PLANT POWER

MEAN, GREEN, TOXIC-CLEANING MACHINES

by LANCE FRAZER

A ROAD THROUGH SOUTHern Arkansas winds through miles of beautiful pine forests that hide a problem. Every so often, a patch of ground devoid of plant life appears like a blighted faery circle. About 50 feet in diameter, these clearings form a link to Arkansas' recent industrial past. The barren land is caused by one of the thousands of oil wells, some dating back 80 years or more, that still dot the state and curse its soil.

When oil spills, "the more volatile elements disappear quickly, leaving behind this gooey, heavy material that is a lot like asphalt, and can be a foot deep," says Greg Thoma, an assistant professor of chemical engineering at the University of Arkansas.

Some days, Thoma can be seen on his knees near these wells, carefully tending plots of crabgrass. To Thoma, who is researching ways to mop up this toxic mess, the grass is an unlikely but invaluable ally. He is one of hundreds of researchers across the country beginning to look at ways to harness the power of plants to cleanse pollutants from the environment, a process known as phytoremediation.

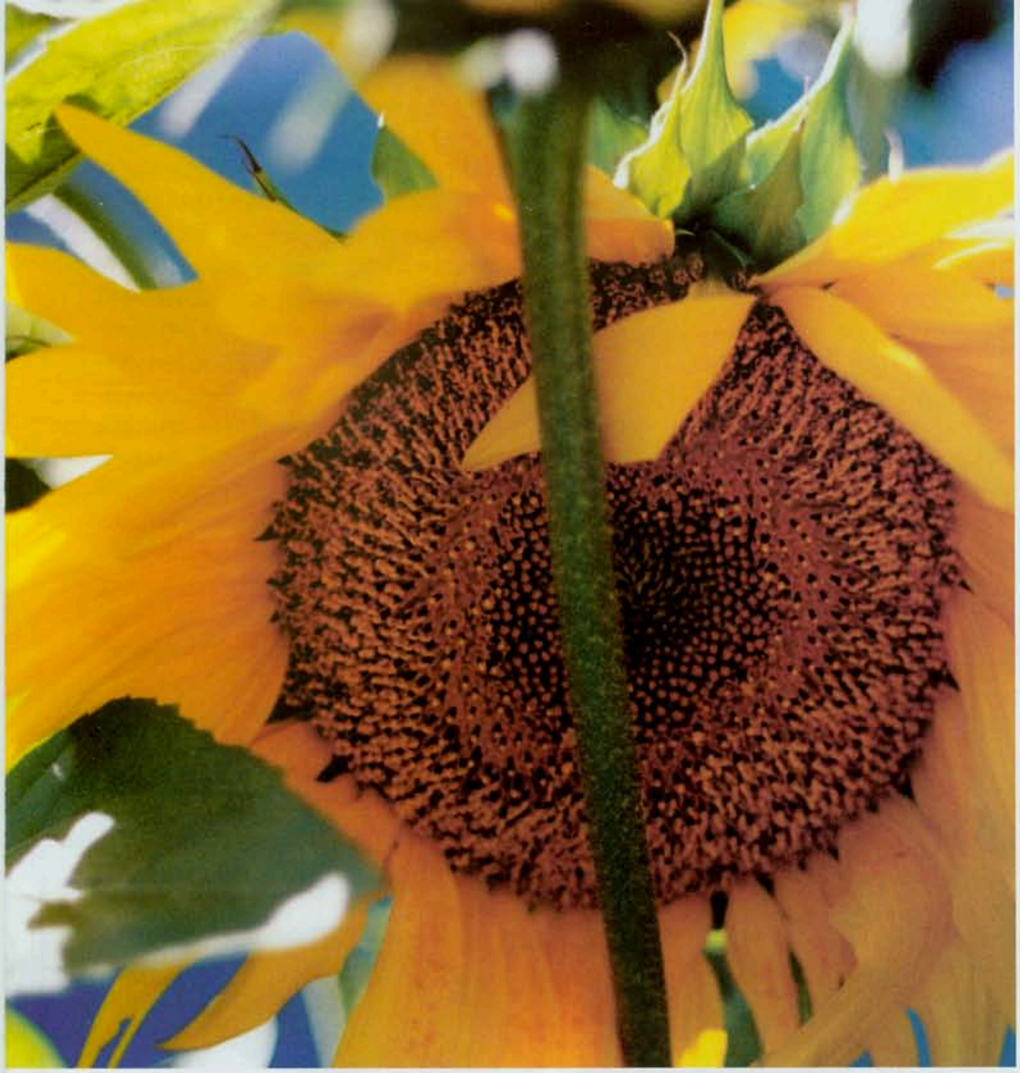
PAUL ZARETSKY

In a reconstructed marsh, European rabbit's foot grass has been shown to reduce toxic levels of selenium.

The need for green cleanup methods is great. By some estimates, the United States alone could spend a staggering $700 billion to clean up spills from factories, former military bases, mines, and farms. More than 30,000 sites across the country are candidates for hazardous waste treatment services. These include everything from otherwise pristine pine forests to inner city lots that once housed industries such as battery plants. Contaminated with toxins, many of these "brownfields" remain abandoned because the cities responsible for them are too cash-strapped to clean up the mess.

Cleaning these sites is both labor intensive and costly. The standard method, often referred to as "suck, muck, and truck," involves digging up contaminated soil, mixing it with a sealant such as cement, and transporting it to a specially designed hazardous waste site. The resulting refuse not only takes up precious space at dumps but leaves an open door for pollution to leak back into the environment.

"Worldwide, enormous tracts of land have been lost to contamination from mining, weapons production, and industrial



The cheery sunflower has lent its contamination cleanup skills to the grim aftermath of the Chernobyl nuclear reactor meltdown. Flowers grown on waterborne rafts with their roots dangling below accumulated radioactive strontium and cesium at concentrations thousands of times greater than the surrounding water.

