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# How to Keep the Home Fires Burning: A Comparative Study of Cooking Hearths for Ceramic Vessels

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**ABSTRACT**
A hearth is the location of an intentional fire, commonly fueled with organic matter such as wood, charcoal, crop waste, or dried animal dung (biomass, or biofuel). Hearths also implicate gender, regional ecologies, and complex, symbolically rich technologies. This article is about household cooking hearths—specifically, biomass hearths used with ceramic cooking vessels. Insights are drawn from international development projects, ethnoarchaeology, archaeology, and related fields to define types of hearths. We identify associations between hearth construction and other key attributes of archaeological relevance, including cooking vessel shape, food preparation methods, fuel choice, labor allocation, methods and materials of house construction, and use of indoor and outdoor spaces. Additionally, we discuss these associations based on our ethnoarchaeological study of development in contemporary Rajasthan, India. We argue that broadening the scope of ethnoarchaeology to consider international development efforts that promote change reveals the complicated ways that cooking hearths are embedded within households.

**KEYWORDS**
Hearth; *chulha*; cookstove; cooking; biomass; biofuel; firewood; feminist theory of science and technology

Archaeologists routinely encounter unfamiliar technologies, and to better understand these technologies is to better understand the daily experiences of people who use them. One such example is the use of hearths fueled with biomass, or biofuel (terms we use interchangeably here). Although archaeologists themselves may not rely on burning organic matter such as wood, charcoal, crop waste, and dried animal dung for their energy needs, biomass is still a key energy source for people with limited access to cash or energy infrastructure. Biomass hearths are also important and ubiquitous features of the archaeological record. Humans and their ancestors have cooked food by burning biomass for perhaps a million years (Sandgathe 2017; Wrangham 2009; Wrangham and Carmody 2010), using ceramic vessels in the last 20,000 years (Wu et al. 2012). Burning biomass contributes to the sights, sounds, smells, and atmosphere of a place. Hearth fires that warm people, light homes, and cook food are a powerful metaphor for home, family, and community, deployed in anthropological titles such as *The Heat*

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*of the Hearth: The Process of Kinship in a Malay Fishing Community* (Carsten 1997) and "Hearth and Home in the Middle Pleistocene" (Kuhn and Stiner 2019).

Hearths require labor and materials, which vary across contexts and shift with availability. Like other products of technological traditions, they can be tailored to specific tasks. Hearths with the residue of fires may leave clear material traces in the archaeological record, implicating inputs, outputs, social and symbolic meanings, cuisines, regional ecologies, and other associations. Many sectors of the world's population largely switched to gas or electricity for cooking in the 19th and 20th centuries (e.g. Chabrol 2016; Foell 2019), and archaeologists who rarely use biofuel hearths may not fully consider these implications, including the women's labor that builds, maintains, and fuels hearths (Chatti et al. 2017) or the health effects of the smoke and particulate matter emissions emanating from them (Barbieri, Riva, and Colombo 2017).

This article is a comparative study of household cooking hearths—specifically, hearths used with biofuel and ceramic cooking vessels. Hearth design is an important part of foodways, domestic architecture, and resource management. We identify associations between hearth construction and cooking vessel shape, food preparation methods, fuel choice, labor allocation, methods and materials of house construction, use of indoor and outdoor spaces, and ventilation within structures. Given our focus on hearths used with ceramic cooking vessels, we primarily address hearths used by people in farming villages, largely sidestepping the voluminous literature on very early hearths and related experimental and ethnoarchaeological work (e.g. Alperson-Afil 2017; Aldeias 2017; Mallol et al. 2007).

We follow Lyons and David's (2019, 102) definition of ethnoarchaeology as an approach that "comprises forms of ethnography carried out by archaeologists wishing to understand the relationships between people and their tangible, intangible and invisible worlds." However, our descriptions of past and present biofuel hearths rely not only on ethnoarchaeological data but also on literature from other fields such as international development. Two of us (Beck and Hill) write as archaeologists and ethnoarchaeologists; the third (Khandelwal) is a feminist ethnographer. As part of our work on contemporary household technology and labor in India, we see other disciplines consider cooking equipment and fuel use in detail. In particular, development and global health researchers have focused on biomass cooking technology and related issues of fuel use, technological innovation, social relationships, environmental impacts, and human health. In contrast, ethnoarchaeologists have understudied fire in general (Mallol and Henry 2017, S218). Recent work explores fire use among hunter-gatherers, with considerable interest in applications to Paleolithic archaeology (e.g. Mallol and Henry 2018; Sandgathe and Berna 2017; Stahlschmidt, Mallol, and Miller 2020. Generally, for groups other than hunter-gatherers, fires appear merely in the background of village life with few exceptions (e.g. Meyer 2003; Reddy 1998).

We begin our hearth review by defining hearths and considering why the international development literature on biofuel cooking is valuable to archaeologists. We then outline key attributes of hearths and define types based on construction, drawing upon the international development literature as well as hearth and structure descriptions from ceramic and village ethnoarchaeology, archaeology, and ethnohistory. For each type of hearth, we describe how ceramic vessels are positioned in the hearth, related characteristics of vessel shape and air flow within and around the hearths. Next we address the qualities of different hearth biofuels in terms of energy efficiency and impacts on health, the importance of availability as a factor in fuel choice, and the relationships between hearths, structures, ventilation, and the use of space. Finally, we consider how some of these considerations fit together in our discussion of international development efforts to change biofuel hearths (*chulhas*) in Rajasthan, India.

