



Smoke from cooking fires, such as this one in Mumbai, India, kills millions of people a year.

Deadly dinners

BY MEERA SUBRAMANIAN

Polluting biomass stoves, used by one-third of the global population, take a terrible toll. But efforts to clean them up are failing.

After returning from her nine-and-a-half-hour shift as a security guard, Savita Satish Dadas begins plucking fenugreek leaves from their stems for dinner. She and her two children, along with three of their cousins, gather in a shed-like structure next to their house in the Satara District of Maharashtra, India. As goats and cows settle in for the night a few metres away, Dadas and the children sit down on a packed dirt floor around the family hearth.

Whisps of smoke rise up from their *chulha*, the Indian name given to a traditional cooking-stove fuelled by wood and other organic matter often gathered from the countryside. Dadas's stove, like several of her neighbours', is sculpted out of clay. But many make a rudimentary three-stone fire — a triangle of elevated points to support a pot — that humans have used for millennia. Dadas feeds roughly chopped logs into the stove and her hands shape moistened flour into *bhakri* bread, the rhythmic movement illuminated by the flickering flames.

With this simple daily act, Dadas shares a connection with more than one-third of the world's population, the three billion people who depend on solid biomass fuels — such as wood, animal dung, agricultural waste and charcoal — or coal for their cooking needs. In India, a nation that is rapidly developing in many ways, 160 million households — some two-thirds of families — still rely on such fuel for their primary cooking energy source. Globally, the percentage of households that use biomass has slowly and steadily decreased over the past three decades¹. But because the world's population has been rising so quickly, the number of people using solid fuels is not declining, says Kirk Smith, an environmental-health scientist at the University of California, Berkeley,

who has studied the health implications of such cooking stoves for 30 years. "This is not going away."

And the urgency to transition billions of people around the world to cleaner forms of cooking has never been greater, in light of recent research revealing that emissions from traditional cooking-stoves pose a bigger threat than previously thought. Results from a global health study released earlier this year project that household air pollution from such fires causes more than four million premature deaths annually — more than one-quarter of them in India alone². Earth's climate is also at risk from the smoke, which contains dark particles that absorb sunlight, alter atmospheric patterns and hasten glacial melting.

Environmental organizations, development groups and others have strived to solve the cooking-stove conundrum for decades, but momentum is finally gathering, thanks to the formation of the Global Alliance for Clean Cookstoves. This far-reaching public-private partnership was launched in 2010 by then US secretary of state Hillary Clinton. The Global Alliance has set a lofty goal of convincing 100 million households to adopt clean cooking-stoves by 2020, with an aim of eliminating deaths from cooking-stoves by 2030.

This massive effort — the most ambitious so far — is uniting specialists in fields as diverse as epidemiology, climate science, global finance and gender equality. It is part of a growing global effort that connects multinational energy companies, non-governmental organizations (NGOs), university design laboratories, governments and young, socially minded inventors. Simultaneously, new funding is flowing in from corporate social-responsibility initiatives, microfinance loans that provide credit to poor people, and the sale of carbon credits.

But all the efforts devoted to solving the problem have yet to make much of a dent. During three months touring the Indian states of Maharashtra and Tamil Nadu in late 2013 and early 2014, I interviewed dozens of women in their homes and found that improved cooking-stoves often sit unused in corners, broken or simply abandoned. My observations tally with those of field studies, which show that adoption rates of the new technologies remain as low as they have been for decades. The ongoing struggle is enough to make many researchers question whether it is truly possible to improve biomass cooking-stoves, and whether it might be better to direct efforts towards expanding access to proven technologies — such as gas stoves and electric cookers — that are already standard in the developed world.

It is time to move beyond age-old methods that cause so much pollution, both inside homes and out, says epidemiologist Kalpana Balakrishnan, director of the World Health Organization (WHO) Collaborating Centre for Occupational and Environmental Health at Sri Ramachandra University in Chennai, India. "If you want clean air anywhere, you don't want to be burning biomass in this configuration: open biomass burning."

COUNTING THE COST

The newest health data paint a stark picture of the impact of cooking with biomass. In March, the WHO estimated that 4.3 million people die annually from household air pollution caused by cooking with biomass and coal³. It is the greatest health risk in the world after high blood pressure, tobacco and alcohol⁴, with more people dying from the incremental, ongoing inhalation of smoke from fires they ignite in their own homes than from malaria, tuberculosis and HIV/AIDS combined.

The new data more than double the WHO's 2004 estimate of the mortality rate from household air pollution. "This is not an energy issue," says Smith. "This is a health issue."

