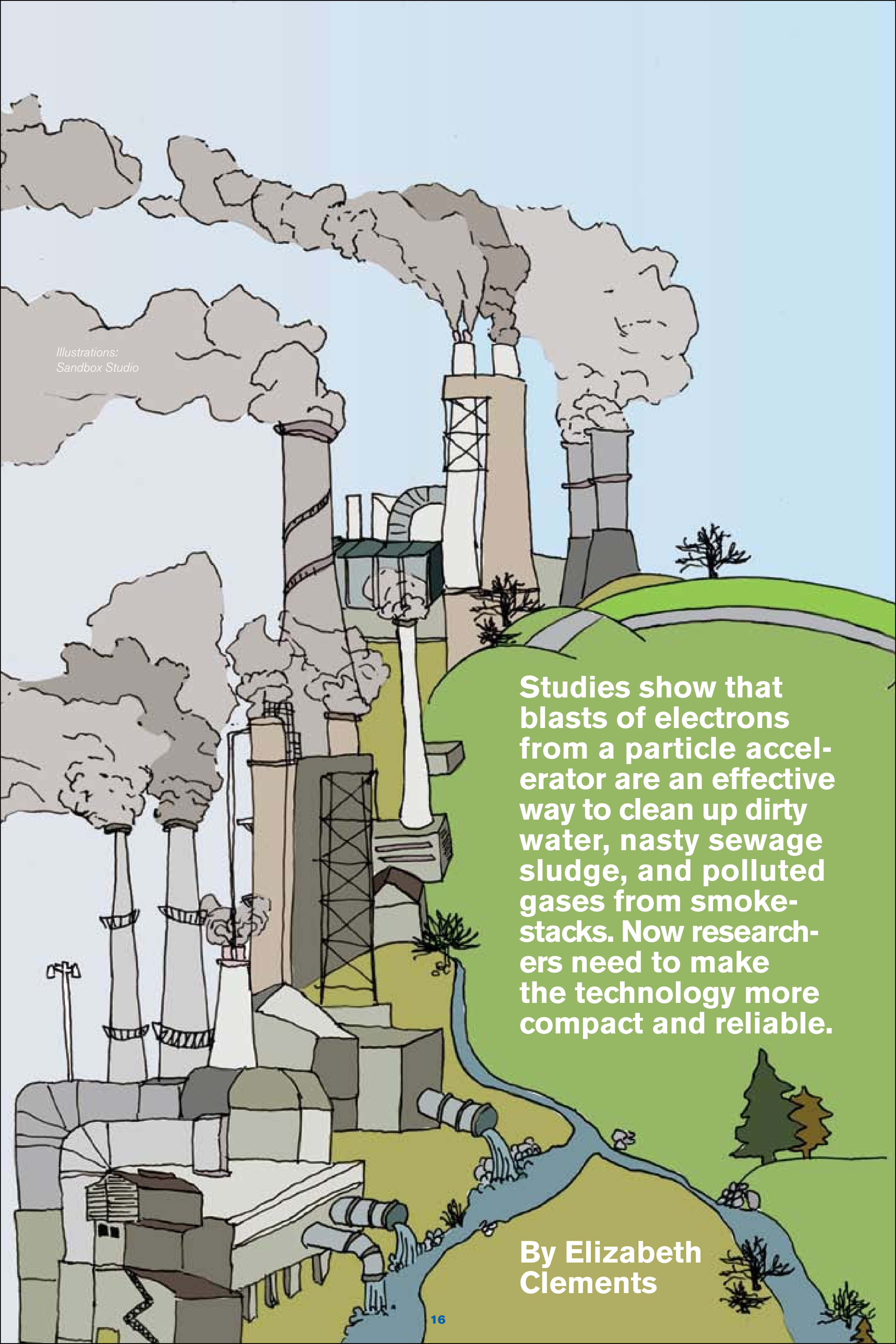