activities," says Norman Terry, a plant physiologist with the University of California at Berkeley who studies phytoremediation. "The question now is what to do about it. You can't dig up a million acres of land and seal it away, and phytoremediation appears to be a pretty economical way of dealing with the problem." Plants are relatively cheap to grow and easy to harvest. Those that accumulate toxins in their tissues can be landfilled or incinerated affordably.

Plants that thrive in nutrient-poor or toxic soils have evolved ingenious ways of dealing with toxins. They can store foul-tasting minerals in their tissues to thwart hungry insects. Or convert pollutants into less toxic forms like green alchemists. Still others chemically or physically immobilize contaminants, preventing them from migrating into other areas. Plants also rely on microbes that grow near their roots to both gather and neutralize soil toxins. These qualities make plants particularly useful for cleaning up wastewater and soils contaminated with heavy metals, organic compounds such as herbicides, and radioactive waste.

Exactly how plants accomplish these feats remains somewhat of a mystery, according to Joel Burken, a civil engineering professor at the University of Missouri at Rolla. "So far, we've looked at a limited number of plants and a limited number of contaminants, so we're still not sure of the processes involved, or even of the end products in many cases," he says. Burken is using poplar tree hybrids to break down organic contaminants such as carbon tetrachloride, once used as a dry cleaning solvent, and tricholoroethylene, used to degrease engine parts.

There's certainly more to phytoremediation than meets the eye. Thoma's crabgrass is one case in point. "Crabgrass is pretty hardy stuff," Thoma says. "For phytoremediation to succeed, the plant has to be able to grow in heavily contaminated soils, and we've had good luck growing crabgrass in soil that's as much as nine percent crude oil by weight." But the grass itself doesn't actually break down the oil—it just helps deliver the construction workers to the site.

"The great thing about plant roots," says Paul Schwab, an agronomy professor with Purdue University, "is that they send out this network of tiny filaments that actually carry the microbes into areas of the soil you couldn't reach under other circumstances. The plants themselves have a limited ability to deal with the complex hydrocarbons found in petroleum, but the microbes are another story." These bacteria live in concentrations 1,000 times higher around plant roots than in soil just a few feet away and feed on the complex chains of carbon and hydrogen that make up petroleum products.

Schwab and his wife, civil engineering professor Katherine Banks, are testing alternative cleanup methods at an old coal-to-natural gas refining site 90 miles south of Indianapolis. Their experiments suggest that garden-variety clover, which sends a network of very fine roots deep into the soil, can consume up to 80 percent of petroleum toxins in moderately contaminated soil within three years.