The data show that household air pollution from such fires causes acute lower respiratory infections, chronic obstructive pulmonary disease, cardiovascular disease and lung cancer⁴. Women and children, in particular, are often exposed to excessive amounts of small particles less than 2.5 micrometres in diameter, known as PM_{2.5}, which are considered the most dangerous to human health. A study¹ published by Smith and his colleagues this year that contributed to the WHO report³ shows that Indian women cooking in households reliant on solid fuel are exposed

to a mean 24-hour PM_{2.5} concentration of 337 micrograms per cubic metre, more than ten times the WHO indoor air quality guidelines (see 'A burning issue').

Even before a match is struck, the stoves put women and girls at risk, because they are usually tasked with collecting the heavy loads of firewood or other materials. They also must often travel to remote locations to find fuel, making them vulnerable to sexual attacks. I have seen the signs of fuel collection across the south Asian landscape. Neat piles of slender branches are stacked high outside homes in Karnataka.

"Thirty years of research has really not produced a cost-effective way of burning wood."

Walls in Bihar are plastered with discs of drying cow dung impressed with petite handprints. Limber children scramble up a tree, hacking away branches with a machete in Punjab. A lone woman drags a 6-metre-long trunk down a sandy path in Tamil Nadu. At least there is fuel; India is more abundant in biomass than many places in Africa, where the situation is even more dire.

IN THE NEIGHBOURHOOD

Lata Kisan Kare, who lives near Dadas, says that she does not worry much about the smoke that pours out of the *chulha* standing just outside her front door. The pollution does not bother her, she explains matter-of-factly: "It goes up and away."

In reality, the smoke from Kare's fire is adding to the pollution in her village and beyond. In India, which now rivals China in terms of air pollution levels, one-quarter of the fine particulate matter in the ambient outdoor air originates from household cooking-stoves. Even people in households that have transitioned to liquefied petroleum gas (LPG) and other cleaner sources of fuel still have elevated pulmonary risk if their neighbours continue to cook with solid fuels, says Balakrishnan.

And the impact of such fires reaches around the globe. Evidence suggests that black carbon — sunlight-absorbing particles from cooking fires and other sources — are helping to weaken the Asian monsoon, melt mountain glaciers and speed up warming in the Arctic⁵. In 2013, a major assessment found that the black carbon emitted by sources such as cooking-stoves, diesel engines and agricultural fires is the second leading cause of climate warming after carbon dioxide emissions. In Africa and Asia, residential burning of solid fuels, including biomass and coal, accounts for a staggering 60–80% of black-carbon emissions.

The Global Alliance is trying to tackle these human and atmospheric problems through a range of activities, including improved monitoring and evaluation of cooking-stove programmes, and increased coordination between the hundreds of public, private, independent, non-governmental and funding entities across the 43 nations that are now partners under the alliance's umbrella. In 2012, the latest year for which data are available, partners distributed 8.2 million clean cooking-stoves.

But distribution is just one step in the move away from smoky fires. Households such as Kare's show how challenging it will be for the alliance to reach its goals, especially if the focus is primarily on improved biomass stoves. As part of a local corporate social-responsibility initiative, Kare received a free improved cooking-stove a few years ago from Cummins, a multinational corporation that operates an industrial megasite in the area. Five hundred stoves, each costing less than US\$15, were installed in village homes by an NGO. Many, like Kare's, sit unused. The stove is a low-tech clay one designed for a cleaner burn, with a combustion chamber made of heat-resistant concrete and an air-intake hole for improved draft. Like dozens of stoves I saw in the Satara District, this one had a brick wedged in the air hole for fear that snakes or scorpions might mistake it for a lair.

Those who chose to use their stoves found that the design was flawed.

The wire holding the combustion chamber bricks together burned out quickly, causing the stoves to crumple under the weight of a pot, and many found that the fire still smoked too much.

Engineers have developed more sophisticated and sturdier designs, many of them portable, to prevent the kinds of problems seen in Kare's village. There are high-tech gasifier stoves, such as one from Philips, that rely on a rechargeable battery pack to run a fan for cleaner combustion. The Oorja also has a fan and burns pelletized field waste. Another option, BioLite, uses a thermoelectric generator to power a fan (as well as a USB charging port that might encourage mobile-phone-wielding husbands to buy improved stoves for their wives). And sleek units such as Envirofit and Prakti stoves use a natural draft to try to achieve a smoke-free fire.

But all of these seem to have limitations in the eyes of the users, who often reject them. Women told me that the stoves are too small to support a pot of bath water, or not hot enough to cook a *roti*, or flatbread. And many complained that they have to sit by the improved stoves and feed them continuously. With a conventional stove, they can just throw in a big log. Even those who do take to their new stoves face problems when the devices break; at present there is a very limited supply system in place for spare parts or repairs. The Global Alliance, along with companies such as Oorja, Envirofit and Prakti, are scrambling to put the necessary infrastructure in place, but the road remains uphill, and the best-performing stoves range from \$50 to \$80, far above the means of many of those who need them most.

