected from fishing tournaments along the east coast, led by graduate student Tony Wood at the University of Rhode Island. Results of this study show that mako shark consumption of bluefish has increased over the last 30 years to about 93 percent of the mako diet; an average mako consumes about 500 kg of bluefish per year.

Juanes has also enlisted commercial fishermen in another research project using passive acoustics. New technology in the field of underwater hydrophones has given Juanes a new look at these deep communications. Along with colleague Rodney Rountree and graduate student Katie Anderson, Juanes has worked with fishermen to deploy underwater hydrophones both in coastal and deep sea waters. Most vocalizing is performed by males and thought to be related to spawning. Haddock vocalizing and female egg production typically peak at similar times. Juanes and his team use hydrohones to study these relationships.

Michelle Staudinger, PhD student, cuts open a yellowfin tuna to examine its diet

Juanes also uses technology that he developed with former graduate student Nikolai Klibansky to study the breeding prowess of Atlantic cod. Using a scanner and computer freeware, Juanes and Klibansky were able to determine the size and number of eggs that can be produced given a cod's body size. This new technology will be a tremendous boon to fecundity studies, as the scanning method is quick, inexpensive, and easy to use. The scanner method has come not a moment too soon, because, Juanes says, "my favorite statistic is that the last time a fecundity and body size relationship in cod was figured out was in 1880." Part of the reason for this lack of information is that cod spawn in the middle of winter when scientific research vessels are not at sea. It was their collaboration with commercial fishermen that allowed enough fish to be collected for the project.

In another research project, Juanes is studying the Hudson River for clues as to why and how fish communities change over time, including the collapse of the native shad population and the invasion of the freshwater drum. The shad population has been so low for the past few years that the state of New York has instituted a mandatory catch and release policy for the fish. Juanes and graduate student Megan O'Connor are using historical records and climate indices to study the shad decline. Juanes and Rountree also plan to use passive acoustics to track the invasion of the freshwater drum as it moves south in the River. In another research project in Florida, Juanes and graduate student John Murt are examining the winter recruitment and growth of juvenile bluefish, something that he hopes will explain the decline in the fishery. Juanes makes sure to include his research in his teaching. "Most of the research I conduct ends up as lessons in the classroom," he states. This reflects his philosophy that real-life examples of good research and involving graduate students in his work makes him a better teacher.

Computing the Way to Biofuels

Scott Auerbach, Chemistry

Scott Auerbach, Professor of Chemistry, uses computers to search for "green" alternatives to the use of petroleum and coal, the largest contributors to the carbon emissions causing the human component of global warming. "I think we've now learned that energy and environment are inseparable, because when you use energy, you impact the environment in some way," says Auerbach, who is also an Adjunct Professor in Chemical Engineering. Much of Auerbach's work has focused on alternative fuels and fuel cells.

Auerbach's computer modeling work in the field of biofuel refinement is funded by a new $2 million grant from the Department of Energy, which also supports George Huber, Curt Conner and Phil Westmoreland, all from the Chemical Engineering Department, and all members of The Institute for Massachusetts Biofuel Research (TIMBR). Their goal is to apply an existing petroleum refinement catalyst, called a zeolite, to the production of biofuels from solid biomass. A catalyst is a molecule or material that promotes a reaction without being consumed by the reaction, ideally steering the reaction towards the most valuable products. Zeolites are nanoporous solid acids that spark reactions with their acidic nature, steering molecules inside the nanopores (like nanometer-sized reactors) to new shapes that mirror the shape of the small pores. "On a per ton basis, zeolites are the most heavily used catalysts, because they are important in the refinement of crude oil into high octane gasoline," Auerbach says. "These zeolites have been the workhorse of the petrochemical industry for fifty years, and now we're thinking of [using them for] what's called the carbohydrate economy."

By "carbohydrate economy," Auerbach means efficiently replacing petroleum products such as fuels and plastics used in massive amounts throughout the world, with new products obtained from the sugars in plant biomass. The biggest draw towards this model of energy is its cyclical nature. After oil is refined and burned, the resulting carbon dioxide gas is released into the atmosphere, likely contributing to anthropogenic global warming. If the economics of biofuels can be improved, and the technology widely adopted, the fuel crops grown to replace those harvested would use carbon for their growth. "That's the fundamental difference between fossil fuels and biofuels," says Auerbach. "Biofuels have their own carbon sequestration built into the cycle."