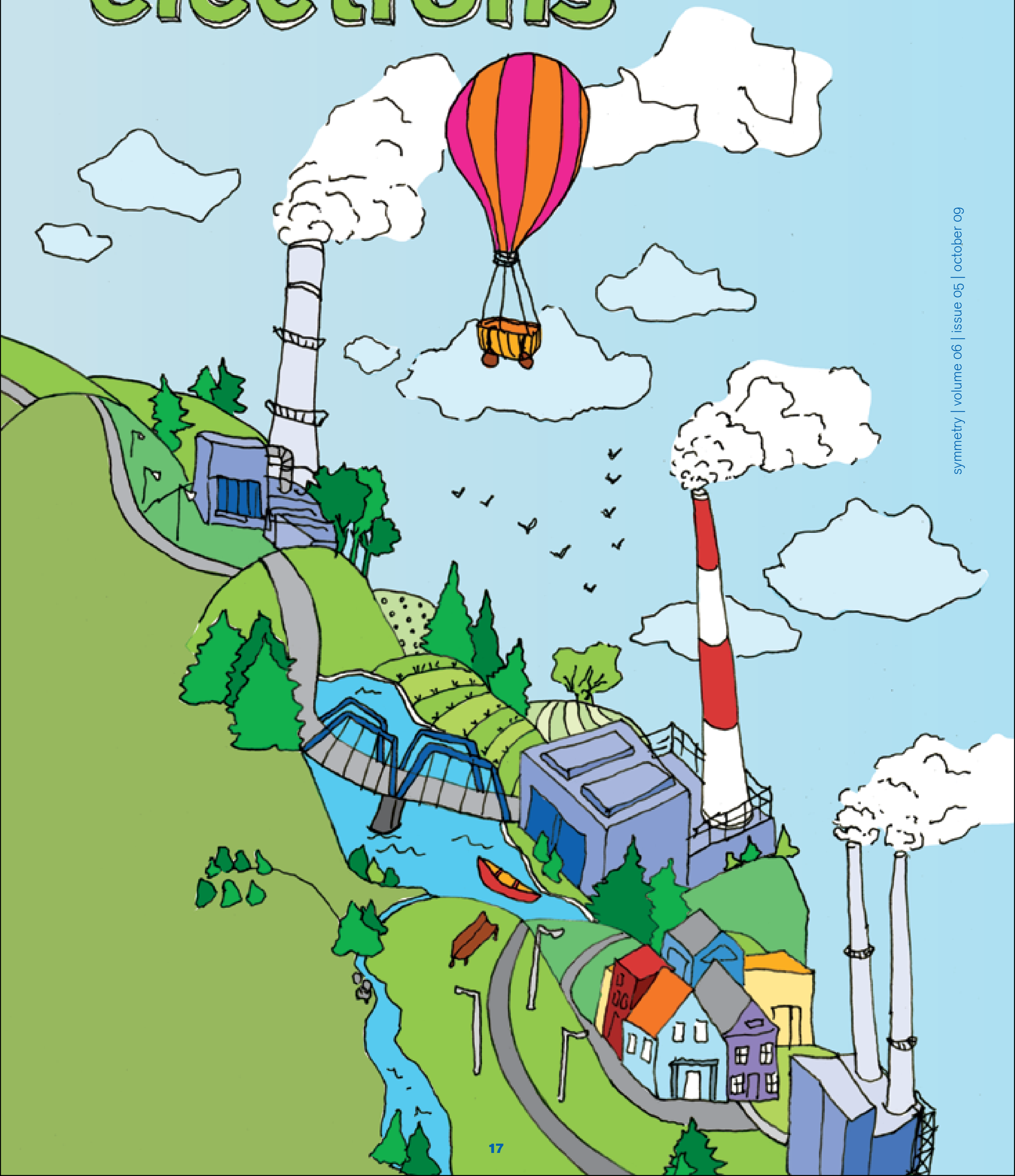


