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Beyond the Last Mile: Piloting High-Efficiency, Low-Emissions Heating Technologies in Central Asia

THE BOTTOM LINE

Chronic underheating is commonplace among poor households in cold-climate regions of developing countries beyond the reach of district heating and gas-distribution networks. Until fuel switching is possible, high-efficiency, low-emissions (HELE) technologies offer a cost-effective, intermediate solution to meet the heating aspirations of underserved populations. Recent pilot experience in Kyrgyzstan shows that switching to HELE heating stoves yields substantial benefits, including dramatically reduced emissions, better health, and savings in household fuel expenditure.

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Why does this issue matter?

In many cold-climate regions, chronic underheating of homes is common

Whether caused by lack of access to modern energy infrastructure or low disposable income, energy poverty leaves many homes underheated. In cold-climate areas of Central Asia, like other high-altitude developing regions with a long winter season, suppressed demand for heating energy is significant, especially among the rural and peri-urban poor. In Kyrgyzstan—one of Central Asia's poorest countries—only 17 percent of the country's 1.1 million households—mainly those in the capital city of Bishkek and other major urban areas—have access to district heating.

For low-income Kyrgyz communities in remote, difficult-to-reach areas beyond the end of district heating and gas-distribution networks, heating options are limited. The capacity of the already strained electricity network is deteriorating, and raising electricity use to meet the need for winter heating is not a viable option. Modern renewable energy sources are not yet financially viable for space-heating applications at the household level, and woody biomass resources are limited.

In attempting to meet their space-heating needs, the vast majority of Kyrgyz households have long relied on solid fuel–fired traditional stoves and simple low-pressure boilers, both of which are highly polluting both indoors and outside. Fueled mainly by coal, wood, and dung, these stoves have a typical thermal efficiency of just 20–40 percent. Combustion and fuel inefficiencies, in turn, aggravate the consequences of being chronically or episodically cold (Gasparrini et al. 2015). The smoke leaked from the stoves causes household air pollution, with adverse effects on human health and the climate.

What has been the response?

Until fuel switching is possible, high-efficiency, low-emissions stoves offer underserved populations a cost-effective, intermediate heating solution

Recent World Bank–supported pilot programs in Central Asia have brought to market advanced high-efficiency, low-emissions (HELE) heating and cooking stoves that have gained broad acceptance by households participating in pilot projects (World Bank 2017a). Development of a small-scale, advanced combustion technology to meet the heating aspirations of underserved households resulted from nearly a decade of international collaboration and field evaluations by similarly motivated researchers, designers, practitioners, and stove users in Mongolia, China, Kyrgyzstan, Tajikistan, and South Africa. In Kyrgyzstan, the KG4, a cross-draft coal gasifier heating stove, was field-tested during the 2016–17 winter heating season, with positive user feedback. The combustion system is an open-source design that has been adapted for low-pressure boilers and other HELE heating stoves by practitioners in Mongolia, Tajikistan, South Africa, Russia, and Poland.

Solid fuels do not contain inherently unburnable smoke.

How does the KG4 work?

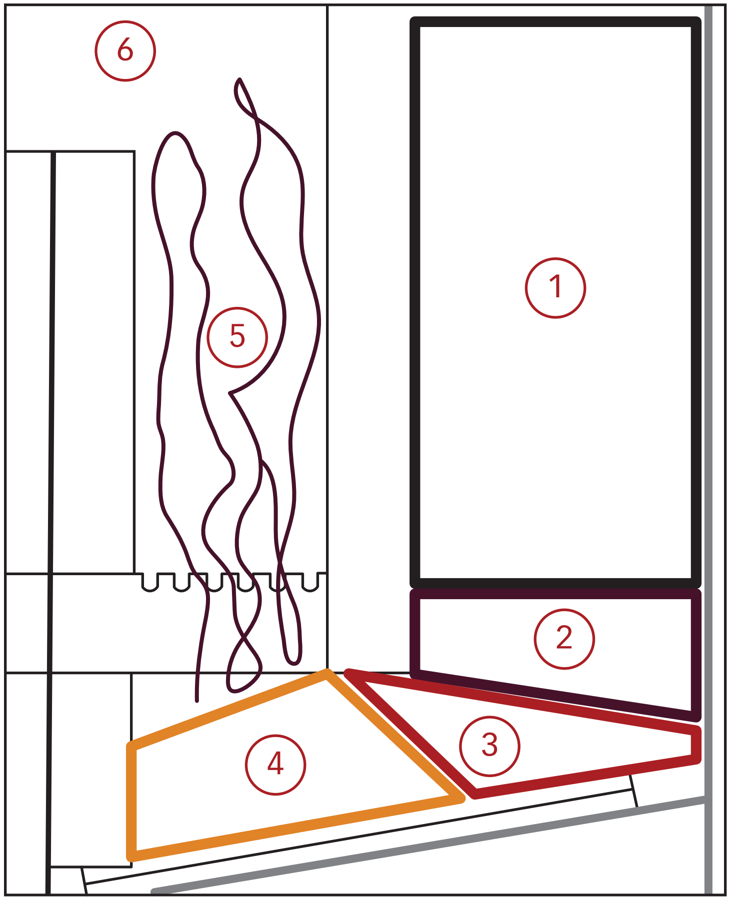
A solid fuel with a known composition can be burned efficiently with low emissions if matched with an appropriate stove architecture

