ANNALS OF INVENTION

HEARTH SURGERY

The quest for a stove that can save the world.

BY BURKHARD BILGER

Two men walked into a bar called the Axe and Fiddle. It was a Thursday night in early August, in the town of Cottage Grove, Oregon, and the house was full. The men ordered drinks and a vegetarian Reuben and made their way to the only seats left, near a small stage at the back. The taller of the two, Dale Andreatta, had clear blue eyes and a long, columnar head crowned with gray hair. He was wearing a pleated kilt, festooned with pockets and loops for power tools, and spoke in a loud, unmodulated voice, like a clever robot. His friend, Peter Scott, was thinner and more dishevelled, with a vaguely Biblical look. He had long brown hair and sandalled feet, sun-baked skin and piercing eyes.

None of the locals paid them any mind. Cottage Grove, like much of Oregon, is home to hippies and hillbillies in equal measure. At the Axe and Fiddle, lumbermen from the local Weyerhaeuser and Starfire mills sat side by side with former Hoedads—free-living tree planters who'd reforested large tracts of the Bitterroot and Cascade Mountains. The bar was flanked by a bookstore and, a few doors down Main Street, a store that specializes in machine guns. "I can't imagine that his market's that big," the bookstore's owner told me. "I mean, how many machine guns does a guy need?"

The featured act at the bar that night was a burlesque troupe from New York called Nice Jewish Girls Gone Bad. Just how they'd landed in the Oregon woods wasn't clear, but they stuck stubbornly to their set list. They sang a song about gefilte fish ("Fear Factor for Jews") and danced suggestively to Yiddish hip-hop. They promised to put the whore back in hora, and when that met with only polite applause—"Look it up on Wikipedia"—they asked for a show of hands from local Jews. There were five. Finally, near the end of the show, one of the performers—a spindly comedian with thick black glasses and a T-shirt that said "Freak"—peered out from under the spotlight and fixed her eyes, a little desperately, on Peter Scott. "Do you have a job?" she said, almost to herself.

Scott said no, then yes.

"That sounds fishy. What is it you do?"

Scott fidgeted for a second, then mumbled, "I make stoves for Africa."

"You what?"

"I make stoves for Africa."

Scott was being modest. In the small but fanatical world of stovemakers he is something of a celebrity. ("Peter is our rock star," another stovemaker told me.) For the past seven years, under the auspices of the German aid agency GTZ, Scott has designed or built some four hundred thousand stoves in thirteen African countries. He has made them out of mud, brick, sheet metal, clay, ceramic, and discarded oil drums. He has made them in villages without electricity or liquid fuel, where meals are still cooked over open fires, where burns are among the most common injuries and smoke is the sixth leading cause of death. In the places where Scott works, a good stove can save your life.

He and Andreatta were in Cottage Grove for Stove Camp. A mile or two from the Axe and Fiddle, a few dozen engineers, anthropologists, inventors, foreign-aid workers, and rogue academics had set up tents in a meadow along a willowy bend in a fork of the Willamette River. They spent their days designing and testing wood-burning stoves, their nights cooking under the stars and debating thermodynamics. Stove Camp was a weeklong event hosted by the Aprovecho Research Center—the engi-

ADRIAN TOMINE

Devising the perfect stove could prevent one and a half million deaths a year in developing countries, and reduce carbon emissions.

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neering offshoot of a local institute, education center, and environmental collective. Now in its tenth year, the camp had become a kind of hippie Manhattan Project. It brought together the best minds in the field to solve a single, intractable problem: How do you build cheap, durable, clean-burning stoves for three billion people?

A map of the world's poor is easy to make, Jacob Moss, a Stove Camper who works for the Environmental Protection Agency and started its Partnership for Clean Indoor Air, told me. Just follow the smoke. About half the world's population cooks with gas, kerosene, or electricity, while the other half burns wood, coal, dung, or other solid fuels. To the first group, a roaring hearth has become a luxury—a thing for camping trips and Christmas parties. To the second group, it's a necessity. To the first group, a kitchen is an arsenal of specialized appliances. To the second, it's just a place to build a fire.

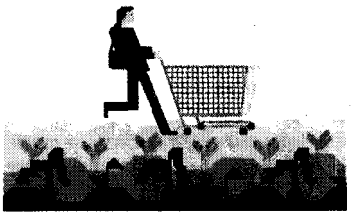
Clean air, according to the E.P.A., contains less than fifteen micrograms of fine particles per cubic metre. Five times that amount will set off a smoke alarm. Three hundred times as much—roughly what an open fire produces—will slowly kill you. Wood smoke, as sweet as it smells, is a caustic swirl of chemical agents, including benzene, butadiene, styrene, formaldehyde, dioxin, and methylene chloride. Every leaf or husk adds its own compounds to the fire, producing a fume so corrosive that it can consume a piece of untreated steel in less than a year. The effect on the body is similar. Indoor smoke kills a million and a half people annually, according to the World Health Organization. It causes or compounds a long list of debilities—pneumonia, bronchitis, emphysema, cataracts, cancers, heart disease, high blood pressure, and low birth weight—and has been implicated in a number of others, including tuberculosis, low I.Q., and cleft palate, among other deformities.

A well-made stove can easily clear the air, by piping the smoke out through a chimney or burning the fuel more efficiently. Yet most appliance manufacturers see no profit in making products for people who can't pay for them. And most aid agencies have found easier ways to help the poor—by administering vaccines, for instance. Stovemakers are a chronically underfunded bunch, used to toiling in the dusty margins of international development. Aside from a few national programs in Asia and the Americas, their projects have tended to be small and scattershot, funded a few thousand stoves at a time by volunteers and N.G.O.s. "We've been watering this rock for a long time," Dean Still, the head of Aprovecho, told me.