Illustrations: Sandbox Studio

Studies show that blasts of electrons from a particle accelerator are an effective way to clean up dirty water, nasty sewage sludge, and polluted gases from smokestacks. Now researchers need to make the technology more compact and reliable.

By Elizabeth Clements

Cleaner living through electrons



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In 1988, two chemists and an environmental engineer turned an abandoned wastewater sludge treatment plant in Miami, Florida into a pilot plant to test a novel technology. They sought to determine if electron beams could remove microorganisms, toxins, and harmful chemicals commonly found in drinking water.

Funded by the US Environmental Protection Agency and National Science Foundation, Charles Kurucz and Thomas Waite of the University of Miami and William Cooper of Florida International University learned how to operate the electron accelerator, conducted experiments and showed, in one of the first large-scale demonstrations of its kind, that a beam of high-energy electrons can effectively and economically treat waste.

Today the pilot plant is abandoned. The accelerator and other equipment remain, but no research has taken place there for more than a dozen years, and not a single facility in the United States treats wastewater or sewage sludge with accelerated electrons.

Cooper, now an environmental chemist and director of the Urban Water Research Center at the University of California, Irvine, believes this can change. A renewed interest in climate change combined with new developments in accelerator technology, he says, make electron beams an optimal treatment method. "The process is not dead yet," Cooper says. "Now is the time to revisit it."

The world's woeful state

Recent years have brought increasing awareness of the impact human activities have on the environment.

The average global temperature rose one degree Fahrenheit over the past century. Fossil fuel emissions from power plants foul the air and are a culprit in global warming. The emissions contribute to dense brown clouds that hang over cities like Los Angeles and Phoenix, triggering asthma and other respiratory problems.

At the same time, a dramatic increase in the world's population has created a global freshwater crisis. Only three percent of the world's water is fresh, and one third of that is inaccessible. Of the planet's 6.5 billion people, 1.5 billion do not have access to clean drinking water, leading to millions of unnecessary deaths a year.

A growing number of scientists believe, like Cooper, that particle accelerators could help make the Earth a little greener by providing a more effective way to clear the air and provide clean drinking water.

Proven, but slow to spread

The idea of using electron beams to treat flue gases, wastewater, and sewage sludge originated in Japan in the 1970s.

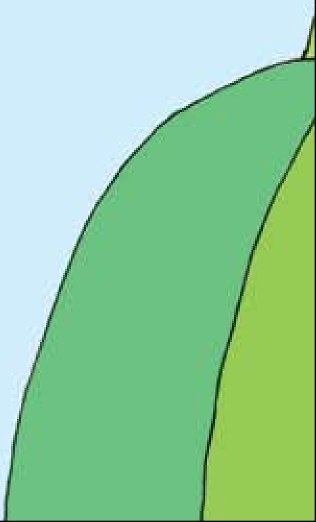
American institutions started researching electron-beam technology for environmental applications around the same time, fueled by grants from an institution established by President Richard Nixon in 1970: the Environmental Protection Agency.

While environmental applications of particle accelerators have made little progress commercially in the United States in the last 40 years, a number of countries in Asia, Europe, and the Middle East are actively pursuing the technology.

In Daegu, Korea, an electron-beam accelerator in a textile factory removes toxic dyes from 10,000 cubic meters of wastewater per day. In Szczecin, Poland, the Pomorzany power station installed an electron-beam accelerator in its coal plant to simultaneously remove sulfur dioxides and nitrogen oxides from roughly 270,000 cubic meters of flue gas per hour. China has started to use electron beams to control air pollution, and a facility in Bulgaria is under construction. Saudi Arabia may soon follow.

Despite the number of new facilities established in the last decade, overall commercial growth remains slow.

"We have proven that the technology works," says Andrzej Chmielewski, director of the Institute of Nuclear Chemistry and Technology in Warsaw, Poland. "The size of the accelerators can be huge, though. We need a technological breakthrough" to make accelerators smaller and easier to maintain.



Turning smokestacks green

For gases from the smokestacks of factories and power plants, the objective is to destroy sulfur dioxides and nitrogen oxides, pollutants that combine with water vapor in the atmosphere and react with sunlight to create acid rain and smog. Conventional treatment typically removes sulfur by scrubbing the flue gas with limestone, a complex process that creates wastewater. A separate scrubbing removes nitrogen oxides. Electron-beam technology removes both at once and does not generate any waste.

The treatment starts with a conditioning process that cools the flue gas by adding water and ammonia. The conditioned gas streams into a chemical reactor, where it's hit with a beam of electrons accelerated to energies of 800,000 to 1.5 million electronvolts. This triggers chemical reactions that convert sulfur dioxides and nitrogen oxides into ammonium sulfate and ammonium nitrate.

The clean flue gas goes out the chimney; and as a bonus, the ammonium sulfate and ammonium nitrate can be sold as ingredients for fertilizer.

Pilot plants and operating industrial facilities in Poland have demonstrated that electron-beam technology can remove at least 95 percent of the sulfur dioxides and 70 percent of the nitrogen dioxides in flue gases, making them competitive with, if not more efficient than, conventional treatments.

In addition, studies show that large-scale electron-beam flue-gas treatment facilities have cost advantages over conventional plants. "Operation costs can be cheaper by about 15 percent," Chmielewski says. "Most importantly, the process creates products that plants can sell later on."

However, the cost of retrofitting power plants to house the electron-beam equipment, combined with the difficulty of building reliable accelerators that operate with very little downtime, has created obstacles for the technology.