Solid fuels do not contain inherently unburnable smoke. By applying advanced combustion science and industrial design principles to small-scale coal combustion, HELE heating stoves can burn all of the smoke generated during initial devolatilization. But to complete the oxidation process for raw coal, the coal gases must be kept sufficiently hot and mixed with an adequate supply of air for a certain period of time. In short, the process requires an appropriate balance of time, temperature, and turbulence (World Bank 2019).

The KG4 has a hopper-fed cross-draft combustor, characterized by six zones (figure 1). Once appropriately-sized raw coal fuel is loaded in the hopper (zone 1) and the hopper cover is sealed, dehydration and devolatilization begin (zone 2). The next step is semi-coking, which generates a large quantity of thick smoke (zone 3). During gasification (zone 4), smoke is "cracked" into simple gases within a bed of hot coke. The resulting coal gas is burned with secondary air in the fire chamber (zone 5). Finally, heat is transferred to the room via the heat exchanger or the cooking pot (zone 6).

With the right fuel, grate, and fuel depth on the lower grate, gravity will feed coal into the combustion zone without user intervention. This self-feeding function is especially important to households because, in practice, once the hopper is filled and the power level set, the stove can operate safely while unattended for several hours. Under the conditions observed in the Kyrgyzstan pilot program, 10 kilograms of fuel permit the stove to burn the popular Kara-Keche coal unattended for 14 hours (at lowest power) or 4 hours (at high power). Coals with stronger ash or high ash content can be burned effectively, but the grate must be shaken periodically (every 2–6 hours), depending on the power level and the physical characteristics of the ash.

Figure 1. KG4 cross-draft combustion process



The range of benefits reported included improved home comfort and convenience of stove use, lower spending on fuel, and markedly better family health.

What were the results?

Perceived benefits of the KG4 stove are supported by independent personal exposure measurements and laboratory emissions testing

During the winter heating season of 2016–17, the KG4 coal gasifier stove and KG5 low-pressure boiler were field-tested in 41 rural and peri-urban homes in Kyrgyzstan. Hands-on instructions in the use and maintenance of the stoves and fuel preparation were provided. User surveys, conducted by CAMP Alatoo, a local nongovernmental organization partnering in the pilot, occurred 10 weeks after installation and again later in the heating season. Personal exposure to smoke for the household members who do the cooking was measured by an independent agency.

User survey responses. The KG4 stove was broadly accepted by the pilot participants (World Bank 2017b). The range of benefits reported included improved home comfort and convenience of stove use, lower spending on fuel, and markedly better family health. All pilot respondents agreed that their homes were consistently warm and more comfortable after installing the new stoves. In fact, because of the increase in thermal efficiency, fuel savings of 60 percent were possible. In practice, however, users typically partitioned the potential savings into reduced coal consumption (about 40 percent) and keeping a larger area of their homes consistently warmer (about 20 percent). Some 90 percent of users reported that they spent less time starting, tending, and refueling the fire. In addition, more than 80 percent perceived a reduction of smoke leakage into the home, with the added benefit of not having to repaint the kitchen walls every few months (box 1).

Personal exposure monitoring. Concurrent with the 2016–17 winter pilot, a program called Fresh Air, implemented by the International Primary Care Respiratory Group, measured 48-hour personal exposure to $PM_{2.5}$ (from all sources) for those household members responsible for cooking—in most cases, a woman—in the 30 homes that installed a KG4 stove in Osh and Jalalabad Districts (the treatment group).