## What is a Hearth?

In the broadest terms, a hearth is a "structured and spatially discrete fire … intentionally lit by people" (Mentzer 2017). Alperson-Afil (2017, S259) writes, "The only common feature of all hearths is the simple fact that people intentionally burn fuel in order to produce a fire. Accordingly, the archaeological definition of a hearth should specify that it is an anthropogenic combustion area variable in structure, size, and depth that preserves the remains of burned materials." Hearths in the archaeological record have evidence of *in situ* combustion, such as ash, charcoal, burned bones, fire-cracked rock, and/or oxidized sediments (e.g. Odgaard 2003).

Likewise, biofuel hearths today are carefully designed and incorporate built features and specific objects that are used repeatedly and for long periods. One example is an Indian hearth or *chulha* (Figure 1) made of mud or fired clay, which may last two or three years, depending on maintenance and exposure to monsoon rains (Lambe and Atteridge 2012). Global health and development experts categorize these as "traditional cooking stoves," defined as "very cheap (or no cost) cookstoves, whose use is well established within people's traditional habits" (Barbieri, Riva, and Colombo 2017, 195).

In this paper, we define "hearth" as the location where a domestic fire is made and used. This may be a formal location within a structure or a temporary location outside, both of which would be recognized by archaeologists as a "hearth." It may also be a portable


**Figure 1.** Built hearth structure (*chulha*) in Rajasthan, India, 2017: (a) top view and (b) side view. This *chulha* has two U-shaped chambers to accommodate two cooking fires simultaneously, although only one fire is burning. In each chamber and in the front, the *chulha* is slightly deeper than floor level to provide more space for the firewood. The rear of the *chulha* is a useful space for storing kitchen equipment, such as the bowls and clay griddle seen here. The house has carbon stains on the interior walls, floor, wooden beams, and furniture from the soot and smoke. Photo by M. Beck.

artifact, like some traditional cooking stoves. Here we use the terms "hearth," "traditional cooking stove," and "non-industrial stove" throughout as roughly synonymous, referring to features or artifacts made by the users themselves or by others in the immediate community. These terms exclude industrially manufactured hearths or cooking stoves, which is consistent with terms and concepts used by archaeologists.

Hearths implicate gender as well as complex, symbolically rich technologies. Feminist approaches to science and technology foreground the invisible free labor of women in society and elevate technologies of everyday life, countering the stereotype of women as technologically less capable than men and focusing scholarly attention on the meanings of artifacts themselves (Wajcman 2010). Archaeologists widely recognize that the study of cooking is one way to investigate women's labor using this approach (Graff 2020). In contrast, relatively little attention has been given to hearths as artifacts and to the gendered technological knowledge required to build, use, and maintain them. This article addresses that gap.

In their work on household energy vulnerability, Day and Walker (2013) argue that home cooking energy is not so much a "system" as an "assemblage" of different elements that are contingent on each other and unpredictable in how they come together. Heterogenous human and non-human actors coalesce into "assemblages" or networks to make cooking possible. An assemblage is not just a collection of things but rather a functioning collective that is more than the sum of its parts, at least for some period of time. Because assemblage thinking de-centers the human role, it encourages consideration of how a family cow or the insulating features of clay influence how situations play out at the hearth. These entities "are not just props to human endeavors but they assert themselves in significant ways" (Day and Walker 2013, 17).

## *Contemporary Hearths and International Development*

Today, an estimated 2.6 billion people in low- and middle-income countries in South Asia, Sub-Saharan Africa, and Central and South America rely on wood, animal dung, coal, and charcoal for their daily household cooking (International Energy Agency 2019; Yadama 2013). Transitions to natural gas, electricity, and other forms of industrialized energy have occurred unevenly across the world, like the distribution of global resources in general.

Governments, non-governmental organizations, health agencies, and environmental groups have worked for the last 90 years to reduce fuel use and emissions by moving people to cleaner-burning biomass stoves and to cleaner fuels such as biogas, natural gas, and liquid petroleum gas (LPG) that are burned in manufactured stoves (Figure 2; see discussion in Khandelwal et al. 2017). This work is motivated by concerns about health, deforestation, climate change, and women's labor. Air pollution from the incomplete combustion of biomass in hearths profoundly affects the morbidity and mortality of more than four million people a year (World Health Organization 2014), especially women and children who spend much time in proximity to cooking fires (Landrigan et al. 2018; Smith and Sagar 2014). The burning of millions of tons of biomass fuel is a source of greenhouse gases and contributor to black carbon in the atmosphere and climate change (e.g. Barnes, Kumar, and Openshaw 2012; Masera et al. 2015; Smith 1994). The demand for cooking fuel is also understood to be a major contributor to deforestation and land degradation (e.g. Barnes, Kumar, and Openshaw 2012; Crewe


**Figure 2.** This airport sign in New Delhi, India in 2020 reflects the promotion of "clean" fuels across the country. The Indian government subsidizes household purchases of liquid petroleum gas (LPG) to encourage its use, and households can choose to forego their subsidies to make more available for lower income households. Photo by M. Beck.