While oil spills pose a major problem for certain regions of the country, lead pollution is much more widespread. Lead was routinely added to house paints and gasoline as late as the 1970s. Then people realized that growing bones absorb lead much like calcium, and children exposed to the element suffer health problems ranging from impaired intelligence to serious nerve damage.

Today, many cities still contain lead-contaminated areas. One such brownfield was the site of a former paint store in Hartford, Connecticut. Tests revealed that the

1.2-acre vacant lot harbored levels of lead exceeding 7,000 ppm in some areas, or 1.4 times the maximum level of lead exposure permitted by the Environmental Protection Agency for residences or agricultural land. Then Hebe Guardiola-Diaz, assistant professor of biology and neuroscience at Trinity College in Hartford, turned the site into a phytoremediation success story. In 1999, six of her undergraduate students sowed Indian mustard (*Brassica juncea*), known to aggressively accumulate lead, on an experimental plot to see if the plants could help cleanse the site.

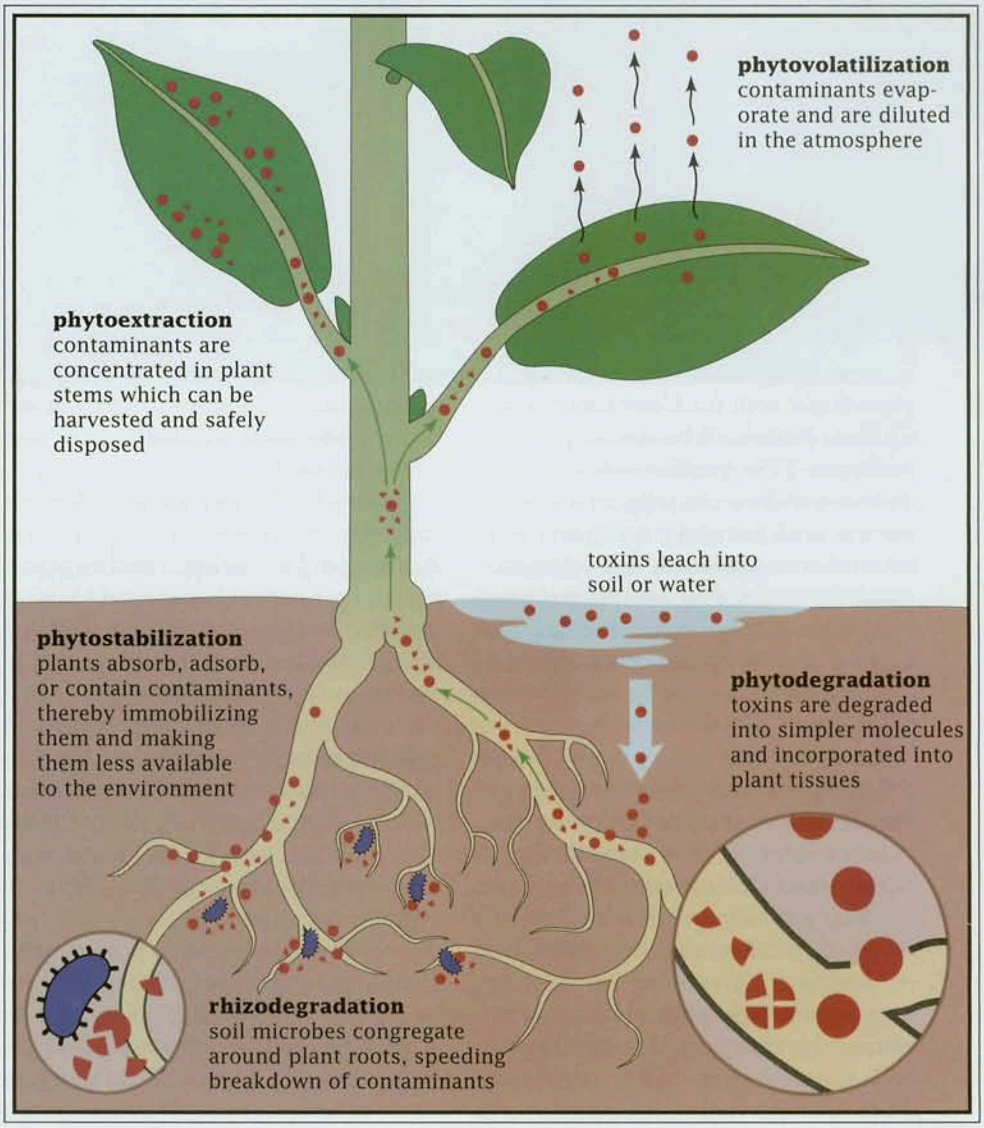
After only two planting and harvesting cycles, the mustard had cut lead levels on the plot by an astonishing 66 percent, exchanging hundreds of cubic yards of contaminated soil for just a few pounds of incinerated plant ashes destined for the local hazardous waste dump. "What we did on that small plot inspired the city to find the money to clean up the rest of the area," says Trinity chemistry professor David Henderson. Today, the formerly blighted spot is home to a neighborhood park and a flourishing vegetable garden.