The control group for personal exposure consisted of household members responsible for cooking in 20 homes that did not switch to the new stoves. Fresh Air's team took personal exposure measurements two months after stove installation and again one year later, in the winter of 2017–18. The results show that the KG4 model improves indoor air quality significantly. In 2016–17, $PM_{2.5}$ concentrations for the control group averaged 153 µg per m^3. Two months after stove installation, average $PM_{2.5}$ concentrations for the treatment group had fallen by an average of 70 µg per m^3 (from 153 to 83 µg per m^3). By the next winter, this average had declined by another 22 µg per m^3 (to 61 µg per m^3) (van Gemert et al. 2019) (figure 2).

Improved indoor air quality and reduced personal exposure to $PM_{2.5}$, in turn, alleviated the respiratory symptoms of household members. After installation, coughing, wheezing, and dyspnea disappeared for most children and adults (table 1).

Following installation of the KG5 low-pressure boilers in Chui, the incidence of chest infections in winter among children in the 11 participant households in that district fell from 86 percent to just 13 percent, and the incidence of children suffering more than two chest infections fell to 1 percent, a remarkable 31 points below the baseline. With the dramatic decline in chest infections, children missed far fewer school days.

Concurrent laboratory testing. The KG4 was also laboratory tested at China Agricultural University during the 2016–17 winter heating season to quantify $PM_{2.5}$ and carbon monoxide (CO) emissions and to establish the unit's thermal efficiency during typical use.

Box 1. Where there is fire, is there always smoke?

One pilot household member from Uchbay Village in the Osh District reported in February 2017 that she (the first of several users) was accused by a meter reader from the power distribution company of "stealing electricity" for heating. The logic behind the accusation was that the house was warm with no visible smoke from the chimney or indoors, and the electricity meter had not moved. The woman reported she had not had to relight the fire since her new KG4 stove was installed in November 2016. Although the stove burned continuously throughout the winter, she estimated that her coal consumption was down by about a ton during the 2016–17 winter heating season, a monetary saving of 40 percent.

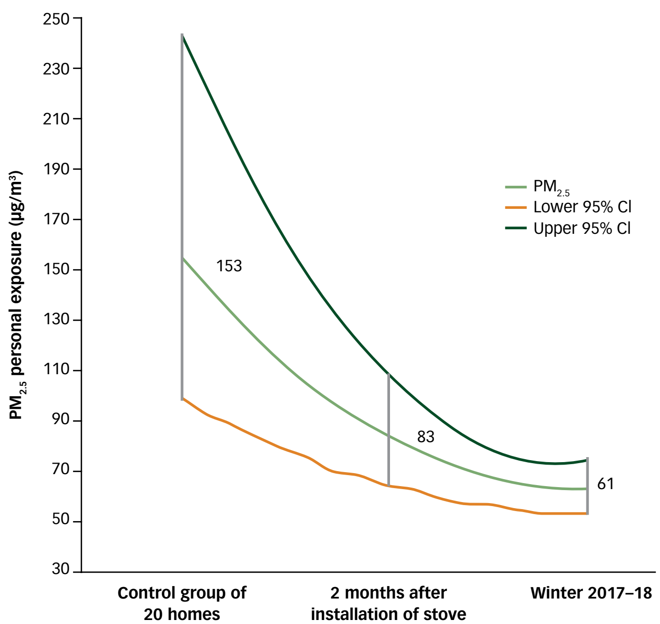
Improved indoor air quality and reduced personal exposure to particulate matter alleviated the respiratory symptoms of household members; coughing, wheezing, and dyspnea disappeared for most children and adults.

Table 1. Comparison of selected respiratory symptoms before and after HELE model installations (percentage experiencing symptom)

Metric	KG4 installation		KG5 installation	
	Before (%)	After (%)	Before (%)	After (%)
Coughing				
Adults	50.0	3.4	71.4	0
Children	32.8	0	53.8	0
Wheezing				
Adults	10.0	3.4	35.7	8.3
Children	7.7	0	7.7	0
Dyspnea				
Adults	40.0	0	57.1	0
Children	53.6	4.4	69.2	0

Note: The KG4 was field-tested in 30 homes in Osh and Jalalabad Districts, while the KG5 low-pressure boiler was field-tested in 11 homes in Chui District that had water-heated radiators.

Figure 2. Reduced personal exposure to $PM_{2.5}$ after KG4 installation, Osh and Jalalabad



Source: World Bank 2019.