Lately, though, the rules have changed. As global temperatures have risen, the smoke from Third World kitchens has been upgraded from a local to a universal threat. The average cooking fire produces about as much carbon dioxide as a car, and a great deal more soot, or black carbon—a substance seven hundred times as warming. Black carbon absorbs sunlight. A single gram warms the atmosphere as much as a fifteen-hundred-watt space heater running for a week. Given that cooking fires each release one or two thousand grams of soot in a year, and that three billion people rely on them, cleaning up those emissions may be the fastest, cheapest way to cool the planet.

In June, the sweeping Waxman-Markey climate bill was passed by the U.S. House of Representatives. Hidden among its fourteen hundred pages was a short section calling on the E.P.A. to identify ways to provide stoves to twenty million households in five years. The bill made no mention of how or where the stoves might be built, or who might pay for them. But there was talk of carbon-credit subsidies, international co-financing, and major-appliance manufacturers entering the fray.

The engineers of Stove Camp, in other words, found themselves suddenly blinking in the spotlight—like a band of raccoons caught digging through a scrap heap. "Kill a million and a half people and nobody gives a damn," one



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government official told me. "But become part of this big climate thing and everyone comes knocking at your door."

The entrance to Stove Camp was marked by a piece of weathered plywood, hung on a rusty railroad trestle, with the words "Fred's Island" spray-painted on it. The place wasn't technically an island—it was bordered by the river on two sides and the railroad on the third—but it did belong to a retired carpenter named Fred Colgan. When I arrived on a Sunday evening, he and Aprovecho's Dean Still showed me an old trailer where I could sleep, a few yards from the tracks. "Wait till that timber train comes through at four in the morning," Colgan said. He gripped an imaginary bedstead and rattled his head up and down. "If you see giant rats in the middle of the night, you haven't had too much to drink. We're infested with nutria."

Still laughed. "A nutria is a rodent," he said. "Entirely harmless."

"It's a rat the size of a cocker spaniel."

Before Colgan and his wife, Lise, bought the island, four years ago, it had belonged to a slaughterhouse and meat-packing operation, which left its buildings scattered across the grounds. Colgan offered the use of them to Still in 2006, after the stove program outgrew its original facilities a few miles up the road. The research center now has seven employees and a rotating cast of volunteers, who spend their time testing and developing stoves for projects worldwide. Their offices occupy a ramshackle complex along the river, with a wooden corral to one side and a labyrinth of labs, workshops, and storage rooms in back. Still holds his stove meetings in the meat locker, where the carcasses used to hang.

"Here's the deal," he told us one morning. "The world is absolutely littered with failed stoves. At the U.N., they laugh at us when we say that we have another project. So if we keep on blowing it we're in trouble." He peered at the bleary-eyed campers, about thirty strong, gathered around mismatched Formica tables. Jacob Moss, the E.P.A. official, sat next to a pulmonologist from the National Institutes of Health; Peter Scott had recently returned from Uganda, and others had worked on projects in Haiti, Honduras, Mexico, Malawi, Peru, India, and China. "It ain't easy," Still told them. "But it ain't impossible. We're going to be offered opportunities. But if there's going to be money for twenty million stoves we have to be ready. And we have to *not* screw this up."

Still, who is fifty-seven, is one of the presiding spirits of the stove community. He has a large ruddy face and a mop of white hair, a wide walrus mustache, and dark eyebrows that curve high above his eyes, giving him a look of perpetual, delighted surprise. Decades of living and working in hardscrabble villages have instilled an improbable ebullience in him, and a correlative roundness of form. I once compared him to Buddha when I was talking to Scott, who quickly corrected me. "Dean's a mystic Episcopalian," he said. "The only thing Buddhist about him is his girth." It's true that Still keeps plastic statues of St. Francis, the Virgin Mary, and the Archangel Michael glued to the dashboard of his truck. (Michael's flaming sword, he says, reminds him that "sometimes to make something good happen you have to kick people in the ass.") But when I was with him they were joined by well-foxed copies of William James and a book of Mad Libs. When it comes to stoves, he said, any spiritual guidance will do.

Earlier that summer, Still had flown to London to accept an Ashden Award for Sustainable Energy, presented by Prince Charles. To prepare for the ceremony and press interviews, he'd had to buy his first suit since his wedding twelve years ago, and the Ashden foundation had given him a week's worth of elocution lessons. ("The English, geez, they're so unconsciously imperialist.") Still has a clear but indecorous way of talking, with an old hippie's loitering rhythms and self-questioning asides. Although he has trained a generation of stove designers and built one of the world's premier stove-testing labs, his science is mostly self-taught and he's uncomfortable playing the expert. "I'm just the mouth," he told us, waving his hands at the engineers in the room. "These guys are the brains." They just needed a little prodding now and then.

He turned to the whiteboard behind him and scrawled out some bullet points

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with a pink marker. "This is now the definition of a good stove, according to Waxman-Markey," he said: "1. Reduces fuel use by more than fifty per cent. 2. Reduces black carbon by more than sixty per cent. 3. Reduces childhood pneumonia by more than thirty per cent. 4. Affordable ($10 retail or less). 5. Cooks love it. 6. Gets funded." The last three weren't in the bill, Still admitted, but no stove could succeed without them. And none had ever met all six criteria at once.

"So this is what we have to do this week, my dears," he said. "Save the damn world." He grinned. "I mean, you didn't want an easy problem, did you?"

Building a stove is simple. Building a good stove is hard. Building a good, cheap stove can drive an engineer crazy. The devices at Aprovecho looked straightforward enough. Most were about the size and shape of a stockpot, with a cylindrical combustion chamber and a cooking grate on top. You stuck some twigs in the chamber, set them on fire, and put your pot on the grate—nothing to it. Yet one stove used a pound of wood to boil a gallon of water, and another used two. Fire is a fickle, nonlinear thing, and seems to be affected by every millimetre of a stove's design—the size of the opening, the shape and material of the chamber, the thickness of the grate—each variable amplifying the next and being amplified in turn, in a complex series of feedback loops. "You've heard of the butterfly effect?" one engineer told me. "Well, these stoves are full of butterflies."