HUMANS AREN'T THE ONLY VICtims of environmental pollution. In the 1980s, biologists noticed that something had gone awry for the many thousands of resident and migratory birds at the former Kesterson Reservoir in California's Central Valley. Runoff from farmers' fields had carried high levels of naturally occurring selenium in local soils down into the marsh. The result, says UC Berkeley's Terry, "was a nightmare that included massive bird die-offs and chicks being born with terrible deformities. It attracted global attention."

The fiasco at the reservoir, which has since been filled in to discourage wildlife use, inspired Terry to see if phytoremediation could offer a solution. He knew that plants could amass large quantities of selenium in their tissues, because in the 1930s, cattle in the Midwest had developed a condition called "the staggers" from the plants they were grazing on. "The animals would develop the shakes, then collapse and die because of the toxic effects of the huge amounts of selenium they were consuming," Terry says.

An ideal site for experiments lay right in his backyard: the Chevron oil refinery in Richmond, California. Selenium and other contaminants present in the crude oil were being extracted and discharged with the wastewater straight into San Francisco Bay. Chevron built an artificial wetland at the site to help clean contaminants from its effluent. According to Terry's calculations, the Chevron wetland processes up to 8 million liters of refinery effluent every day and reduces the concentration of selenium from 30 parts per billion (ppb) selenium per liter to less than 4 ppb. He discovered that the plants' enzymes convert the selenium into a form that evaporates as a gas through leaves and roots. At harvest, the plants retain so little selenium in their tissues that they can be used as a supplement for cattle feed.

Following up on the Chevron wetlands' success, Terry and colleagues constructed more wetland ponds near the farm community of Corcoran, California, to see how best to reduce selenium levels in agricultural runoff. They stocked the wetland with native marsh plants including saltmarsh bulrush *(Scirpus robustus)*, rabbit's foot grass *(Polypogon monspeliensis)*, cattail (family *Typhaceae*),



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and widgeon grass *(Ruppia maritima)*. The wetland slashed levels of the toxin from 25 ppb to fewer than 5 ppb.

In the lab, Terry demonstrated that genes from the bacterium *E. coli* and the lab rat of the plant world, thale cress (*Arabidopsis thaliana*), could help boost selenium assimilation of Indian mustard and poplar trees. The introduced genes helped the plants grow more root hairs, which increased the amount of surface area available to absorb toxins. They also found that bacteria around the plants' roots manufactured a chemical compound that helped them absorb selenium.

The Terry lab and other researchers have also genetically modified plants to take up heavy metals. Terry demonstrated that genes from the bacterium *E. coli* increase the ability of plants to take up and tolerate large amounts of cadmium.

Plants that accumulate metals generally do so by producing proteins that bind them. "They can't just get up and walk away, so they have to find some way to deal with toxics like lead. By binding with these metals, they allow natural cellular processes to move these contaminants into vacuoles, little containers within the cell" that keep the toxins from poisoning the plant, says Julian Schroeder, a biologist at the University of California at San Diego. Schroeder recently discovered one of the genes that gives plants the ability to detoxify heavy metals. He says plants probably use up to ten genes to accomplish these tasks, all of which can easily be inserted into large plants such as trees that could take up larger volumes of toxins.

