Student Chemist G To Do the

Think high school students can't make a difference? Think again. Marc Burrell spent his high school years researching some novel solutions for cleaning up our environment.

By Jay Withgott

Perhaps he's no ordinary high school student, but Marc Burrell's prize-winning research on how to get plants to remove toxic lead from contaminated soil shows what a student can accomplish given some smarts, some conviction, and a whole lot of persistence.

When soil becomes contaminated with heavy metals, it's not easy to clean up. Tens of thousands of sites worldwide are contaminated with toxic metals and organic pollutants from manufacturing industries, mining, oil extraction, and military ammunition. When these industries close up and move on, the land they leave behind is often too polluted for other uses.

The standard solution is to dig up tons of soil, piling it all into a hazardous waste dump. This is being done at many sites throughout the country by order of the Environmental Protection Agency (EPA). But bulldozing so much dirt can actually release harmful chemicals into the air, putting nearby residents at risk. It wastes soil and leaves ugly gaping holes. And it can cost huge amounts of money—often $1–3 million per acre.

So some scientists are studying a better way to get the job done—using plants to do the "dirty work".

Called phytoextraction, or *phytoremediation*, the approach uses plants ("phyto" means plant) to remediate, or detoxify, contaminated soils. "You use the plants to do the cleanup for you," says Purdue University professor Peter Goldsbrough, a phytoremediation expert. "You end up with a less-expensive solution, and a greener solution, to the problem."

One researcher making advances in phytoremediation is Marc Burrell. For his work, Burrell, who is 18 and a 2002 graduate of Nicolet High School in Glendale, WI, won fifth place and a $25,000 scholarship in the prestigious Intel Science Talent Search last spring. He's has also won prizes in other high-profile competitions that have taken him around the country, from Orlando to San Jose to New Orleans, across the Atlantic to London, and more recently, to Japan. He's appeared on "Good Morning America" and has been profiled in Wired.com, as well as in local TV and newspapers. Last fall, after sorting through the flood of college admission offers, Marc entered his freshman year at Rice University in Houston, Texas.

Dr. Goldsbrough, one of his mentors, says he was "just delighted" to work with Burrell. "What was really amazing about Marc is that as a high school student, he was very able to access the relevant scientific literature in technical journals and understand most of it without a whole lot of assistance from anyone else — *and*, he was able to pinpoint interesting questions. It was really quite remarkable." How'd he do it? "He was very persistent, very dogged," Goldsbrough says. "He really wanted to get an answer."

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But Marc says, "I'm a pretty laid-back guy." *Really???* "… Okay, when I'm not in the lab or gone for science competitions," he admits. Nonetheless, between his scientific pursuits, Marc, who likes jazz, sports, and travel, also found time to play varsity basketball and football and to play saxophone in the jazz band.

Getting into some serious science

Marc got seriously interested in science in seventh grade. During his freshman year of high school, he began doing research and competing in science fairs. Enrolled in NASA's Sharp Plus program, he spent the summer of 2000 at Jackson State University in Mississippi. That's where he began work on phytoremediation.

Working under Jackson State professors Greg and Maria Begonia, he tested how well wheat grown in the lab could take up lead from soil under a variety of chemical conditions. Marc found that adding acetic acid and EDTA (ethylene diamine tetraacetic acid) to the soil increased the wheat's ability to draw up lead through its roots. Under this combined chemical treatment, the wheat accumulated lead to the tune of 1% of the plant's dry biomass. Marc found that when treated with EDTA alone, the plants took up only one-third of this amount. Without either EDTA or acetic acid, they took up only a millionth as much.

What was happening? Normally, when lead is in the soil, it's not accessible to plants. That's because it's tied up in compounds such as lead carbonate and lead oxide—neither of which is water-soluble. But some chemicals can bind to lead, making it water-soluble. The plant roots can then take up these water-soluble metal compounds and gradually join to form long polymers.

Organic chemicals capable of grabbing metals (EDTA is one) are called chelating agents or chelators (from the Greek word for "claw"). Adding acid enhances the effect of the chelating agent, because the acid donates protons. And these hydrogen ions help break the bonds between lead and its former partners, freeing up more of it to bind to EDTA.

Of course, it's not quite so simple, as Marc points out. "Soil chemistry has very complex dynamics," he says, with factors such as temperature, humidity, soil moisture, and nutrients all playing a role. But his findings suggest one avenue by which the efficiency of phytoremediation could be improved.

Looking at plants from the inside

His findings were published in the May 2002 issue of the *Bulletin of Environmental Contamination and Toxicology*. But Marc wanted to better understand what was happening on the molecular level inside plants to enable them to take up toxic metals such as lead. In particular, he wanted to understand how genes and proteins affect lead uptake. "The long-term goal is to bioengineer plants to be able to accumulate lead," Marc says. "And you can bioengineer super-plants only when you understand the systems and their mechanisms."

So he sought out Goldsbrough, who had studied how cadmium and other metals are handled by *Arabidopsis*, a small mustard plant commonly used in laboratory genetic studies. Many plants, when they take up toxic metals, will send forth peptides called *phytochelatins* to bind to the metals. The phytochelatins drag the toxins to vacuoles, or empty cellular sacs. Here, the poisons are stashed away where they won't harm the plant. Phytochelatins were thought to work with numerous types of metals, but no one had tested their interaction with lead.

So that's what Marc set out to do. Working under Dr. Heather Owen, director of the electron microscopy lab at the University of Wisconsin–Milwaukee, Marc tested a strain of *Arabidopsis* from transgenic seeds Goldsbrough had provided him. In this mutant strain, geneticists had knocked out the gene responsible for producing phytochelatins. Marc found that these mutant plants lacking the ability to produce phytochelatins were more susceptible to lead poisoning than normal plants and died sooner. So apparently,

Growing plants like these wheat plants for extracting metal ions from the soil is relatively new. Environmentalists find the approach interesting because it's cleaner, healthier, and cheaper than bulldozing up vast heaps of contaminated soil.