The treatment begins with a conditioning tower that cools the flue gas. The cooled gas moves into an accelerator, where an electron beam triggers a chemical reaction to convert the sulfur dioxides and nitrogen oxides into ammonium sulfate and ammonium nitrate. The electrostatic precipitator removes the sulfate and nitrate byproducts and collects them to be sold to fertilizer companies. The clean gas goes out the chimney stack.

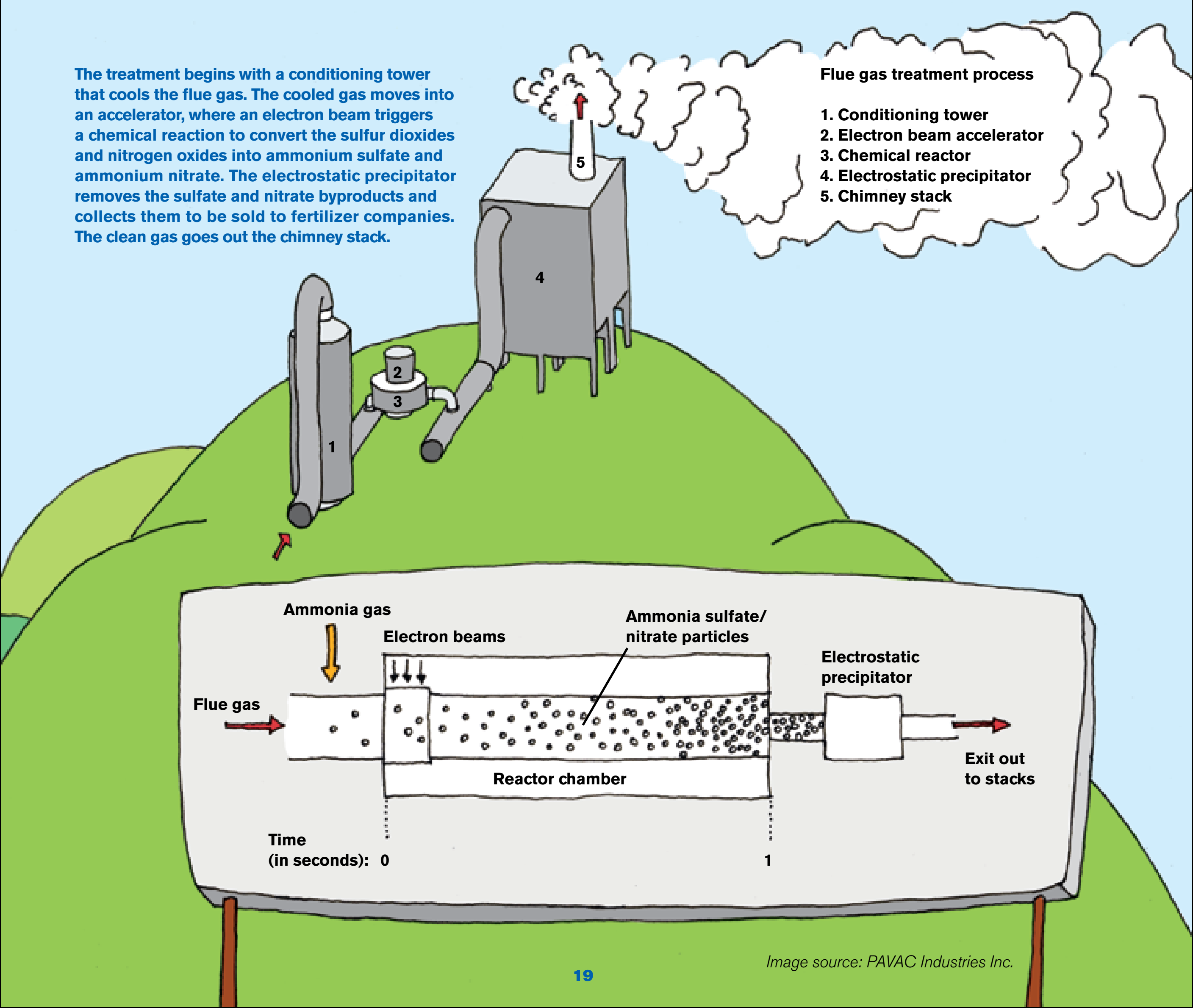


Image source: PAVAC Industries Inc.

Clean water in fewer steps

Traditionally, wastewater treatment plants use a three-step process: A disinfectant, such as chlorine, kills microorganisms. Filters extract suspended solids. Finally, pipes that contain additional disinfectants distribute the treated water. Breaking down organic molecules such as benzene, an industrial solvent used in the production of drugs, plastics, and rubber and which is a known carcinogen, can require several treatments, known as digestions.