Like science and religion, stove design is riven into sects and disciplines. Some engineers use only low-cost materials like mud or brick; others dabble in thermoelectric generators and built-in fans—cleaner and more efficient, but also more expensive. Most stoves are built for combustion: they consume the wood and reduce it to ash. But a few are designed for gasification instead. These stoves heat the wood until it releases its volatile compounds, which are ignited in the air. (All that's left of the wood afterward is its carbon skeleton, which can be burned separately as charcoal or used as a fertilizer.) Gasifiers can be remarkably clean-burning, but they're also finicky. Because the fire burns at the top of the stove, rather than rising up from a bed of coals at the bottom, its flames are easily stifled when new fuel is added, turning the stove into a smoke bomb.

In the vestibule of the Aprovecho building, Still had set up a small "Museum of Stoves" on facing wall racks. Its contents came from more than a dozen countries, in an odd menagerie of shapes and sizes: an elegant clay chulha from India, a squat steel Jiko from Kenya, a painted coal burner from China, like an Easy-Bake oven. Most were better than an open fire, yet all had failed the test in some way—too flimsy or inefficient or expensive or unstable or unclean or hard to use. "We still haven't cracked the nut," Peter Scott said.

Scott had come to Stove Camp to build a better injera stove. Injera is the spongy pancake that Ethiopians eat with almost every meal. The batter is usually made of an ancient grain called teff, and fermented until it's bubbly and tart. It's poured onto a ceramic griddle, or *mitad*, then set over an open fire or a concrete hearth. In Ethiopia, injera is often cooked by women's coöperatives, in kitchens that may have forty or fifty smoky, inefficient stoves running simultaneously—one reason that the country has lost more than ninety per cent of its forests since the early sixties. "In the north, people will travel hundreds of kilometres to get wood, then double back to bring it to market," Scott told me. A good stove, he figured, could cut that fuel use in half.

For the past several months, Scott and his kilt-wearing friend Dale Andreatta—a mechanical engineer from Columbus, Ohio, who often did stove projects pro bono—had been collaborating on a prototype. It had an efficient ceramic combustion chamber, shaped like a miniature fireplace, with a round griddle perched above it like a tabletop. Scott had tried using a traditional *mitad*, since local cooks would much prefer it, but the ceramic wouldn't heat evenly, so he'd switched to steel instead. Steel conducts heat much more efficiently than ceramic, and it's often used for the plancha griddles in tortilla stoves. Injera, though, is an unforgiving dish. Its batter is thin and watery, so it can't be moved around like a tortilla, and any hot spots in the griddle will burn it. "The Ethiopians are unbelievably particular," Scott said. "If the injera doesn't have the exact size of bubble in the batter, they'll say it's garbage."

Luckily, Scott was used to improvising under much rougher conditions. His years in the African bush had left him, at forty, as sober and sinewy as Still was gregarious and stout. Scott had lived in mud huts in Swaziland, battled intestinal infections in Zambia, and been robbed by bandits in Uganda. When he first went to Africa for a stove project, in 2002, he was taken hostage on his third day, in an Internet café in Pretoria. "They tied us up, laid us on the ground, a gun at the back of the head," he told me. "I had a strong premonition that I was going to die. But I didn't die. So after that I didn't worry too much about my own safety." He went on to build stoves for refugees in the Congo, tobacco-curing barns in Malawi and Tanzania, and institutional stoves throughout eastern and southern Africa. In 2006, he became the first Aprovecho member to receive an Ashden Award. (As a Canadian, he told me, he was excused from the elocution lessons.)

Over the next few days, I'd periodically find Scott and Andreatta skulking around the Aprovecho workshops and laboratories, looking for tools or discussing metallurgy. Their preliminary tests had not been encouraging: the griddle was two hundred degrees hotter at the center than at the edge. When I asked Andreatta how it was going, he lifted an eyebrow. "The optimist thinks the glass is half full," he said. "The pessimist thinks the glass is half empty. The engineer knows the real truth: that the glass is twice as large as it should be for optimum utilization of resources."

When Aprovecho was founded, in the late nineteen-seventies, building stoves was a good deal less complicated. "Appropriate technology" was the byword then. Grounded in the teachings of Gandhi and the economist E. F. Schumacher, the philosophy held that poor countries are best served by low-cost, low-tech, local development. Better to teach villagers to make a stove than to give them stoves that they can't afford to repair or replace.

Aprovecho took the idea a step further. "We wanted to work as an inverse Peace Corps," Ianto Evans, one of the

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founding members, told me. Evans was an architect and ecologist who'd done research and volunteer work in Guatemala and was then teaching at Oregon State. Instead of exporting American know-how to the Third World, he and a small group of artists and academics decided, they would try to teach Americans to live more sustainably. "We would bring in villagers from Kenya or Lesotho, have them stay with us, and teach us what they knew—everything from cooking to growing things to assessing how much is too much." They would build a model Third World village in the Oregon woods.

In 1981, with the help of a Canadian foundation, the group bought forty acres of second-growth timber five miles west of Cottage Grove. The land lay on a south-facing slope at the end of a logging road. It was rough, marginally fertile ground, wet year-round and often freezing in the winter. But the new owners spared no effort in improving it. They deep-tilled the soil and enriched it with compost. They planted pear, apple, and quince trees, a grape arbor, and a bamboo grove. They built a library, a workshop, an adobe hut, and passive solar cabins, and, to top it all, a giant tree house thirty feet above the ground. To neighbors or passersby they might have seemed like squatters, yet they were ambitious, industrious, self-serious folk. *Aprovecho*, in Spanish, means "I make good use of."

"There has been a split among the party faithful."

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Deforestation was the issue of the moment, and Evans believed that stoves were an ideal solution. A few years earlier, at a research center in Quetzaltenango, Guatemala, he and a team of local craftsmen had tested a variety of designs and materials and brought in cooks to try them out. "Any fool can do technical things," he told me. "But if people don't want it, don't bother." The team eventually hit upon a mixture of sand, clay, and pumice that was stable and freely available. They cast it into a massive hearth, about waist-high, carved out a firebox, burners, and interior channels to direct the heat, then added a chimney for the smoke. They dubbed it Lorena, after the Spanish words for mud and sand, *lodo* and *arena*.