1997; Eckholm 1975), although in many cases firewood-dependent people are more likely to suffer from deforestation and firewood shortages than to cause them (Swaminathan 1999). The work of gathering and transporting fuel also puts people—usually women —at repeated risk of allergic reactions, fungal infections, and falls and injuries. Carrying heavy loads of 20–30 kg of wood on top of the head can lead to skeletal, muscular, and neurological injuries to the spine, and it is even associated with damage to reproductive organs (e.g. Pandey 1996/1997; Subba 1999).

Development programs document traditional cooking stoves and measure their fuel use and emissions in order to design more efficient "improved cookstoves" (ICs). Hundreds of improved cookstove projects around the world encourage rural households to replace their traditional hearths, but adoption rates for many IC projects are very low (e.g. Barnes et al. 1993, 1994; Urmee and Gyamfi 2014), in part because of the hearth's embeddedness in other aspects of daily life. Some or all of the key attributes of traditional cooking stoves are lacking in many improved cookstoves, making ICs less attractive to energy-poor households.

## Key Attributes of Traditional Cooking Hearths

Review of global health and development literature on traditional hearths reveals several key attributes. First, hearths are *custom built, often by the mother or grandmother who does the cooking*, to fit a specific space in the home and to accommodate cooking pots and other utensils (Barnes et al. 1994; Gill 1987). Big pots or griddles require large hearths or stoves; small pots are used with small hearths or stoves (Barnes et al. 1993). The size of utensils and the hearth vary according to family size. If a cook occasionally needs to use a very large cooking vessel, she may build a temporary cooking hearth, often outside, instead of using her usual hearth.

Second, hearths are *made from easily obtainable local raw materials*, such as stones, bricks, and mud. When repairs or replacements are needed, the user makes them quickly at little or no cost to the household (Rhodes et al. 2014). The user can also change the design or position of a hearth relatively easily if desired.

Finally, hearths *heat up quickly and are easy to load with fuel*. These performance characteristics influence the position of the cooking pot over the fuel and the size and placement of the opening where fuel is added (Barnes et al. 1993, 1994). Hearths also need to accommodate different types and sizes of fuel (Gill 1987; Rhodes et al. 2014). For example, pieces of firewood in the kitchen often vary in size, based on chopping and trimming during collection, and cooks prefer to avoid further, tedious firewood trimming once they begin cooking. It may be necessary to change fuel type depending upon the cooking task, such as rapidly frying vegetables or meat; slowly heating milk; simmering food for an extended time; or boiling large quantities of water.

### *A Typology of Cooking Hearths Used with Ceramic Vessels*

Based on hearth descriptions from global development, ethnoarchaeology, ethnohistory, and experimental archaeology, we define four types of hearths used with cooking vessels: (1) expedient hearths without formal vessel supports, (2) prepared hearths with hearth "furniture," (3) built hearth structures, and (4) small portable non-industrial stoves. This typology prioritizes traits that should be archaeologically visible, such as prepared surfaces and sides, removable or built hearth furniture, and fire portability. Cooks may use more than one of these hearth types to accomplish different cooking tasks, a practice known as "stove stacking" (Barnes et al. 1993; Smith and Sagar 2014).

### *Expedient Hearths Without Formal Vessel Supports*

This type includes hearths used for a relatively short time by people who are residentially mobile. The fire is built on the ground or in a quickly prepared depression, frequently outside structures. Ceramic vessels used with such a hearth often have conical bases used to nestle the pot into the fire (Figure 3). This reduces or avoids the need for pot supports (Linton 1944; Reid 1990). Helton-Croll (2010) describes Navajo conical cooking vessels, noting that the "basin-shaped, relatively shallow hearths built by the Navajo were well suited for building a fire *around* the vessel" (Helton-Croll 2010, 162; emphasis added). Stewart (2005, 2) argues that "the bases of [Khoehoe] vessels were being nestled directly into the coal and ash beds of their cooking hearths," based on his comparison of pre-colonial archaeological ceramics to experimentally used vessels.

### *Prepared Hearths with Hearth Furniture*

Prepared hearths are repeatedly used for an extended period. As such, they often have prepared surfaces and physical borders that formally delineate the space. They also include hearth furniture, specifically vessel supports. By "furniture," we mean objects