"By contrast, when you blast wastewater with an electron beam, it produces huge concentrations of hydrogen and hydroxyl free radicals that are extremely aggressive chemically," says Peter McIntyre, an accelerator physicist at Texas A&M University and president of Accelerator Technology Corporation, a Texas company that develops applications for technologies arising from accelerator technology, such as superconducting cable. "The bottom line is with an electron beam, in one process you can make a digestion go from hazardous to trace levels that are benign."

By the year 2050, the world's water supply will need to support an additional 2.7 billion people.

From foul muck to fertilizer

The same process applies to sewage sludge.

The United States and Europe together produce more than 13.8 billion tons of sewage sludge each year. Clean sewage sludge is a valuable commodity; in the United States, about 40 percent of sludge is applied to land as fertilizer, so any bacteria, viruses, and parasites in it must be destroyed.

One conventional treatment technique, called "sludge wasting," creates a microorganism brew in which bacteria grow and feed on one another. Then a centrifuge squeezes water out of the sludge, leaving a paste that can be heat-sterilized to produce dry particles for fertilizer.

Seventy percent of industrial waste in developing countries is dumped untreated into the water supply.

Studies at pilot plants show that high-energy electrons can remove 99.9 percent of bacteria from sludge. Industries worldwide use the same technique to sterilize medical products for hospitals.

But even though the EPA approved electron beams as a way to produce Class A sludge that is safe for agricultural purposes, treatment plants don't use the technology.

"It is a question of the manpower needed," says Mike Thayer of the New England Fertilizer Company. "A smaller operation wouldn't be able to handle it."

One in six people worldwide does not have access to clean drinking water.

No breakdowns, please

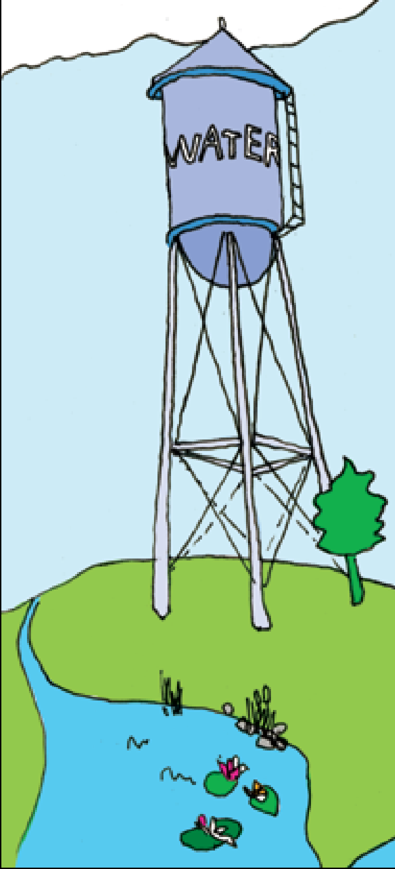
Now that pilot plants have proven the effectiveness of electron beam treatment, the next step is to develop low-maintenance accelerators that can operate around the clock to meet the demands of a full-scale treatment plant.

Reliability is critical. If an accelerator in a power plant shut down, flue gas would continue to flow out the chimney. Soon the unfiltered emissions would exceed permitted levels, and the power plant would get hit with a fine.

"Reliability is the biggest factor," says Ralf Edinger, president of PAVAC Industries, a company near Vancouver, Canada that is commercializing the technology for flue-gas treatment. "People are excited about electron-beam technology, but they are not excited if it doesn't work year round, about 8500 hours a year."

Edinger's company has patented a design for flue-gas treatment that fits two parallel accelerators inside a compact container; if one breaks down or closes for maintenance, the other keeps running. The system can be operated by trained technicians and does not require an accelerator expert at the power plant. "We can monitor the accelerator and address any maintenance issues online," Edinger says. "It is a completely integrated and reliable system."

He hopes to obtain government funding to install the patented design in several small power plants in Brazil, Canada, India, and the United States.



Saving lives

In Texas, McIntyre has a similar plan for wastewater treatment facilities. He patented a design for a compact, highly efficient accelerator, driven by a single electric motor or gas-powered engine, that can produce electron beams with energies of up to two million electronvolts. The sealed system has the capacity to treat the waste from a city of 25,000 people. McIntyre also hopes to get government funding to install the compact units in wastewater treatment plants. Eventually he would like to take the units to villages in Africa that don't have access to clean drinking water.