The difficulty lies in the production. Changing crude oil into high octane gas is relatively simple – a liquid into a refined liquid. Changing solid plant matter into liquid transportation fuel is another matter. "The whole challenge in biomass refinement is getting that solid, recalcitrant plant material to succumb to the dark side of the force and become a liquid," Auerbach says. Fossil fuels are hydrocarbons, lacking in oxygen, which is the reason for their liquid state. The oxygen in plant matter serves to bind the molecules tightly together. The key biofuel production is the controlled removal of this oxygen without making carbonaceous materials like "char" (although "biochar" is favored by some as a natural fertilizer/carbon sequestration system of its own.)

Huber, a member of TIMBR, developed a method of driving water from the plant matter, leaving hydrocarbon behind. Called "catalytic pyrolysis," the method involves rapid heating of a plant for a split-second, until the temperature reaches around 600 degrees Celsius. The plant itself is vaporized, leaving the carbohydrate molecules to drift through a zeolites' unusually efficient "shape selective" pores. The majority product in Huber's process is a high-octane fuel called an aromatic, a molecule similar to benzene.

Catalytic pyrolysis has its drawbacks, however. While it effectively converts roughly half the carbon to usable fuel, half is still rendered useless. To make biofuel refinement cost-effective, nearly all the carbon must be available as fuel. The method needs to be adjusted, but improvements require understanding how the method works. Otherwise, the TIMBR team will spend too much time in trial-and-error research. "During the rapid heating, all the biomass gets vaporized, and we don't know how that actually works," Auerbach says. "We don't know exactly the species [of molecule] that are in the gas phase….but the biomass is gone." On top of this difficulty, the team is unsure how such rapid heating affects the zeolite itself. They do not know which species of molecules fit inside the zeolite's pores (though they do know that some make their way there), and they need to better understand the reaction chemistry once the molecule is in the pore. "The biomass molecules are kind of bouncing around like popcorn in a popcorn maker, from time to time having a kind of trajectory that puts it right into one of those pores," Auerbach says. "Once it gets inside there, there can be catalytic reactions and we have no idea what those actually look like."

The TIMBR team is exploring these issues using a number of methods. Spectroscopy, the identification of chemicals according to their signature response when exposed to certain wavelengths of light, and the use of computer modeling, are giving the scientists a better view of what happens inside the zeolite. Conner and Westmoreland are probing the process using different forms of spectroscopy. To get accurate data under rapid heating, Conner uses vibrational spectroscopy, which uses vibrational frequencies to identify molecules, and Westmoreland employs mass spectrometry, which determines the identities of vaporized biomass molecules from their characteristic masses. In contrast to these experiments, Auerbach is focusing on recreating the situation using computational methods. Auerbach's team uses quantum mechanics to compute the energies of molecules in zeolites; then his team uses "molecular dynamics" to explore how thermal vibrations in nanopores lead to reactions and eventually to biofuels. "My job is to calculate those energy levels for different kinds of molecules and find out, as a function of those, what's sort of the least energy pathway to get from reactants to various products," Auerbach says. "By performing these quantum calculations, it's sort of the most powerful microscope in the world."

Once the process is understood and made more efficient, it will need to be commercialized. Huber, who specializes in reaction engineering, is determining the most efficient model for a pilot plant. He is considering a batch reactor, a fixed bed continuous flow reactor, and a fluidized continuous flow reactor. Currently, the best choice seems to be the fluidized continuous flow reactor. By allowing the zeolite to flow freely with the biomass, the team can regenerate the zeolite catalyst without disrupting the process or causing too much excess waste.

"So the combination of the reaction engineering, the molecular modeling and the spectroscopy is sort of the magic triangle, the trinity, that's going to get this problem solved," Auerbach says. And he is optimistic about his team's progress. "I predict that in five years we will have a pilot plant commercial process," he says.