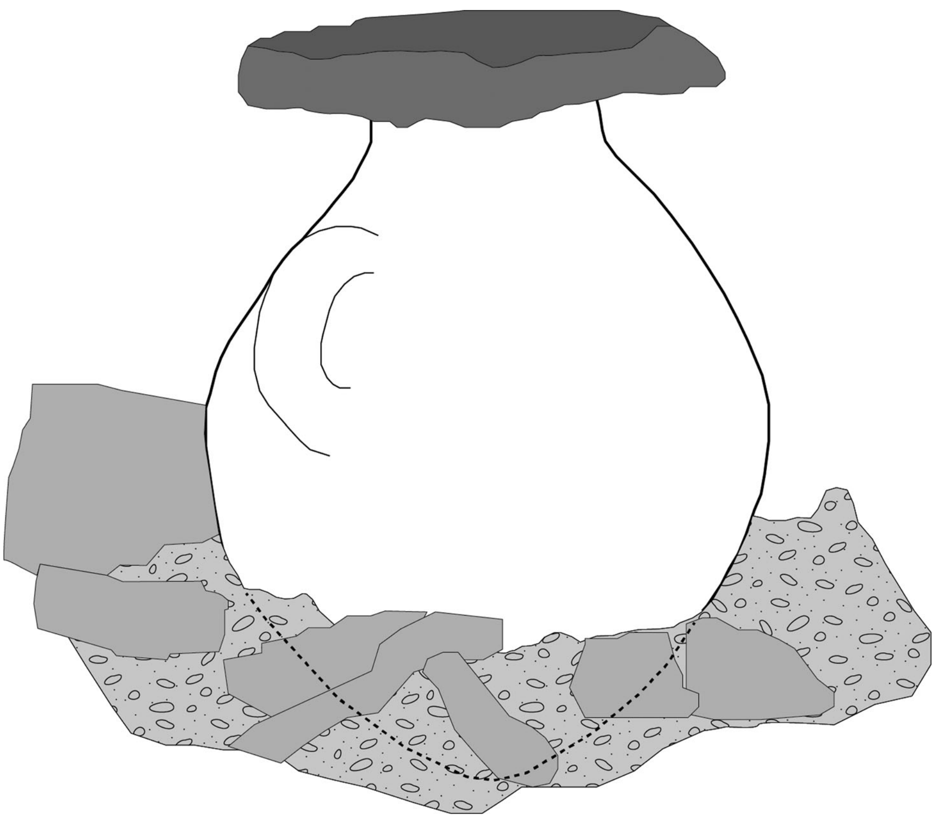

**Figure 3.** Expedient hearth. A conical, ceramic cooking pot is embedded in the ash of the hearth to stabilize it and surrounded by firewood. A rock is used as a lid. (Based on Stewart 2005, Figures 7–9).

that remain in place as part of the feature, similar to Binford's (1978, 339) definition of site furniture as "site-specific 'hardware'… items that go with the place, not necessarily the persons occupying the place." Although this furniture is considered part of the hearth, it can be shifted or transported to another hearth if necessary.

The simplest of these has been called a three-stone hearth, or a three-stone fire (TSF) cookstove" (Riva et al. 2016, 59). Similarly, Barbieri, Riva, and Colombo (2017, 195) describe "three-stone fire stoves … often named open-fire stoves" as

> simple and zero cost fires built directly on the ground where three stones work as the pot support. The main drawbacks of such devices are the large amount of radiative thermal losses toward the environment, the huge amount of PM [particulate matter] produced during the combustion, and the exposure to open burning flames. On the other side, the fact the flames surround directly the pot makes them sometimes more efficient than other cooking devices.

The three-stone hearth is a standard traditional cookstove to which improved cookstove designs are often compared (Bussman et al. 1985; Riva et al. 2016). Common around the world, this type of hearth has been described in ethnoarchaeological projects such as the Kalinga Ethnoarchaeological Project in Southeast Asia (e.g. Skibo 1992, 2013), the Coxoh Ethnoarchaeological Project in Mesoamerica (e.g. Deal 1998), and the Gamo Ethnoarchaeological Project in eastern Africa (e.g. Arthur 2007). Contemporary Ebira, Yoruba, Tiv, and Hausa households in Nigeria prefer three-stone hearths "for being free of cost, easy to construct and very flexible as the three stones can easily be moved apart to accommodate different pot and fuelwood sizes" (Akintan, Jewitt, and Clifford 2018, 19).

A three-stone hearth typically has three stones to support a vessel, as illustrated for the Aztecs in the sixteenth century Florentine Codex (Figure 4) and observed elsewhere in Mesoamerica. Writing about Maya homes in Mexico and Guatemala, Wauchope (1938, 117) describes the hearth as having "three round stones … usually about 30 cm in diameter." A similar hearth was discovered at the Maya archaeological site of Ceren (Sheets 1992, Figures 4–6). In practice, the supports may be objects other than stones, such as purposely made vessel supports or simply recycled objects. Terms used by archaeologists for these vessel supports include "fire dogs" (Reiter 1938, 49) and "andirons" (Smogorzewska 2012, 233). Kalinga households in the northern Philippines use three supports made of fired clay (Figure 5; Beck 2009, Figure 2; Skibo 1992, Figure 4.9). Gamo households in Ethiopia use ceramic supports or round stones (Arthur 2007). A Tzeltal Maya household in Mexico used a broken ceramic jar as one of the vessel supports (Deal 1998, Figure 4.36). Within the rectangular, slab-lined hearths used in the Puebloan U.S. Southwest for centuries (Mindeleff and Mindeleff 1891), stone vessel supports are documented in pre-colonial contexts (e.g. Reiter 1938, 49). A nineteenth century large cooking pot at Zuni Pueblo is shown supported over the hearth by rocks by Cushing (1882-1883, 203). The Nepalase *ageno* uses three or four bricks or stones to support the vessel (Pandey et al. 1990; Subba 1999).

In all these examples, three-stone hearths have some space between the fire and the nearest wall. Often they are placed in or near the center of the room. This position allows air to reach the fire from all sides and heat to move throughout the entire space.