The Lorena never made many inroads to American kitchens, but it was an immediate hit internationally. While Evans was still testing it, a United Nations representative saw the stove and persuaded him to publish the design. "The facts are stunning," Evans wrote, in a 1979 book on the Lorena. "Data from several sources indicate that improved stoves—and of these the Lorena stove appears to have advantages over the others—can save one-half to three-quarters or more of the wood normally used in cooking." Projects for the Peace Corps, World Bank, USAID, and the governments of Senegal and Lesotho followed, often inspiring others in turn. In some areas, the Lorena was so popular that its name became a generic term: it simply meant "improved stove."

In one sense, though, it was no improvement at all. The Lorena was good at removing smoke and preventing burns (no small things). It was handsome, easy to use, and helped warm the house. What it didn't do was save fuel—at least compared with a well-tended open fire. Its thick walls, rather than concentrating the heat, absorbed it: the stove warmed the room because it wasn't warming the food. Studies later found that the Lorena used up to twice as much wood as an open fire and needed up to three times as long to boil a pot of water. "It sounds funny, but there are still people making Lorenas today," Dean Still says. "They don't understand the difference between insulation and a heat sink."

By the time Still arrived at Aprovecho, in the summer of 1989, funding for stoves had dried up. The Lorena, as it turned out, was only one of hundreds of well-meaning but misconceived projects worldwide. There were mud stoves that dissolved in the rain, designer stoves that worked only with a certain pot, portable stoves that fell over when you stirred

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cornmeal mush on them. In 1983, the Indian government launched a national program that distributed some thirty-five million stoves across the subcontinent. The units came in various designs from local manufacturers; most were neither sturdy nor especially efficient. Several years later, when a doctoral student from Berkeley surveyed the results in Andhra Pradesh, she found a single stove still in use—as a bin for grain.

"They were good-hearted people," Still says of his predecessors at Aprovecho. "But they were idealistic artists. They were farmers and architects and artisans more than they were engineers." Still didn't seem, on the face of it, much better qualified. Before coming to Aprovecho, he'd worked in a trauma ward in Illinois, lived in a trapper's cabin in Colorado, and served as a security guard on an ocean freighter. He had owned a gas station, worked as a janitor in a synagogue, earned a master's degree in clinical psychology but never used it professionally—"Not one day," he says. Instead, he built a seagoing catamaran with two friends and crisscrossed the Pacific in it. Then he sold the boat, moved to Baja, built a thatched hut by the Sea of Cortez, and stayed there for nine years. "My idea was this," he says. "Can Dean learn to sit under a tree and be contented?"

The answer was no. But his wanderings left him oddly suited to building stoves. He was a skilled carpenter and designer, used to improvising with cheap materials. He was intimately familiar with the needs and hazards of life in developing countries. And he was a born community organizer. His parents, Douglas and Hanna Still, were political activists in the heroic sixties mold. They'd worked with César Chávez in California, the Black Panthers in Chicago, and Martin Luther King, Jr., in the South. (King and Still's father, who was a Presbyterian minister, spent a night in jail together in Albany, Georgia, after a protest.) By the age of thirteen, Dean was tagging along to a civil-rights rally in Milwaukee, wearing a "Black Power" T-shirt among crowds of bellowing racists. At sixteen, he was among the rioters at the 1968 Democratic National Convention in Chicago, narrowly escaping arrest. His parents always encouraged him to be a freethinker, he says. "So when I was in seventh or eighth grade I told them, 'You're right. School is just a training ground for cogs. I'm going to quit and have adventures.'"

Still was first drawn to Aprovecho by its work in sustainable agriculture and forestry. But it was the stoves that kept him there. Not long after he arrived, in 1989, he met a local inventor named Larry Winiarski—a mild, bespectacled, dumpling-shaped man in his forties, perennially clad in overalls. Winiarski had a doctorate in engineering from Oregon State and had worked for the E.P.A. for thirteen years, analyzing the heat discharge from power plants. It didn't take him long to spot the Lorena's inadequacies.

Working as a volunteer, Winiarski sketched out ten principles of stove design and began to build prototypes with Evans and other Aprovecho members. The new devices, which they called rocket stoves, for the powerful roar of their draft, were the physical opposite of the Lorena. They were small and lightweight, so that little heat was wasted on warming the stove itself. They had vertical combustion chambers that acted as chimneys, mixing the wood's volatile gases with air so that the rockets burned more efficiently. And they had well-insulated walls that forced the hot gases through narrow gaps around the pot, heating it as quickly as possible.

"Larry is one of those rare people in my life, when you ask him a question about stoves he's almost always right," Still says. "He just really, really understands fire." Aprovecho went on to build a number of rocket stoves and to publicize them in books and newsletters, but the group's loyalty still lay with the Lorena. "People were basically ignoring Larry when I showed up," Still told me. "Hippies love earthen structures." The community's open-air kitchen, for instance, was dominated by a clay bread oven that took hours to heat up and consumed great quantities of firewood. With Winiarski's guidance, Still conducted an experiment. Next to the bread oven, he built a simple rocket stove. It was made of a fifty-five-gallon drum, laid horizontally, with a thirty-three-gallon drum inside it and a rocket combustion chamber below. The new stove looked nothing like a traditional bread oven, yet it was hot within fourteen minutes on the strength of a few twigs. An hour later, when the bread was done, the clay oven was still warming up. "That's what won people over," Still says.

Over the next few years, Still and Winiarski built ever more elaborate devices for the community: room heaters, water heaters, jet-pulse engines, wood-fired refrigerators. They were just tinkering, mostly, in the absence of funding for more ambitious work. Aprovecho, by then, was in turmoil. Evans was evicted from the property in the early nineties, after a dispute over the community's finances. Then county inspectors declared the tree house and other structures illegal, and everything had to be torn down, rebuilt, and reorganized. "It was a hippie nightmare," Still says.