In another project, Auerbach is working with the UMass Amherst Center for Chemical Innovation on Fueling the Future, funded by the National Science Foundation. The center is developing new understanding and new materials for more efficient charge transfer technologies. This has potential applications such as improving hydrogen fuel cells, a promising alternative because they are more efficient than internal combustion engines, and their only emission is water. In a fuel cell, electrons start at the high energy of the hydrogen molecule, power a device and hence lose energy, then meet up with protons and oxygen to form water. The problem is that electrons are so fast, protons have a hard time keeping up because they are nearly 2,000 times more massive. Auerbach is working with the Center for Fueling the Future to find new nanostructured materials, called proton exchange membranes, through which protons can move more quickly. Other applications of charge transfer being considered by the Center for Fueling the Future include new sensors, new solar energy harvesting materials, and new light emitting diodes for display technologies.

Auerbach is also working on a project using zeolites as nanofilters. He models the process of exposing a zeolite to a mixture, then selectively heating the system with microwaves to drive off the more polar species in the mixture. This process has a number of practical implications, including separating volatile organic compounds.

All of Auerbach's work holds the overarching theme of less waste, more efficient "greentech," using the nexus between computation and nanotechnologies such as zeolites. At the same time, he realizes that going green is not easy. It's a big task, but one that may require the power of tiny nanotechnologies. "It's all about controlled energy transfer from one source to another," he says. "Using nanotech to exert such control may mean big breakthroughs from tiny things."

Protecting Water Resources: The Massachusetts Water Resources Research Center

Paula Rees, Director

A volunteer collects water for the Water Center's Acid Rain Monitoring project at Beaver Brook in Ware, Massachusetts

The Massachusetts Water Resources Research Center aims to make New England water safer with the help of community volunteers and university faculty researchers. As one of 54 centers based across the United States with seed funding from the U.S. Geological Survey, the UMass Water Center, based in The Environmental Institute, is working to become a more active player in Massachusetts water research and policy, according to Director Paula Rees. "We'd like to increase our ability to serve the needs both of the faculty and the campus, and of the state in terms of water needs," she says. "[We want] to increase our ability to serve as a cohesive role between disciplines and between the campus, other campuses and state needs."

In one project begun in 2001, Rees has been sampling and compiling data from the Blackstone River to evaluate water quality. With the data collection phase now complete, Rees and the Water Center team are using the information to create a model of the river dynamics. "The real purpose of the Blackstone monitoring and modeling is to create a tool that we can play with to say, 'ok, what's going to happen in the basin in the future?'" Rees says. The contaminants affecting the Blackstone River include bacteria and nutrients and come from both point- and non-point sources. Point source pollutants flow from a known location, such as a waste water treatment facility, and must be reported as they are regulated under the National Pollutant Discharge Elimination System. Non-point sources enter the river over long stretches by means of storm water run-off from parking lots, suburban lawns, forests, and other sources more difficult to identify. A combination of these two pollutant sources has compromised the Blackstone River to the point where it is not considered safe by the Massachusetts Department of Environmental Protection for swimming or fishing. Rees and her team hope their model will help them identify ways to bring the river up to a Class B category - fishable and swimmable.

Currently, the model is being calibrated for a number of parameters, including nutrients, which will allow the team to make the virtual conditions mimic reality. "Through the model we are trying to recreate the physical environment as much as possible, so we utilize as inputs to the model such as actual rainfall that has occurred, observed air temperatures, evapotranspiration, and land use characteristics. These model inputs allow us to simulate non-point sources, which we combine with what we know about point source loads. " Rees says. Once the model is calibrated, the team will be able to input various pollutant load reduction options to determine the best course of action for river clean up. "If we reduce point sources by this much here, what happens in the river?" she asks. "If we reduce non-point sources by this much, what happens in the river? Ultimately we are concerned with the health of Narragansett Bay – the Blackstone is a major source of freshwater to the bay." Changes in point source pollution levels would come from regulations on waste-water treatment facilities and other businesses along the river. Some facilities have reduction projects coming online. Others are challenging more stringent effluent restrictions, since the construction needed to reduce point source pollution can be costly. The Water Center's model can help determine the cost-effectiveness of these various controls. "As you reduce point sources that are fairly high, you see visible improvements in the river - generally a nice, steep trend initially," Rees says. "But at some point, as you approach the limit of technology, further reductions in point sources have less of an impact on the river for every dollar that you spend." At this plateau, Rees says, it's time to start focusing on non-point sources.