On the other side of the world, researchers Chris Anderson and Robert Brooks of Massey University in New Zealand discovered that plants can be used as miners to pull minerals out of the soil. In 1977, they realized that plants in the cabbage family can accumulate metals at concentrations thousands of times greater than in the surrounding soil. "We got this idea that, if you could somehow convince a plant to absorb a high enough level of some metal, they could be used to mine in certain areas," Anderson says. They've

Chevron Corporation planted an artificial marsh to help cleanse the effluent its Richmond, California oil refinery was sending into San Francisco Bay. The wetland has been a boon to the environment, removing almost 90 percent of the selenium from refinery outflows.

PAUL KAGAWA/CHEVRON

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Ordinary marsh plants such as cattails can pull out toxins from refinery wastewater while affording precious wetland homes to native wildlife.

Pickleweed the Magician

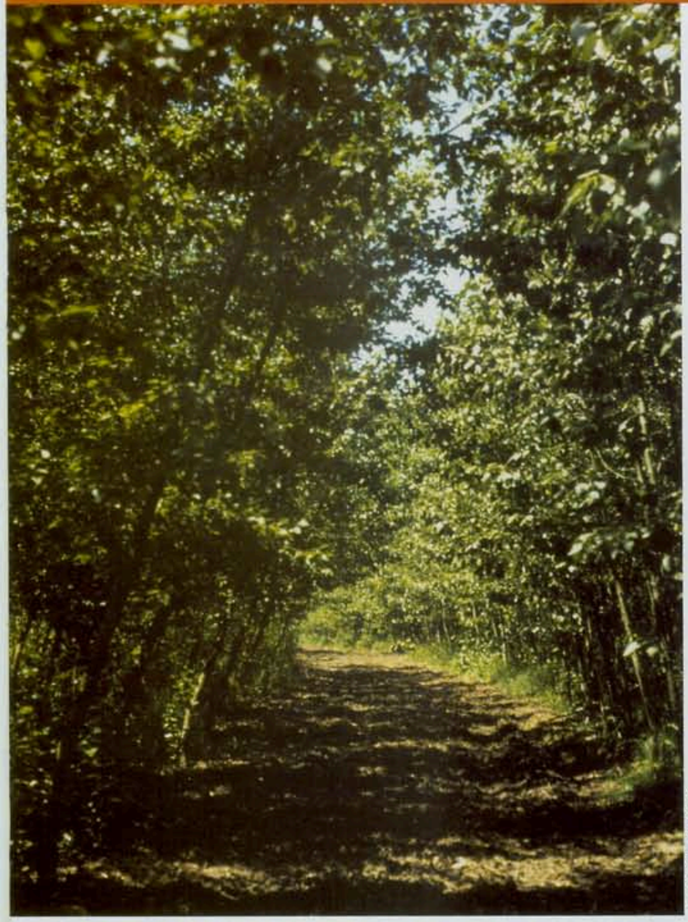
A common marsh plant with an uncanny resemblance to tiny sweet gherkins could be the answer to San Joaquin Valley farmers' soil contamination problems. Irrigation leaches naturally occurring selenium from Valley soils and concentrates it in runoff ditches. The standing water poisons wildlife and the salts left behind make plants grown on the soil toxic. Recent research by scientists in Norman Terry's University of California laboratory shows that beds of annual pickleweed **(Salicornia bigelovii)** *irrigated with contaminated drainage water is more efficient at removing selenium than any other plant tested. The plant absorbs and releases the selenium into the atmosphere as a gas, where prevailing winds can disperse the element throughout the West. Also known as sea asparagus and glasswort, pickleweed is a staple food for the endangered salt marsh harvest mouse.*

since found that plants can hyperaccumulate elements such as nickel, lead, and cadmium, making them ideal for cleaning up mine tailings.

Some purists might say that using genetically modified plants for phytoremediation is just swapping one evil for another. But it's all relative, Schroeder argues. "A sunflower is the expression of 50,000 genes, many of which have already been modified by humans. To make a sunflower a good remediator, you might have to add another ten genes, which is much less of an influence than humans have already had."