To Peter Scott, who came to Aprovecho in 1997, the situation seems not uncommon. "People in environmental communities tend to be escaping from normal society," he told me. "If things were great where they came from, they wouldn't have left. And that sort of opens us up to the pain of the world and what's happening to it. We're all a little crazy, maybe." Scott was twenty-eight when he showed up in Oregon and already a veteran activist. In British Columbia, where he was born, he had stood in front of bulldozers on logging roads, climbed old-growth trees to spare them the axe, and acted in an environmental-theatre troupe. An article on solar cookers in *Mother Jones* first led him to Aprovecho, he says—that and memories of a trip to the Congo and the denuded landscapes there. "I'm here to save the forests of Africa by building stoves!" he remembers declaring on his first day. Dean Still just laughed and told him to go pick some vegetables.

Even more than new designs, Still began to realize, stovemakers needed data—to win back their credibility with reliable laboratory and field research. In 2000, when the stove lab was just a toolshed in the woods, Aprovecho built its first emissions detector and began

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testing Winiarski's designs. By 2004, Still had grants from the E.P.A. and the Shell Foundation to test stoves from other programs. By 2006, when the lab moved to Fred's Island, it had half a million dollars in funding and a staff of scrappy young engineers. (Nordica MacCarty, the lab manager, runs her jury-rigged Datsun on French-fry oil from a local diner. Karl Walter, the electronics designer, once built an airplane by hand and flew it to New York.) The research center now supports itself, in good part, with sales of microprocessor-controlled portable emissions detectors, designed and built in-house. The hippie commune has become a quality-control center.

Early in October, Still and I flew to Guatemala to visit the world's longest-running stove study. The village of San Lorenzo, where it's based, is in the remote western highlands, close to nine thousand feet above sea level. It feels like one of the world's forgotten places—its houses, made of mud and straw, cling to terraces that look out over plunging valleys and volcanic peaks—yet its cooks are among the most closely observed in the world. Walk into many local kitchens, and you'll find, attached to the walls or in the children's clothes, an array of electronic sensors and transmitters. Some measure particle emissions; others are motion detectors or carbon-monoxide monitors. Next to the chimney, on top of the stove, is a piece of black duct tape with a small silver disk beneath it. Plug the disk into a Palm Pilot, and it will tell you exactly when and for how long that stove was used in the previous month.

In seventeenth-century England, when a stovemaker wanted to test a new design, he'd soak a piece of coal in cat's urine and throw it into the fire. If the stench went up the chimney with the smoke, the design was deemed a success. Stove-testing is more of a numbers game now: minutes to boil, grams of fuel, milligrams of black carbon. Yet the practical effects of those numbers aren't always clear—especially on the emissions side. "We have no idea how low you have to go before you get the majority of the health benefits," Jacob Moss told me. "Is it peak exposures you want to get rid of, or is pollution a steady-state thing? Rocket stoves still have a whole slew of emissions that are an order of magnitude higher than E.P.A. standards." Cutting them in half, or even by two-thirds, may not be enough, he said.

The study that Still and I observed was aimed squarely at such uncertainties. Its detectors were the work of Kirk Smith, a professor of global environmental health at Berkeley and one of the world's leading authorities on indoor air pollution. Seven years ago, Smith and a team of students, researchers, and Guatemalan collaborators began tracking more than five hundred local families, all with pregnant mothers or infants less than four months old. The families were divided, at random, into two groups. Half were given plancha stoves with

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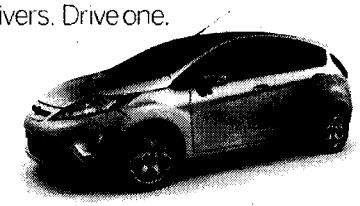

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*EPA-estimated Fusion 41 city/36 hwy mpg, midsize class per R. L. Polk & Co; Escape 34 city/31 hwy/32 combined mpg, FWD, small SUV class. **Mustang coming spring 2010 with automatic; Fiesta coming summer 2010 with SFE Package. Ford preliminary data. Pending EPA certification. †Coming late 2011.

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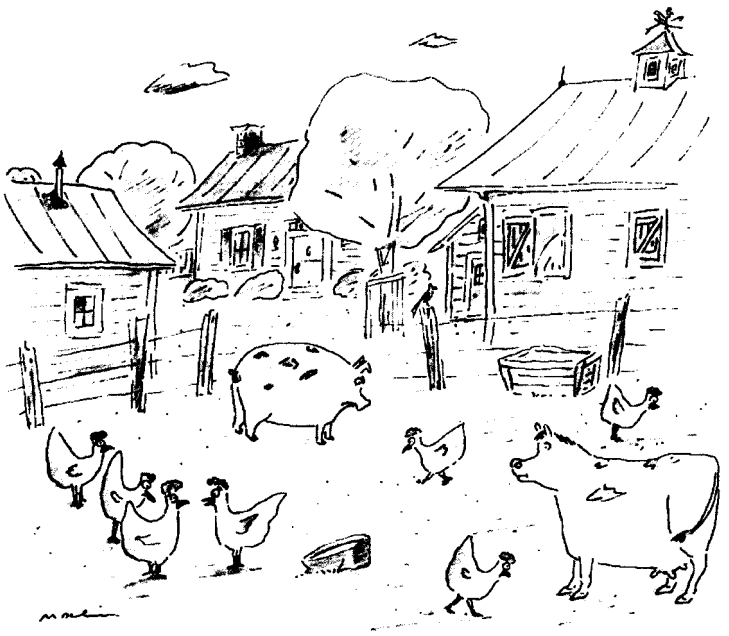
chimneys; the other half continued to cook over open fires. (After two years, when the first phase of the study was over, the second group got stoves as well.) Every week, Smith's team would give the families a medical checkup and download the data from its sensors. In this way, they could track their pollution exposure and its effects in real time. "My wife likes to say that most men spend their lives watching women cook," Smith says. "Her husband has managed to make a career of it."