**Figure 4.** Sixteenth-century depiction of an Aztec woman putting corn into a ceramic cooking pot on a three-stone hearth (Sahagun 1981; public domain).

Ceramic cooking vessels used with three-stone hearths are often globular with rounded bases, in contrast to conical-base vessels often used with expedient hearths without formal vessel supports. In the U.S. Southwest, Helton-Croll (2010) compares

**Figure 5.** Three-support hearth in Pasil Municipality, Kalinga Province, Philippines, 2001. Kalinga households in the northern Philippines use three supports made of fired clay. Here a metal pot sits on the hearth supports over the embers of the fire. Another metal pot is kept warm to the side. Photo by M. Beck.


**Figure 6.** A U-shaped mud stove (*chulha*) in Rajasthan, India, 2017: (a) top view of food cooking in a ceramic pot on the *chulha*, (b) top view of the *chulha* while not in use, and (c) front view. Photos by M. Beck.

the round-bottomed cooking vessels and formal hearths in Puebloan (Jemez) archaeological sites to the conical-base cooking vessels and expedient basin-shaped hearths in nearby Navajo archaeological sites. Considering the descriptions of cooking vessels preferred by Okiek (Blackburn 1973) and Zulu (Krige 1936) people in Africa, Stewart (2005) argues that pots with rounded bases sit more securely on hearth stones than other forms, such as "the flat bottomed aluminum pot" (Blackburn 1973, 63), and should be expected with this hearth type. Kalinga households used some flat-bottomed metal vessels with three-stone hearths, however (Beck 2003).

Another alternative to the use of three supports is to hang the vessel above the fire. In what is now the United States, 17–eighteenth century European colonists used metal pots for cooking, including cauldrons suspended over the fire (Hume 1970). This practice was also used by Native North Americans after European colonization. In his description of nineteenth century Mandan lodges in the Great Plains, Catlin (1842, 82) writes, "Over the fireplace, and suspended from the apex of diverging props or poles, is generally seen the pot or kettle, filled with buffalo meat." He illustrates this in his painting "Interior of a Mandan Lodge" (see also Catlin 1842, Plate 46). The pot over the fire is clearly a metal vessel, flat-bottomed and gray, and hanging the vessel over the fire might indeed be more common with metal vessels than ceramic. In her experiments with a wide variety of wood-fired cooking techniques, Marcoux (2014) only suspends metal pots and uses clay pots on a bed of coals instead. Another alternative is to attach vessel supports to the ceramic vessel to give it stability in the hearth. For example, nineteenth century Zuni Pueblo had "enormous [ceramic] cooking-pots, some with prong-like, irregular legs" (Cushing 1920, 296, Plate XIII).

### *Built Hearth Structures*

Built hearth structures are repeatedly used for an extended period, with hearth furniture built in place. These structures are generally placed along the edges of rooms, with the closed back of the hearth positioned against the wall. Many types of built hearth structures lack chimneys. Barbieri, Riva, and Colombo (2017, 195–196) describe them as mud stoves:

> Mud stoves are structures made of sun-dried mud dried by heat from the fire with a hole for placing the pot on the top and three sides that enclose the fire … They are semipermanent stoves and they are usually built on site, with no-cost or at least very low. They are supposed to be more efficient than three-stone fire stoves since the enclosed fire caused a reduction in radiative losses … Mud stoves are suited to be home-made.

U-shaped or horseshoe-shaped built hearths (Figure 6) are common across Asia where they have been used for thousands of years, as documented archaeologically (e.g. Meyer 2003), and similar built hearths are found across the globe in contemporary and past contexts. Unlike three-stone hearths, built hearth structures with three sides are open only in the front, where fuel is placed, and on top where the cooking utensil is placed, such as a pot or griddle. This configuration restricts air flow but may also increase fuel efficiency as noted above. In Rajasthan, India, the ceramic cooking pots used with U-shaped hearths had pronounced shoulders (Kramer 1997), although it is now common to see straight-sided, flat-bottomed metal pots on these hearths instead.

Built hearths are often part of a group of clay or mud cooking structures that may include multiple hearths to accommodate both griddles and cooking pots (e.g. Lyons 2007 in Ethiopia; Meyer 2003 in Pakistan) and ovens or other insulated features. In Uzbekistan, Gur-Arieh et al. (2013, 4332) describe "traditional installations, locally called *tandir* and *ochock* … built from mud and vegetal matter (most commonly straw) … The *ochock* is a partially enclosed hearth used for cooking, which includes roasting, frying, and stewing." The *tandir* is very similar to the Turkish *tandir* baking oven (Gur-Arieh et al. 2013; Parker 2011), the Syrian *tannur* (Smogorzewska 2012), and the northern Indian *tandoor* (Saxena, Haridas Rao, and Raghava Rao 1995). Punjabi households in Pakistan cook on a U-shaped *chulha* (Meyer 2003), a built hearth similar to an *ochock* in Uzbekistan. They also use a hearth type called a *dudh karna* or "milk cooker," a heavily insulated feature used to heat milk slowly for yogurt (Meyer 2003, 291).