IT SOUNDS EASY ENOUGH TO TOSS some seeds on a contaminated lot and grow those hazardous waste worries away. But according to Scott Cunningham, a senior research scientist with DuPont, "it's never that simple." He says even those most eager to try phytoremediation might hand in their hoes when they discover the bureaucratic regulations they'll need to battle before starting a project. The laws in most states regulating cleanup of hazardous soils tend to hinder experimental cleansing methods such as phytoremediation.

When Cunningham's company tried using plants to clean up a contaminated site, he discovered that the very act of digging a hole constituted a legal catch-22. "If you're dealing with contaminated soil," he says, "once you lift a shovelful of dirt out of the ground, you've changed the legal status of the material from hazardous material to hazardous waste, and if you then dump it alongside the hole you're digging, you've then landfilled hazardous waste, which requires special permits. And once you put the soil back around the plant's roots, that's



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Top: This former construction debris landfill site in Beaverton, Oregon, has gone from a barren wasteland in 1990 to a thriving poplar grove. The trees' roots immobilize contaminants and prevent them from spreading into the environment. Above: Wastewater from a landfill collection pond in McMinnville, Oregon, is pumped to this 14-acre plot of poplar trees, which absorb the wastewater and metabolize the contaminants.

Both projects use hybrid trees developed and patented by Ecolotree®.

land-disposing a known hazardous waste, which requires a permit to operate a land disposal unit."

Moreover, hyperaccumulator plants can't just be thrown on a compost pile when their work is done. They must be treated as toxic waste and landfilled, incinerated, or processed to reclaim minerals such as lead. Still, the volume these plants or their ashes occupy at disposal sites is many times smaller than the volume of soil they can clean.

Industries are now bullish on phytoremediation, because it could make a real difference to their bottom lines. The cost of cleaning up polluted sites using traditional engineering approaches ranges from $10 to $100 per cubic meter of soil on site, and up to three times that if the soil must be carted off to a distant hazardous waste facility. By comparison, phytoremediation can cost as little as five cents per cubic meter. That would be a boon for mom and pop oil producers like many of those in Arkansas, who can ill afford the price tag of cleanups that can cost tens to hundreds of thousands of dollars for even small sites.

From a few university research projects, the phytoremediation field has expanded in the last ten years to include dozens of universities and private firms across the country. For example, Virginia-based Edenspace Systems relies on garden staples such as sunflowers to draw radioactive uranium and cesium from the water supply. Researchers like Richard Meagher at the University of Georgia are experimenting with genetically modified poplar trees to detoxify methyl mercury, which is used in industries such as mining.

"If the producer could rely on something like phytoremediation, appealing because of its low cost and high efficiency, that would be a tremendous advantage," says Kerry Sublette, director of the Integrated Petroleum Environmental Consortium, a group of universities developing environmentally friendly ways to solve petroleum industry pollution. "I think phytoremediation could be one very valuable bullet in our gun." He envisions a day in the future when phytoremediation might be as natural a part of an oil field as the rigs themselves.

Although plants aren't able to remove 100 percent of the toxins from the soil they're planted in, "I think we should also consider whether that's really necessary," says Purdue University's Schwab. "Maybe the goal should be a reasonable and safe endpoint, rather than striving for something which might not be possible."

No one believes phytoremediation is a "magic bullet" for every type of environmental contamination. Because the process goes only as fast as plants can grow, it can't be used when the pollution problem poses an immediate threat to people's lives. And plants' roots can't reach toxins that have seeped deep into the soil.

Additionally, pressing environmental questions about phytoremediation remain unanswered. "You can't treat phytoremediation as a low-cost, walk-away technology, which many people want to do," Burken says. It can be difficult to prevent the toxins of hyperaccumulating plants from entering the food chain through large animals and insects. No one knows if genetically modified plants used for phytoremediation will cross with wild plants and how that might affect their populations. And the effect of toxin-processing wetlands on nearby ecosystems essentially remains a black box.

Still, phytoremediation is proving to be an effective and relatively benign way to cleanse the environment of industrial wastes. Green plants and sunflowers are far more pleasant than mile after mile of sludge ponds and concrete-lined waste disposal sites. "Sow, grow, and hoe" has a certain ring to it.

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