Similar problems have plagued stove-improvement efforts for decades. A government cooking-stove programme in India reports distributing more than 30 million improved stoves between 1983 and 2002, but the World Bank and numerous researchers have criticized the programme, like many other stove initiatives over the years, for poor stove design, high programme costs, low adoption rates and lack of stove maintenance. Giving devices away has not seemed to work, and several stove designers told me that heavily subsidized programmes undermine the growth of a local market for stoves and spare parts that might help to buttress long-term use.

TRADITION WINS

In late 2013, Smith prepared to revisit some of the villages he had first studied in the early 1980s. When we met up in Delhi just before his trip, he said, "I'm afraid that I'm going to see that nothing has changed." He was wrong. In the villages, people were chatting away on mobile phones, and many houses had electricity, satellite dishes and running water. But one thing had not changed: nearly all households still used *chulhas* for at least some of their cooking. "Development," Smith says, "has become unconnected with cooking."

Up in Smoke, a 2012 study by researchers at the Massachusetts Institute of Technology in Cambridge, highlighted some of the ongoing challenges⁶. A randomized controlled study in Odisha, India, identified no long-term improvements in health, fuel consumption or — the authors inferred — greenhouse-gas emissions in households that had been given a clean cooking-stove, primarily because the stoves were not being used. Although the devices had been distributed by the award-winning NGO Gram Vikas, they quickly fell into disuse, or were not maintained at a level that kept emissions low.

Smith criticizes the Up in Smoke study, saying that the introduced stove in question was known to be a poor one. His charge highlights the fact that no one knows how to define a 'clean' cooking-stove because there are no agreed standards for particulate emission from stoves.

Gautam Yadama, a professor of social work at Washington University in St. Louis, Missouri, and author of the book *Fires, Fuel & the Fate of 3 Billion* (Oxford Univ. Press, 2013), agrees that clean is a nebulous term. "What are the metrics?" he asks. "Who is calling them improved, and are they improved?" Efforts are afoot to address this issue. An International Organization for Standardization technical committee met in February in Nairobi to initiate development of standardized ways to test cooking-stoves, and the Indian government has also been busy developing labs that can approve certain cooking-stoves on the basis of



Although improved stoves produce less pollution, many people prefer traditional designs.

thermal efficiency, as well as production of carbon monoxide and total particulate matter.

But none of the designs can get around some fundamental problems of burning biomass. Such fuels vary tremendously in terms of their moisture content and chemical composition, which makes it difficult to design an inexpensive stove that can burn cleanly in many situations. Moreover, users will invariably operate their stoves differently from a lab technician. And, no matter what the stove, biomass cannot pack as much energy as fossil fuels. "Thirty years of research has really not produced a cost-effective way of burning wood," Balakrishnan says. "Wood is not a calorific-enough fuel to burn very cleanly."

In some places, development is helping to make the question of adoption moot and hinting at a future without open fires. Many households are now using multiple types of cooking device, a strategy called 'stove stacking' that combines both modern and more traditional methods. This is especially evident in the southern state of Tamil Nadu, one of India's most developed areas.

When I step into Emily Teresa's house, above the Ladies and Gents Tailor Shop in the Krishnagiri District on a Saturday morning, a pressure cooker is whistling on an LPG stove in the kitchen, and a kerosene stove is stored under the counter. Teresa prefers the LPG, but limits her use of it — and the kerosene stove — according to how long her subsidized fuel supply lasts. To heat bathwater, she uses a traditional *chulha* outside. And, in another room, she keeps an Envirofit biomass stove that she purchased through a woman's cooperative that she belongs to. The NGO Integrated Village Development Project helped to bring 25,000 of those stoves to her district.

Her sister-in-law down the road also has multiple stoves, including an induction burner, an increasingly popular streamlined electrical unit that uses electromagnetic induction to transfer heat to pots. Where electricity is dependable, induction offers a stove that is much cleaner and more efficient, at a cost that is comparable to mid-range improved biomass stoves.

This stove-stacking by those at the bottom of the energy ladder is reminiscent of the way that those higher up segue seamlessly between gas ranges, microwaves and electric kettles, while a hot-water heater quietly does its work unnoticed. But amid the stack of options, the Envirofit stove is often the last one that Teresa and her sister-in-law reach for.