Table 2. Stove performance comparisons

Factor	Traditional Mongolian stove[a]	KG4 cross-draft gasifier
Thermal efficiency (%)	30	87
$PM_{2.5}$ (mg/MJ_{NET})	794	2.3
CO (g/MJ_{NET})	16.6	1.4
$PM_{2.5}$ reduction (%)	Baseline	99.7
CO reduction (%)	Baseline	92
Black carbon reduction (%)	Baseline	92

Note: PM = particulate matter; CO = carbon monoxide.

a. The traditional Mongolian heating stove was used as the baseline stove because it has been repeatedly evaluated and because the traditional Kyrgyz heating stoves are similar in construction, operation, leakage, emissions, and efficiency. Laboratory testing at China Agricultural University in Beijing attempted to quantify emissions from a traditional Kyrgyz heating stove using various fuels; however, the emissions for coal were so high that the equipment became clogged and tests had to be abandoned after two hours.

Six-hour cooking and heating tests were conducted on the cross-draft coal combustor used in the Kyrgyz KG4 and KG5 stoves, logging the real-time performance.

The lab test results show that the KG4 model has a thermal efficiency of ~87 percent, compared with just 30 percent for a traditional Mongolian stove during typical use. Per megajoule of heat energy delivered to the home, the KG4 reduces $PM_{2.5}$ emissions by 99 percent, while CO and black carbon emissions are reduced by 92 percent each (table 2).

What were the success factors in the pilots?

Intensive engagement with household users, stimulation of the industrial sector, and technical assistance for targeted producers were crucial in improving design, production, and adoption of the HELE stoves

The HELE technology designers began by learning about Kyrgyz household consumers' needs and perceptions, aspirations, and realities. They considered a range of factors that could influence potential stove users. Apart from adequate heating, key concerns included the ability to heat multiple pots of water, having adequate cooking power and control, the social status of the fuel used, and pride of ownership.

Recognizing that the behavior of stove users might depart from laboratory testing procedures and that there would be a point of diminishing returns on additional costs, the quality of typical local fuel was an important design input, whereas optimum fuel particle size was an output. The chemical and physical analyses of available coals were checked, and new models were fine-tuned to accommodate the fuels households were likely to use.

The KG4 was sized to heat homes of 50–70 square meters in areas where winter temperatures can fall below –30 °C. In collaboration with CAMP Alatoo, the KG4 was adapted to fit each pilot region's available materials, producer skills, and performance requirements, which vary by altitude, cooking culture, fuel type, and traditional patterns of behavior. Great care was taken to engage with producers about consumers' preferences, concerns, and their level of acceptance and enthusiasm for the new stoves.

The designers also recognized the need to ensure that the KG4 could be produced by local workshops. The challenge was how to retain all of the functions of the ideal prototype, while adapting it to rural Kyrgyzstan's on-the-ground realities, considering locally available materials, tools, and skills. This required the technical assistance team to make an expert assessment of the capabilities of local producers: what they could already do, what they could learn to do, and what could reliably be rolled out within the pilot timeline.

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All sheet-metal parts were made using a computer-controlled plasma-cutting contractor to ensure reliable dimensions and thus performance. Producers without this machine could opt to use an artisan version of the drawings with small design changes so they could perform all operations manually. Producers with plasma-cutting and metal-bending machines could make a bent-metal version, which required less welding.

Presently, at least four producers located in or near the capital city of Bishkek have demonstrated the skills needed to produce the HELE stoves to a satisfactory standard. Some of these have invested in additional equipment to expand their production capacity.

The KG4 heating stove is considered affordable for rural and peri-urban households in Kyrgyzstan. A field visit to a mountain village near Osh District shows that households that switched from a traditional solid fuel–fired heating stove to the KG4 model enjoy net savings on fuel of US$48 per month. It is expected that, in the future, repairs can be handled by Kyrgyzstan's many welding shops. The model's new cast-iron grate is a locally manufactured, owner-replaceable part. The cast-iron top is expected to last for many years. Further product evolution and field testing continued throughout the 2017–18 winter heating season.

What has been learned?

The science of advanced combustion and efficiency can be adapted to a defined cultural context using the production skills and materials available in the local market

Prioritizing user engagement. Successful design and adaptation of HELE technologies depends on intensive engagement with users to understand the local context: their needs, preferences, living conditions, operating capabilities, and access to competing fuels and equipment. Apart from heating services, the cooking power, duration, and frequency must be studied and characterized. In the case of rural Kyrgyzstan, this stage took about a year to complete, during which time production problems, localization, and cost issues were also addressed.