Built hearths can be replicated expediently for temporary use. For example, our own work in urban and peri-urban India (Khandelwal et al. 2022) documents numerous examples among laborers who live in temporary housing or cook on job sites. In these cases, portable vessel supports (usually five loose bricks) are placed in a U-shape. A clay water pot is sometimes deliberately broken on one side to create a U-shaped cooking vessel support, which has the three sides and restricted air flow of a formal U-shaped built hearth. An informal hearth or *chulha* made from a ceramic vessel (*matkawala chulha*) also can be considered a small portable stove, a type of hearth discussed further below.

In built hearth structures, as in prepared hearths with hearth furniture, fuel is often placed directly on the ground surface or hearth floor (Figure 7). This fuel placement may reduce air supply to the fire, leading to incomplete combustion with increased emissions and indoor air pollution (Barbieri, Riva, and Colombo 2017). A perforated insert to raise fuel off the floor and improve air flow reduces smoke and particulate emissions and increases fuel efficiency (Barbieri et al. 2018; Khandelwal and Lain 2017; Udaykumar et al. 2015) but is not a common feature in the traditional hearths described above.


**Figure 7.** Woman and child beside a cooking hearth in the French countryside during World War I, April, 1918 (Taylor 2014, Figure 26; public domain).

### *Small Portable Stoves*

Small portable stoves are made of fired clay or metal, such as scrap metal from cooking oil containers or old oil drums (Barbieri, Riva, and Colombo 2017, 196). The design is essentially a column, with a hole on the lower side to place fuel and with support for a cooking vessel on top. Examples of traditional portable clay stoves include the *kalan* in the Philippines (Ruaya 2020) and *lapohan* in Borneo (Ono 2006; Figure 8).

Uninsulated metal stoves are slightly more fuel efficient than built hearths and substantially more fuel efficient than 3-stone fires. "In terms of energy saving, metal stoves offer a discreetly higher saving rate than mud stoves with a range of 40-55% over three-stone fires. Emission rates (emissions per time) for these types of stoves are similar to those of the 3-stone fire, but total emissions are lower, because of the shorter time needed to boil and cook" (Barbieri, Colombo, and Riva 2015, 87). Thick-walled clay stoves may be more fuel efficient still, with possible energy savings of "higher than 60% over three-stone fires" (Barbieri, Colombo, and Riva 2015, 92). Further improvements in efficiency involve additional insulation and features to increase air flow (Barbieri, Colombo, and Riva 2015).

Small portable metal and clay stoves may be used with charcoal as well as wood, ideally with the addition of a grate to hold the charcoal off the floor and allow air to flow underneath (Barbieri, Colombo, and Riva 2015). Metal stoves made specifically for charcoal use are essentially a raised grate (see Lask, Booker, and Gadgil 2017, Figure 1 for a Haitian example). The online collections of the British Museum include twentieth century metal charcoal braziers with grates, such as object Af1973,19.69 made in Zambia with metal from a Shell oil tin (https://www.britishmuseum.org/collection/object/E_Af1973-19-69) and object Am1985,32.335 made in Bolivia (https://www.britishmuseum.org/collection/object/E_Am1985-32-335).

At its simplest, a small portable charcoal stove or brazier may be just a clay bowl or column to hold charcoal, with three prongs at the rim to support the cooking vessel. The Moroccan *majmar* is one example, often used with a lidded ceramic tajine for cooking (e.g. Garratt 2013). In his short story "The Majmar," Taïa (2017, 31) describes the evening ritual of a poor Moroccan family in the winter: "My mother and sister

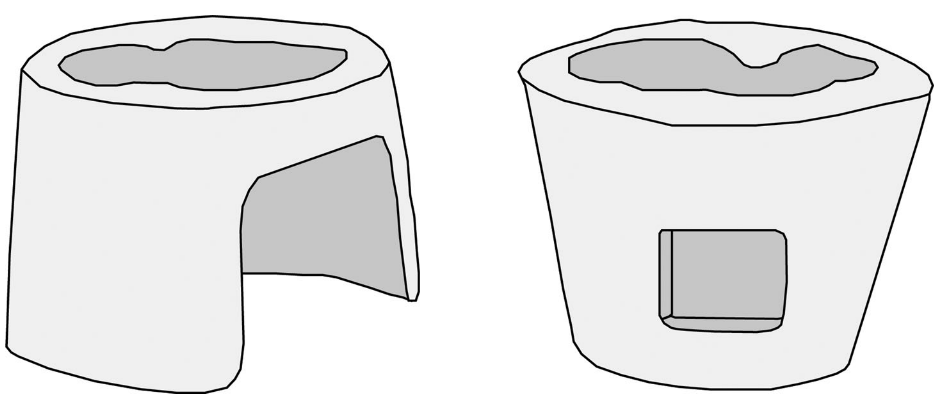

**Figure 8.** Different examples of traditional portable ceramic stoves in Borneo (redrawn from Ono 2006, Figure 4).

Najat would light a fire in the majmar with coals bought from Soussi Hassan. We stayed in the same room, around our little glowing majmar. One by one, we'd warm our hands, feet, even faces … Dinnertime came, and we'd heat our food on the majmar as well."