Smith is a rumpled sixty-two-year-old with tousled gray hair and eyelids as heavy as a basset hound's—he seems both tireless and perpetually short of sleep. When Still and I drove up to his site with him from Guatemala City, he spoke absorbingly, and almost continuously, for six hours about public health. (Last June, for a vacation, he took his wife and daughter to Chernobyl.) San Lorenzo is a six-hour flight plus layover on the red-eye from San Francisco, followed by a vertiginous trek, by truck or multicolored bus, up whipsawing mountain roads. For three years, Smith made the trip every month. His funders left him little choice, he told us.

"I'd go to an air-pollution conference and show them my measurements, and they'd say, 'Good Lord, these are orders of magnitude higher than in our cities! And these are the most vulnerable populations in the world. Just go out and fix it!'" Instead of funding stove projects, though, they'd pass him along to the next agency. "So I'd go across the street, to the international health meeting," Smith went on, "and they'd say, 'Well, Mr. Smith, you have a pretty convincing problem, but we have seven dollars a year per capita. Do you really expect us to take a dollar out of our budget for vaccines? We need to be damn certain that we can make a difference.'" The pharmaceutical companies had dozens of randomized trials to back up their claims. What did Smith have?

San Lorenzo is his answer. The study, which was funded by the N.I.H. in 2001, now generates so much information that Smith needs two full-time workers to enter it into computers. On the morning after we arrived, Still and I joined the team on their rounds through the village. While Still scrutinized the stoves and suggested ways to improve them (he and Smith were hatching plans for a more efficient "hyper plancha"), I sat and watched the women cook. Diminutive and shy, in their bright embroidered blouses and tapestry skirts, they quietly answered questions as their children clutched their legs or peeked out from behind doorframes. The houses were low-ceilinged and bare, with earthen floors, corrugated roofs, and a tree stump or two for furniture. Some had sheaves of Indian corn drying from the rafters, or raised eaves that allowed a little light to leak in. A field hand in San Lorenzo makes about twenty dollars a week, Smith said—"Truth be told, they haven't recovered since Cortez." But in most of the houses with stoves at least the air was clear. In those with open fires it hung so thick and noxious that the walls were blackened, the joists and beams shaggy with creosote. It was like sitting inside a smoker's lung.



"That's not what I heard. I heard they're keeping the pig and getting rid of five chickens."

Near the end of our rounds, we paid a visit to Angela Jiménez, a small, sharp-featured woman who was part of Smith's original control group. Jiménez is thirty-five and has five children, including four-month-old twins. When we walked in, she was simmering a pot of corn for tortillas and sautéing a *recado de pescado*—a thin brown sauce made with dried fish and cornmeal, ground together on a slab of volcanic rock. Smith's team had given her a stove six years earlier, but she hadn't bothered to maintain it. The clay tiles and steel griddle were pocked with holes, and smoke was billowing into the room. On the wall behind the stove, the team had hung a poster explaining the dangers of carbon monoxide, but the words were too covered in soot to be legible.

We were getting ready to leave when Jiménez's nine-year-old son, Wilder, lurched in with his baby sister, Milvia, in his arms. She was tightly bundled in blankets, with a blue-and-white knit cap on. Her face was covered in dried phlegm and she was crying hard, with a steady, wheezing cough. Jiménez lifted her up and laid her against her shoulder. Her daughter had been sick for eight days, she told us, and was running a fever. "You should take her to the clinic," Smith said. "Eight days is a long time at that age." Jiménez looked at him with hooded eyes and turned back to the stove. If she went to the clinic, they'd just

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send her to the hospital, she said. "And that's where people go to die."

Smith later prevailed upon Jiménez to let his team drive her to his clinic, where a physician gave both infants a diagnosis of severe pneumonia. Milvia was hypoxic: her lungs were so full of fluid that they couldn't get enough oxygen into her blood. Her twin brother, Selby, was even sicker: his blood was only eighty-two per cent oxygenated, and his lungs made crackling noises under a stethoscope. "He could pass away tonight," Smith said. Pneumonia is the leading killer of children worldwide, and San Lorenzans are especially susceptible to it. They're so malnourished that their height, at eighteen months, is already two standard deviations below the norm. And their immune systems are further weakened by the toxins in wood smoke. On average, Smith has found, the children in the village get pneumonia every other year.

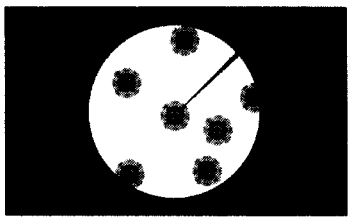
"So this is the bottom line," he told me that night, bringing up a graph on his laptop. "This is seventeen years of applying for grants, seven years of research, three and a half million dollars, and me coming down here for a week of every month." Thanks to his electronic sensors, Smith knew his subjects' cooking habits in microscopic detail. He knew when they lit the stove but left the room while it was burning. He knew how much smoke was in the air when they were cooking and how much carbon monoxide was in their breath. And by combining such data with their weekly medical records he could show, for the first time, how the risk of disease increased with exposure—what epidemiologists call a dose-response curve.

"For groups like the Gates Foundation and USAID, the metric is cost-effectiveness," Moss had told me. "How many people are you going to save with a hundred million dollars? That's what they want from this field, and they don't have it yet." Until now. Smith had data on half a dozen diseases that a decent stove could help prevent (it could lower blood pressure about as much as a low-salt diet, for instance). But the most dramatic numbers were for pneumonia. The graph on his laptop had an x-axis for exposure and a y-axis for disease. In between, the data followed a steeply rising curve. The children who inhaled the least smoke were between sixty-five and eighty-five per cent less likely to contract severe pneumonia than those who inhaled the most.

"Those numbers are as good as for any vaccine," Smith said. The plancha stoves cost about a hundred dollars each, yet they were a bargain in public-health terms. "In our country, we pay forty thousand dollars per year of life saved," Smith said. "Even if you take the lower end of the benefit, this would cost at most a few hundred dollars per life-year. It's a no-brainer." In a country like India, he and a team of co-authors later estimated, in an article in *The Lancet*, stoves could save more than two million lives in ten years.