One of the Water Center's efforts to help facilitate non-point source reductions is the Massachusetts Storm Water Technology Evaluation Project (MASTEP). Jerry Schoen, a Water Center staff member, is leading the evaluations of studies that have been done on storm water treatment systems. Since performance effectiveness studies vary in their reliability, Schoen and his team are developing a comprehensive guide detailing the validity of the studies themselves. Another project evaluates stormwater routing and treatment models to identify optimal management strategies for different situations. Eventually, a town aiming to install a storm water management system could use guidance provided by the Water Center when choosing a system with the ideal size and function for a certain area at the minimum cost. The Center is currently helping to review a modeling system with these capabilities, developed on a pilot basis to reduce nutrient loading in the Charles River.

The Water Center is working to bring some of these cost effective methods to the University as well. "We'd like to bring things together on campus that wouldn't normally have been brought together," Rees says. Currently, UMass uses traditional non-point source collection and treatment methods like storm sewers and in-line treatment. Rees and the Water Center would like to assist in updating its management systems. For example, systems like porous pavement and rain gardens could be used to filter storm water in an aesthetically pleasing manner.

Schoen is also managing the Watershed Community Initiative, an effort that uses information technology and social networking tools to make science more engaging and accessible to grade schoolers, college undergrads and community organizations. In one project with the Athol School District, children create podcasts to share their field work discoveries with fellow students and community members. In another project, the Center is collaborating with the Center for Educataional Software Development to develop virtual tours of the Connecticut River Watershed, accessible on desktop and handheld computers.

Another project, headed by Marie Françoise Walk, is the Water Center's Acid Rain Monitoring Project. The project started in 1983, when the effect of acid rain on New England's forest ecosystems caught the attention of legislators. While the monitoring project has scaled back since its height in the 1980s, the Water Center currently collects data biannually on the impacts of acid rain on streams and lakes across the state. The number of sampling locations has changed, but the main goal of monitoring the pH and alkalinity of Massachusetts lakes and streams has provided an invaluable look at trends in New England. Each year, 50 volunteers collect water samples across the state from 153 designated water bodies and bring the samples to volunteer laboratories for pH and alkalinity analysis. Of those 153 samples, 26 are also sent to the Water Center's Environmental Analysis Lab (EAL) for color, cation, and anion analysis. The ARM long-term data set is of interest to both the Massachusetts Department of Environmental Protection and outside groups. One use is for identifying maximum acceptable acidity values for New England.

The Center is also participating in a multi-state volunteer monitoring effort along the Connecticut River. As data is collected, information is posted on an interactive Web site. Along with the aforementioned virtual tours, "the water quality web site is an attempt to blend traditional Citizen Science activities with information technology advances that are changing how people seek and respond to information," Rees says.

The EAL is put to use for other Water Center projects, as well. Through the Massachusetts Water Watch Partnership, for example, volunteer groups can send samples from their streams or ponds to be analyzed for various nutrients. The Partnership also provides quality control samples and guidance documents to ensure water is sampled correctly. EAL is also open to University researchers in need of water analysis.

Since 2003, the Massachusetts WRRC has held an annual conference to provide an interdisciplinary forum for scientists, practitioners, and policy makers to discuss critical water research, foster greater collaboration among scientists and practitioners, and strengthen the connection between research, extension, and policy.

In the future, Rees says the Water Center will be more involved in climate change issues such as providing necessary data to assess existing policies, identifying areas needing improvement, and assisting to implement new policies. "[We're] trying to bring up to speed some of the traditional things that we do in water quality monitoring and modeling so that it fits those changes in societal expectations."

The Environmental Institute

Blaisdell House
University of Massachusetts Amherst
Amherst, MA 01003-9280
413.545.2842
email: tei@tei.umass.edu

www.umass.edu/tei

University of Massachusetts Amherst