Stimulating the industrial sector. A virtuous cycle of product development, test marketing, formal market expansion, cost reduction, and quality improvements can be set in motion among industries in cold-climate developing countries. In Kyrgyzstan, prototypes were developed in partnership with welders in the informal sector. Larger producers were attracted to participate in the pilot only after they understood the potential market and were shown first-hand how well the products worked.[1] Producers in or near the capital city of Bishkek have demonstrated their ability to produce HELE stoves by

[1] Demonstrations were required to convince those who believed coal could not be burned with low emissions.

attending pilot-supported technical training sessions and following the open-source designs.

Providing technical assistance for product design and development. Setting high targets for emissions, combustion, and thermal efficiency can stimulate product development. In developing countries where the capacity for research and development is relatively low, technical assistance in open-source product design and development is essential. Partnering international experts with local experts and producers has had, and can continue to have, profound and sustained impacts on improving local capacities. Among the keys to upgrading local producers' skills and enabling them to continue to improve their services are design assistance; bidirectional knowledge transfer; and initial investments in prototypes, testing, casting patterns, and field installations.

The projects involved in this journey (Kyrgyzstan, Tajikistan, South Africa, Mongolia, and China) are leading by example. They are working closely with local partners and participating in such knowledge exchanges as the South–South Knowledge Exchange Event held in Beijing in April 2017 and the South-South Sustainable Stoves Group (S^4G), which meets every October at the China Agricultural University. They also continue to share technical advances with other project teams and countries' stakeholders.

Switching 100 million households to the HELE technologies would mean annual reductions of 272 million tons of CO_2, 2 million tons of $PM_{2.5}$, and 0.46 million tons of black carbon.

What is the way forward?

If underserved households can switch to HELE heating stove technologies, the fuel savings, emissions reductions, and health benefits will be substantial

An estimated 500 million people—about 100 million households—worldwide rely on traditional, solid fuel–fired (mainly coal) heating stoves. Most of these households are located in remote rural areas beyond the reach of district heating and gas networks and are unlikely to be connected in the near or medium term. A business-as-usual scenario carries substantial negative implications for the national economy, household finances, public health, and the climate. The HELE technologies can offer currently underserved populations a cost-effective, intermediate heating solution.

Assuming that the average household currently uses 2.5 tons of coal each year, switching to the HELE heating technologies could provide annual fuel savings of 40 percent and $PM_{2.5}$ and black carbon reductions above 90 percent and 85 percent, respectively.[2] Such a switch will reduce annual emissions per household by 2.7 tons for CO_2, 20.5 kilograms for $PM_{2.5}$, and 4.7 kilograms for black carbon. Switching 100 million households to the HELE technologies would mean annual reductions of 272 million tons of CO_2, 2 million tons of $PM_{2.5}$, and 0.46 million tons of black carbon.

2 These are conservative figures that assume an average baseline technology better than what was observed in the Central Asia region (table 2).

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Live Wire 2014/7. "Understanding the Differences Between Cookstoves," by Koffi Ekouevi, Kate Kennedy Freeman, and Ruchi Soni.

Live Wire 2015/46. "Results-Based Financing to Promote Clean Stoves: Initial Lessons from Pilots in China and Indonesia," by Yabei Zhang and Norma Adams.

Live Wire 2016/62. "Toward Universal Access to Clean Cooking and Heating: Early Lessons from the East Asia and Pacific Clean Stove Initiative," by Yabei Zhang and Norma Adams.

Live Wire 2016/63. "The Lao Cookstove Experience: Redefining Health through Cleaner Energy Solutions," by Rutu Dave and Rema N. Balasundaram.

Live Wire 2016/64. "Universal or Contextual Design and Promotion of Clean Stoves? The Case of the Indonesia Clean Stove Initiative," by Laurent Durix, Helene Carlsson Rex, and Veronica Mendizabal Joffre.

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The information in this Live Wire comes from the technical report, Advancing Heating Services Beyond the Last Mile: Central Asia Pilot Experience with High-Efficiency, Low-Emissions Heating Technologies*, produced under the Advisory Services and Analytics project, Clean and Efficient Heating in Kyrgyzstan and Tajikistan (https://openknowledge.worldbank.org/handle/10986/31282). The authors are grateful to Gailius Draugelis, Yuriy Myroshnychenko, and Harold Annegarn (North-West University, South Africa), who peer reviewed the report. Financial and technical support was provided by the Energy Sector Management Assistance Program (ESMAP).*

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