Smith's data may be good enough for the Gates Foundation, but the harder part will be convincing local villagers. Most of the San Lorenzans liked their stoves, and maintained them well enough. But they considered the smoke from cooking more of an annoyance than a threat. (In Africa, some even welcome it as a defense against flies and mosquitoes.) "These kinds of correlations just aren't that easy to make," Smith said. "Think of cigarettes. They kill one out of two smokers prematurely—no war has ever had that effect. Yet famous scientists have died saying there is no connection." To imagine cooking as harmful is an even greater leap. "It's not cyanide," Still said. "They can always think of an eighty-nine-year-old who's been cooking over an open fire all her life. And Grandma's doing just fine."

The best examples of this insouciance, in San Lorenzo, were the wood-fired saunas that most of the villagers used. The tradition dated back to the ancient Mayans, who would heat rocks over an outdoor fire and carry them into a stone bathhouse. The modern version, known as a *chuj*, was just a mud-caked hut about the size of a large doghouse. It had an open fire inside, a pallet to lie on,



and a blanket to seal the door. A *chuj* was essentially a human smokehouse, yet the same villagers who swore by their plancha stoves—including Vincente Tema, one of Smith's Guatemalan staff—took sauna baths once or twice a week for half an hour. (The baths were especially good for pregnant women, they said.) When I asked Tema if I could try his *chuj*, Smith shrugged. I might want to take a carbon-monoxide monitor with me, he said.

The experience wasn't altogether unpleasant—there are worse things, apparently, than becoming a giant slab of bacon. But by the time I stumbled out, sixteen minutes later, my head was swimming. When Smith later downloaded the monitor's data at his office, it showed the carbon monoxide in the *chuj* spiking to five hundred parts per million, then abruptly levelling off. The program wasn't designed to show levels any higher than that, he explained. "Oh, buddy," Still said, staring at the screen. "If you'd gone to a thousand for ten minutes, you'd be in a coma now."

Stories like these were a source of endless frustration to stovemakers. The trouble with tradition, they'd found, is that it can be remarkably thickheaded. Ignore it, and your shiny new stove may get turned into a flowerpot. Cater to it, and you may end up with a new version of the same old problem. The campers in Cottage Grove spent half their time agonizing over cultural sensitivity ("We're highly dominated by elderly white engineering types," a stovemaker who'd worked in Uganda told me. "So you get a lot of preposterous ideas that'll never fly in the kitchen") and the other half grousing about "design drift." Too many stoves start out as marvels of efficiency, they said, and are gradually modified into obsolescence. Once the engineer is gone, the local builder may widen the stove's mouth so it can burn larger sticks, only to draw in too much cold air. Or he'll make the stove out of denser bricks, not realizing that the air pockets in the clay are its best insulation. The better the stove, the tighter its tolerances, the easier it is to ruin.

"When we first got into this, we had this utopian vision of working with local communities to build locally grown stoves," the E.P.A.'s Jacob Moss told me. "We've moved away from that—I

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won't say a hundred and eighty degrees, but maybe a hundred and sixty. I don't really listen to small stove projects anymore. When I hear Dean say that one millimetre can make a non-trivial difference, it's inconceivable to me that all these local stovemakers can make all these stoves efficiently. You have to work in a different way."

Three years ago, on a taxi ride in southern China, Still had a glimpse of the future. He was working as a consultant for the E.P.A. at the time, passing through the city of Kunming, when he spotted some odd little stoves for sale on a street corner. He shouted for the driver to stop and stepped outside to examine one. "It was like Shangri-La," he told me. The stove was meant for burning coal, so its design was all wrong for wood, but it was sturdy, compact, and cleanly manufactured. More important, its combustion chamber was made of a hard yet miraculously light and porous clay—a combination that stovemakers had been scouring the earth to find. "There, in this two-dollar coal burner, was everything needed to make the world's perfect rocket stove," Still says.

The stove had a telephone number printed on it, so Still called it on his cell phone. Two months later, he was visiting the factory where the stove was built, in eastern China. Within two years, the factory was producing a stove to Aprovecho's specifications. Sold under the name StoveTec, it isn't much to look at: a hollow clay tube, clad in green sheet metal, with an opening in front and a pot support on top. But it incorporates all ten rocket-design principles with a consistency that only mass production can offer. The StoveTec uses about half as much wood as an open fire, produces less than half as much smoke, and sells for eight dollars wholesale. In the United States, where it retails for five times as much, it has been especially popular among Mormons and survivalists.

Still's stove is a kind of proof of principle. It shows that an efficient, user-friendly stove can be mass-produced at a cost that even the very poor can afford. But it also shows what's missing. The StoveTec isn't suited to some dishes—tortillas, chapatis, heavy porridges—and its life expectancy is less than two years. While it's much less smoky than an open fire, it can't quite meet the Waxman-Markey standards.

The search for the perfect stove continues, in other words. Not long before Stove Camp, I visited a company called Envirofit, in Fort Collins, Colorado. Envirofit's laboratories are housed at Colorado State University, in a converted power plant from the nineteen-thirties. On the morning of my tour, half a dozen experiments were going on simultaneously. One glass case held nine stoves, all furiously burning pellets fed to them by an automatic hopper. Across the room, the smoke was being parsed into its chemical components by a rack of blinking machinery. (Wood smoke may not be cyanide, as Still put it, but hydrogen cyanide turns out to be one of its trace elements.) On a catwalk upstairs, a programmer was modelling green and yellow flames on his computer, while a biologist down the hall was subjecting live human lung cells to wood smoke. "We grow them in the basement, but they're fully functional," I was told. "They even produce phlegm."