Portable charcoal stoves are often part of a stove stacking strategy in which a household uses multiple stoves, choosing different types for different cooking tasks (Jagadish and Dwivedi 2018, 50; Khandelwal et al. 2017, 22; Subramanian 2015, 155). In northern

**Figure 9.** A *sigri* stove in use outside a home in Odisha, India, 2020. A *sigri* is a portable metal stove that can be fueled with wood or charcoal to cook, heat water, or provide warmth. Photo by M. Beck.

India, the *sigri* is an iron or steel stove that is portable and can be fueled with wood or charcoal to cook, heat water or provide warmth in the cold season (Figure 9). Communities of displaced people in South Sudan use both a "a portable ceramic charcoal stove and a stationary mud/brick stove which uses both fuelwood and charcoal" (Barbieri, Riva, and Colombo 2017, 196). French artist Jean Baptiste Mallet, working in the late eighteenth century and early nineteenth century, depicts European "stove stacking" with wood and charcoal. In one unnamed illustration (Mallet 1774-1835), (a woman stirs the steaming contents of a globular cooking pot over a ceramic brazier while a flat-bottomed (apparently metal) vessel is suspended over a wood fire in the fireplace.

## Types of Biofuel

Wood is the preferred hearth fuel in the contemporary communities described below. It may be collected as large branches and tree trunks (often requiring significant labor to cut down, lop off, or chop into smaller pieces) or as smaller twigs that are combined to create a fire (e.g. Khandelwal et al. 2022). It may also be used in completely dry condition or as green wood. People incorporate a variety of supplements or substitutes when wood is not available. People may carefully choose between different tree species and condition based on intended use (e.g. Henry et al. 2018) Alternative biomass fuels include charcoal, animal dung, peat, grasses, bones, cactus parts, crop waste such as corn cobs and coconut husks, and crop residue such as stems from harvested corn, oilseed, mustard, sesame, guar, and sugarcane (Agarwal 1987; Dewees 1989; Laxmi et al. 2003; Subba 1999).

Charcoal is an inefficient use of energy, requiring large volumes of wood to produce (Das et al. 2018; Horne 1982; Khandelwal et al. 2022; Luoga, Witkowski, and Balkwill 2000; see Yadama 2013, 91–95). Das et al. (2019, 297) observe that "more than half of the energy content of fuelwood is typically used in the carbonization process." For example, in rural households surveyed in Nepal, firewood use per capita averages 2.6 kg/day with a yearly per capita estimate of 960 kg (Das et al. 2019); this would rise to an estimated 1600/kg if firewood was consumed as charcoal in the same hearths (Das et al. 2019, 497; see also Okoko et al. 2017 for Kenya and Tanzania). Although rural communities usually do not fuel their hearths with charcoal (Das et al. 2018), they may produce charcoal for sale (Yadama 2013, 91, 95) because it is a good commodity: "lightweight, easily transported, easily stored, and constantly in demand" in energy-poor urban areas (Walsh 2019). It also releases less smoke when burned than wood (Horne 1982). Urban residents purchase charcoal and use charcoal braziers or stoves in their dwellings.

Wood is the fuel of choice with three-stone hearths in the agricultural villages of the Kalinga Ethnoarchaeological Project in Southeast Asia (e.g. Skibo 1992, 2013), the Coxoh Ethnoarchaeological Project in Mesoamerica (e.g. Deal 1998), and the Gamo Ethnoarchaeological Project in eastern Africa (e.g. Arthur 2007). Ebira, Yoruba, and Hausa people in Nigeria describe cooking with wood and three-stone hearths, as used for generations, preferring wood because it cooks food quickly and because its smoke is used to cure salted meat suspended above the fire (Akintan, Jewitt, and Clifford 2018). In the Indian Himalayas, the importance of wood use for fuel is reinforced by its use in the winter for heating homes (Jagadish and Dwivedi 2018).

Wood is used, alone or with dung or other biofuel, with U-shaped built hearths. Meyer (2003, 289–290) describes fuel choice in the Punjab region of Pakistan:

> Wood, specifically tree branches, has been a long-term preferred fuel type because it heats quickly and burns hot. Wood, however, is a scarce and expensive resource in the Punjab; therefore, it is often supplemented with animal dung [particularly water buffalo dung] when cooking … When Punjabi residents lack adequate wood resources, they often resort to burning leaves, chaff, or dung alone.

The intensity of wood use is related in part to proximity to wood sources. Households near dense forests, especially forests that are locally controlled and managed, have higher rates of use of wood as fuel. In northern India, rural populations in wood-rich hill settings consumed twice as much firewood as similar groups in wood-poor plains (Agarwal 1987). According to survey data from the 1970s, the wood consumption of people in wood-rich Papua New Guinea was double that of people in Nepal and six times that of people in arid parts of Afghanistan (Agarwal 1986). As Dewees (1989, 1161) notes, "the not-surprising conclusion [is] that woodfuel consumption is a function of the cost of obtaining it."