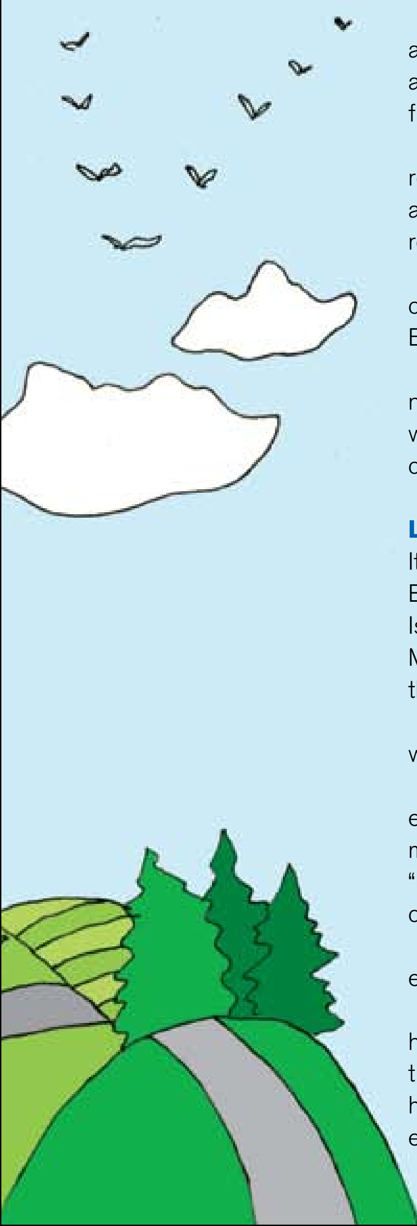
"More people die from contaminated water in this world than from any disease," McIntyre says. "Electron beams have the capacity to treat water for a sizeable town with a sealed unit that can be powered by a diesel engine."

Edinger credits research and development at national laboratories and universities for advancements in accelerator technology. "Without the institutions, there is no chance that the electron-beam technology would ever become commercially available," he says. "When we get a new technology, we need the institutions to first understand how it works. Industry then figures out how to make it easier to manufacture."

An abandoned plant recycled

In 1976, a group from the Massachusetts Institute of Technology built the first US electron-beam test facility at the Deer Island Treatment Plant near Boston, Massachusetts. It operated for a few years and inspired the Miami-Dade Water and Sewer Authority to install an electron-beam wastewater sludge unit in its new treatment plant in southern Florida.

Miami-Dade invested $1.75 million to construct the plant, equipped with a 1.5 million electronvolt accelerator to treat one million gallons of sewage sludge a day. But just one year after starting operations in 1984, the electron-beam facility closed.



"The idea was to use the treated sludge as a soil conditioner, but then the regulations changed," Cooper says. "They weren't allowed to use the sludge for agricultural purposes anymore because of the close vicinity to the only water resource. So they stopped using the facility."

Three years later, Cooper and his team arrived on the scene with an army of graduate students. They reactivated the plant in 1988, naming it the Electron Beam Research Facility.

"It provided us with an unbelievable opportunity," Cooper says. "It was a phenomenal research facility because it had sludge, secondary water, potable water, plus two 6000-gallon trucks that we could fill with multiple combinations of waste."

Looking ahead

It took the team about a year to refurbish the abandoned plant. The High Voltage Engineering Corporation, the company that built the accelerators for the Deer Island pilot plant in the 1970s and the Miami-Dade plant in the 1980s, trained the Miami team—which had no previous experience with accelerators—to operate the equipment.

"The accelerator we had was a simple, rugged machine," Cooper says. "After we got trained, we ran it all the time on our own."

During the Electron Beam Research Facility's eight years of operation, which ended when funding ran out, the team demonstrated that accelerators are the most economically competitive method for treating wastewater and sewage sludge. "It's the only method that takes care of both the biological and toxic components of wastewater in one process," Cooper says.

Today Cooper would like to see how electron beams would work for treating emerging pollutants, such as pharmaceuticals in drinking water.

He especially likes the idea of using the old pilot plant as a teaching facility. "The hardware is perfect. The accelerator is perfect," Cooper says. "It's just sitting there." Given some funding and some elbow grease, Cooper bets that he could have the abandoned Miami accelerator back up and running in no time, moving electron-beam treatment one step closer to a cleaner future.