Envirofit's C.E.O., Ron Bills, is a former executive of Segway, Yamaha, and Bombardier. His new company is technically a non-profit, yet Bills believes that stovemakers, for too long, have treated the developing world as a charity ward instead of a business opportunity. "A lot of the poor—call them emerging consumers—get inundated with crummy stuff," he told me. "So we're going back to Henry Ford." Envirofit's first new product was essentially a rebranded version of Aprovecho's stove, made by the same Chinese factory with a few improvements in durability and design. In July, however, the company unveiled a new model. It was shaped like an ordinary rocket stove, though much more stylish, and had a major innovation at its core: a durable metal combustion chamber. Made of an alloy developed together with Oak Ridge National Laboratory, in Tennessee, it could withstand the caustic fumes of a wood fire for more than five years, yet cost only three dollars a unit to produce. The Envirofit combustion chamber could be shipped for a fraction of the cost of a fully built stove, and adapted to local designs and cooking traditions. It was mass production and appropriate technology rolled into one.

"That's the goose that laid the golden egg right there," Bills told me. "That's the Intel inside." He had nothing against groups like Aprovecho, he said. They could continue to hold their Stove Camps and sell their stoves made out of clay. "But Henry Ford didn't stop with the Model T. If we are going to make an impact in my lifetime, it has to be done at scale. And when you have a three-billion-product opportunity, what is enough scale? One million, two million, five million? I like to dream big." Thanks, hippies, he seemed to be saying. Now, please step aside.

On the last day of Stove Camp, I stumbled out of bed late, in search of coffee—the timber train having catapulted me awake, as usual, four hours earlier. Aprovecho was as busy as a science fair. The pulmonologist from N.I.H. was putting the finishing touches on a rocket stove made from an oil drum. A Norwegian designer was running emissions tests on a little tin gasifier. And another camper was watching emission measurements unspool across a laptop. "Look at that!" he shouted. "It's flatlining! There's almost no particulate matter!" On the whiteboard next door, the words "Save the World" had long since been erased and replaced with mathematical equations.

Scott and Andreatta were in the far corner of the workshop, probing their injera stove with an infrared thermometer. Their week had been a succession of setbacks and breakthroughs. When their first prototype, with its steel griddle, had too many hot spots, Scott had suggested that they try aluminum. It conducted heat even better than steel and was considerably cheaper. A few e-mails to Ethiopia had confirmed that the metal could be locally cast from recycled engine blocks. By the next morning, Andreatta had roughed out a plywood mold for the griddle and they'd taken it to a foundry in Eugene. But the design proved too complicated to cast—it had radiating

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fins along the bottom to distribute the heat. So they'd settled on something simpler.

The new griddle was a third of an inch thick and flat on both sides. Andreatta had put a ceramic baffle beneath it to temper and diffuse the flames, but he still had his doubts. The melting point of aluminum is twelve hundred and twenty degrees Fahrenheit—about half as high as the peak temperature inside a rocket stove. If they weren't careful, the griddle would dissolve before their eyes. Andreatta switched on his L.E.D. headlamp and peered at the infrared thermometer. For now, the griddle was holding steady at four hundred and thirty-three degrees—just five degrees short of the target temperature. Better yet, the center was less than twenty-five degrees hotter than the outer edge. "Even Ethiopian women don't get it in that range," Scott said.

Still strolled by, wearing a T-shirt with a giant longhorn beetle on it. He had a groggy grin on his face, as if he'd just woken up to a redeemed and revitalized world. Sometimes he saw the stove community more as Ron Bills seemed to see it—as a gathering of undisciplined hobbyists, engaged in the equivalent of building iPods out of toothpicks and aluminum foil. But this wasn't one of those days. Earlier that summer, a research group under Vijay Modi, a professor of mechanical engineering at Columbia, had surveyed cooks in Uganda and Tanzania who had tested a variety of improved stoves. In both studies, the StoveTec/Envirofit design had won the highest rating, beating out the most recent Envirofit stove in the Tanzanian study. "My people, they aren't always very smart," Still had told me. But they were inventive, resourceful, and doggedly resilient. And, after thirty years of trial and error and endless field research, they understood fire very, very well.

The injera stove was the kind of project that might always fall to them. "What is the market for an improved cookstove, really?" Still said. "People hope that it's big, but we have an eight-dollar stove and it's not easy to sell. Everyone forgets that poor people are *really* poor." In Africa, where less than a quarter of the population has electricity and the most efficient technologies are beyond reach, an open fire can still seem hard to beat, if only because it's free. "But you know what? We're going to do it," Still said. "A lot of people think that if you don't make a whole lot of money at something it can't be good. I think those people are wrong. If you want to do what poor people need, and you really don't stop, you're not going to be rich. Not unless you're a lot smarter than I am."

Just before we broke camp the next morning, Scott came to find me in the meat locker: the prototype was ready for its first pancake. He and Andreatta had hoped to cook true injera bread for the occasion, but they couldn't find the time—or the teff—to make a proper sourdough. So they'd settled for Aunt Jemima. "This is our first test," Scott said, holding up a pitcher of pancake batter. "People of the world, cut us some slack." Then he poured it onto the hot griddle.

Over the next three months, the stove would go through more rounds of fiddling and redesign. The aluminum would prove too conductive for real injera and get swapped out for a traditional *mitad*. To get the ceramic to heat evenly, the baffles beneath it would have to be removed. At one point, in Addis Ababa, Scott would nearly abandon the project, only to have an Ethiopian cook make some key suggestions. Yet the result would be even better than it seemed on this sunny August morning: the world's first successful rocket injera stove—twice as efficient and many times more durable than those it was meant to replace.

As the batter hit the griddle, it spread into a circle that nearly reached the edge. Within a minute, it was bubbling up evenly across its surface. "Yeah, baby!" Scott said. "If we'd tried that last Friday, it would be blackened char in the middle." He slid a spatula under the batter and tried to flip it, leaving half on the griddle but the rest well browned. He stared at the pancake. "We can't really fucking believe it," he said. "I mean, these designs usually take months and you're still scratching your head." The stove was almost ready, he thought. Now they just had to convince a few million Ethiopians. ♦

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