After decades of battling to get people to use improved

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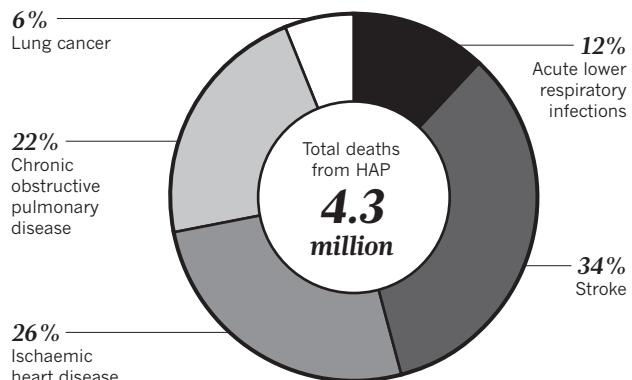


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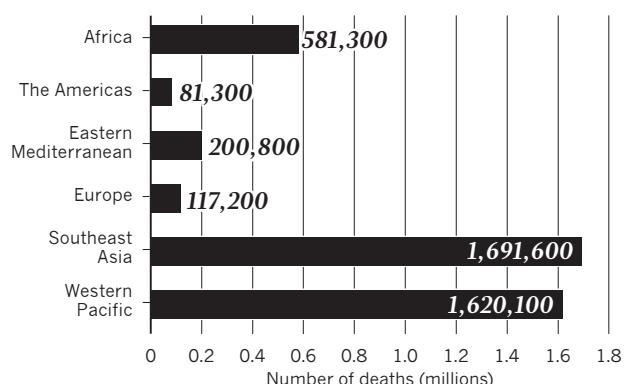
A burning issue

Nearly 3 billion people burn wood, dung and other types of biomass in open stoves to cook their food and heat their homes. The World Health Organization has estimated the number of deaths caused by household air pollution (HAP) from burning biomass and coal.

Cause of death from household air pollution in 2012



Total deaths attributable to HAP in 2012, by region



cooking-stoves, many researchers worry that such devices will never win over consumers and thus never achieve the desired health and climate gains. "My bottom line is that nothing works," Smith says. "The only thing we know that's ever worked is gas and electric."

Balakrishnan makes a moral argument against improved cooking-stoves, which still produce harmful amounts of pollutants compared with LPG or electric ones, powered by remote energy plants that commonly use fossil fuels. "Are you justified in saying that it's OK to be just a little bit better?" she asks. "If it's OK for 40% of the population to use fossil fuels, then why is not OK for the other 60% of the population? How can we have dual standards?"

ENERGY TRANSITION

Smith, Balakrishnan and others think that the answer may be for people to jump several rungs on the energy ladder, bypassing improved biomass stoves. It would be better, they suggest, for designers and policy-makers to direct their efforts to helping more people transition directly to gas or electric stoves.

One of Kare's neighbours has done just that. She saved up enough to buy an induction stove and an LPG stove, and spends as much on refilling her subsidized gas cylinders, which she says last three months, as Kare spends buying just three-week's worth of wood fuel. Kare, too, would like the cleaner stoves, but the up-front costs are too high for her.

The rapidly changing energy landscape may be opening up new opportunities. Although Indians are apprehensive about the future of LPG subsidies, which are highly variable, many people are gaining access to new sources of alternative and renewable energy. In India and other developing countries, entrepreneurs are setting up decentralized electrical distribution systems fuelled by solar power, hydropower or biogas derived from agricultural waste (see *Nature* **507**, 154–156; 2014), which the world's rural poor have in abundance. Electric microgrids coupled with induction cookers could provide a means for millions to move away from polluting biomass stoves.

Even the Global Alliance of Clean Cookstoves acknowledges the advantages of abandoning biomass stoves of any type. "If people can afford to and are able to access the cleaner cooking technologies, including electric and LPG stoves, then that's wonderful from our perspective," says Sumi Mehta, director of programmes for the alliance. "But we also know that in the short term not everybody's going to be able to leapfrog to that." Of the three billion people burning biomass, at least one-third have little hope of moving up the energy ladder any time soon. For them, she says, the alliance will continue to invest in creating a cleaner biomass stove, no matter how challenging the job.

Putting the finishing touches to dinner as the children sit patiently beside her, Dadas has little time to worry about such issues. She dips a spoon into a Vicks container full of salt and adds the seasoning to the fenugreek greens that will accompany lentils and one *bhakri* bread for each of the six family members she is feeding tonight. Tomorrow is Christmas, which means a precious day off from the factory. As a Hindu, Dadas does not celebrate the holiday. When I ask her what she plans to do, she laughs sadly and says that she will use her axe and the extra time to go out collecting firewood. ■ SEE EDITORIAL P.533

Meera Subramanian is a freelance writer in Cape Cod, Massachusetts. She travelled to India on a Fulbright-Nehru fellowship, which provided partial support for this piece.

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