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Dirty Work

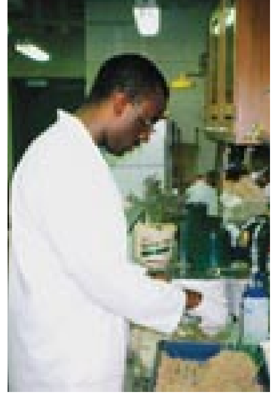
phytochelatins are, in fact, functioning to squirrel away lead into vacuoles.

Arabidopsis is a great model organism for lab studies, but Marc wanted to work with something more applied, so he contacted Dr. Hillel Fromm of the University of Leeds in the United Kingdom, who works with tobacco plants. Remaining in Owen's lab, Marc obtained some of Fromm's mutant tobacco plants that overexpress the protein for producing phytochelatins, enabling the plants to take in more metals. Marc found that presenting the plants with lead induced them to produce even more phytochelatins, increasing the amount they could accumulate.

Marc Burrell entered Rice University in Houston in the fall of 2002. Selected as a member of the university Century Scholars Program, he was invited to join a bioengineering research team headed by Dr. Antonios G. Mikos (www.rufrice.edu/~mikosgrp/). Marc describes the work at Rice as "challenging and rewarding". He adds, "I'm still undecided about majors, but possibly bioengineering."

One of the highlights of his 2002 fall semester was a trip to Japan sponsored by Army Research Laboratories (ARL). As part of his prize for being one of the finalists in the May 2003 Intel International Science and Engineering Fair in Louisville, KY, he participated in the two-week Operation Cherry Blossom Program in Tokyo. While in Japan, Marc's group toured several ARL labs, visited the U.S. embassy, and toured cultural sites.

Before returning to the United States for the holidays with his family in Milwaukee, Marc was honored to represent the United States at the Japanese Student Science Awards Program, a ceremony that included his introduction to Prince and Princess Akishino of the Imperial Family—a tradition of the program.



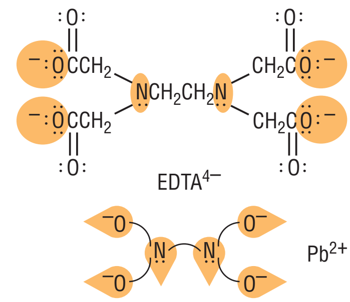
Finally, Marc assisted Owen with her work on phytoferritins, proteins that help regulate the amount of iron in a plant's system. Plants need iron for proper photosynthesis, but too much of it is harmful. Any excess must be sequestered away into vacuoles. Marc wondered how plants differentiate between toxic metals like lead and helpful metals like iron—and whether the phytoferritins could also help sequester lead.

Marc and Dr. Owen's experiments showed that they could. Making iron scarce at first and then resupplying it in excess to the plants caused the phytoferritins to take up both iron and lead. Owen says there's still work to be done to confirm the findings, but Marc's experiments gave them hope that they'd pinpointed phytoferritin's uptake of lead.

"A lot of my colleagues told me I was nuts" to take on a high-school student, she laughs. But the long hours she worked with him paid off, she says, with some valuable research results.

Can plants get the job done?

Phytoextraction procedures are still relatively new and undeveloped, but the approach is attractive because it's cleaner, healthier, and cheaper than bulldozing up vast heaps of contaminated soil. If the plants can concentrate the metals enough, they can be put through a smelting procedure to recover the metals. If they can't, then the plants are dried and disposed of in a hazardous waste site. The metal does not disappear this way, but its presence in the environment is more safely confined.



EDTA is a chlelating agent. Like a chemical "claw", it wraps around a metal ion to form multiple coordinate bonds. The result is a very stable water-soluble compound that is readily absorbed by plant roots.

Phytoremediation faces some big hurdles, though. For one, it takes a long time. Plants can only take up so much. When one crop has done its job, it is harvested and another must be planted. It may take 5–20 years of repeated plantings before the soil's metal content is reduced to an acceptable level. Furthermore, the cleanup is limited to the depth of soil that the plants' roots will reach. And the metals need to be in a form that plants can take up (remember the need for water solubility discussed above). Finally, plants that accumulate toxins can potentially harm insects that eat them. Birds and other animals eat those insects, passing toxins along the food chain.

Such obstacles help explain why real-world applications so far have been limited. But there are plenty of examples even now. For instance, the U.S. Army Corps of Engineers is using vegetation in artificial wetlands to clean up groundwater contamination from ammunition at military bases in Iowa, Tennessee, and Nebraska.

Edenspace, a private company based in Virginia, has used plants to extract lead from residential sites, to remove arsenic from military and energy facilities, to clean up zinc and cadmium at EPA Superfund sites, and to reclaim tungsten from abandoned mines. It has even used them to extract radioactive uranium, strontium, and cesium from U.S. military sites and the infamous Chernobyl nuclear reactor in the Ukraine. Another company, Ecolotree, in Iowa, has used poplar trees, legumes, and grasses at 55 landfills, wastewater treatment sites, agrochemical spill areas, and other locations in the United States and Europe.

Such promising efforts are at the forefront of modern environmental chemistry. Will these efforts be effective enough to replace the bulldozers when it comes to soil cleanup? Marc Burrell and other bright hard-working researchers are confident the answer is yes.

Jay Withgott is a science writer and journalist based in San Francisco, CA. His most recent *ChemMatters* article, "Chemical Profiling—Tracking Down the Source", appeared in April 2002.

REFERENCE

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