Available labor is another important consideration in fuel choice because the labor required to collect wood may be substantial. For example, in parts of India with moderately dense forests, women regularly walk 1–4 km to the nearest source of wood and take up to 4 h to collect firewood (Barnes, Kumar, and Openshaw 2012). However, in rural areas of India with denuded forests, women walk 8–10 km to acquire their household fuel (Agarwal 1987). Women and girls in 22 African countries spend between about 1 and 5 h (average = 2.1 h) collecting firewood per day (World Bank 2014, 22). Ouerghi's (1993) study of rural Pakistan households found that per capita consumption of wood was actually higher in tree-poor desert areas in Baluchistan Province than in well-forested areas, such as Khyber Pakhtunkhwa and Sindh provinces. Households in Baluchistan had almost no access to alternative fuel sources, such as dung cakes and crop residues, but they did have an abundance of household labor to trek long distances to collect wood.

Dung is used for fuel throughout South and Southwest Asia and Africa and has been for millennia (Dewees 1989; Lancelotti 2018; Miller 1984; Reddy 1998). In India in particular, cow dung has broad significance in Hindu traditions. Dung also has heating properties that make it useful in certain situations. Experiments reveal that although "dung alone fails to produce the necessary temperature for expeditiously heating items placed on chulhas … when dung supplements wood, the fuels achieve adequate flames that reach the chulha top and immediately heat the cooking vessel" (Meyer 2003, 289). In northern India, dung's lower-temperature cooking properties make it useful for ghee preparation (Lewis and Barnouw 1958). Punjabi households purposely use only dung to provide low, steady heat when making yogurt in the *dudh karna* or "milk cooker" (Meyer 2003, 291). These households can also rely on the labor of Dalit women who will prepare dung cakes very cheaply (Nathan and Kelkar 1997, 217). Dung cakes consist of dung mixed with chopped and dried plant matter, patted into discs, and put in the sun to dry.

Other biofuels may supplement or replace wood as needed. Some rural households in China use straw extensively because it produces a hot enough flame to quickly fry foods (Wu and Chen 1983). In India, crop waste and residue supplements other fuel when available (Nathan and Kelkar 1997; Swaminathan 1999), and landless laborers without access to crop residue must spend more to buy additional fuel (Nathan and Kelkar 1997, 209).

There are limits to how much energy-poor households can reduce wood consumption without significantly changing or limiting food preparation. During wood fuel shortages in South Asia and Africa, households forced to use less wood or use lower-energy-producing fuels, such as crop residue, often shifted their diets to less nutritious foods requiring less cooking time or lower temperatures (e.g. Agarwal 1987; Dewees 1989; Hughart 1979). Fuel shortages often create greater nutritional shortages for women and female children (Agarwal 1986).

## Hearths Within Structures: Use of Space, Air Flow, Heat, and Emissions

Three-stone hearths, the type of hearths with the largest particulate matter emissions (Barbieri, Riva, and Colombo 2017), are routinely placed in structures without chimneys (e.g. Deal 1998; Skibo 1992, 2013). How do residents live with air quality problems and avoid routine carbon monoxide poisoning? One answer is that houses with porous roofs and other ventilation, whether intentional or accidental, allow smoke to escape in other ways (e.g. Yadama 2013, 52–53, 102-103, 109). For example, around AD 1400, timber-framed "Wealden" houses occupied by English farmers were designed with a central hall, two stories high but open to the thatched roof. This hall was heated with an open hearth in the center, and the adjacent one-story high rooms were unheated (Brunskill 1997, 51–56, 208-211).

Goodman (2016, 126–127), based on architectural data and experimental reconstructions of life in England's Tudor period, describes smoke movement from wood fires before and after chimneys:

> Before 1500, domestic buildings, with the exception of stone-built castles, had central hearths and no ceilings. The smoke made its own way out, drifting gently up to the rafters and percolating out through gaps in the eaves, open windows, and any other cracks and fissures it could find. That bottom layer of [roof] thatch was heavy with preservative soot. But during the sixteenth century came the great 'chimneying' of Britain. Home after home was 'improved' by the addition of a smoke hood or full chimney, a second floor was inserted and ceilings put up. No more smoke made its way up to the thatch but was channeled away and out.

This smoke from the hearth, along with the heat, is valuable itself for preserving meat and fish, with examples among indigenous peoples in both the Subarctic (Henry et al. 2018, 107) and Nigeria (Akintan, Jewitt, and Clifford 2018). Smoked food may be hung from the rafters above the kitchen hearth (Akintan, Jewitt, and Clifford 2018, Figure 3). Even when people note some discomfort from hearth emissions, they may regard it as a short-term problem and "an inevitability that one grows accustomed to" (Rhodes et al. 2014, 10320).

Colonialism, targeted development efforts, and globalization have changed both hearths and architecture but not always coherently. Sometimes ventilation has been reduced unintentionally for biofuel hearths by the transition to less permeable building materials. Metal roofs and concrete walls make structures more airtight and watertight, increasing heat retention but reducing ventilation. Burning charcoal rather than wood reduces visible emissions but does not eliminate carbon monoxide emissions, which can be fatal with inadequate ventilation. Taïa (2017, 32) describes this danger with the charcoal-burning *majmar*:

> Finally, we would move the majmar into a corner of the room, for if we huddled around it too long we'd get headaches. We would bring it out to the courtyard before bedtime so it could also go to sleep and quickly air out the room (to get rid of the carbon monoxide, we remembered how our Berber neighbors' two sons almost died because they forgot to take the majmar out of the bedroom).

After moving into a more airtight structure, some people banish the biofuel hearth to the outside, particularly if it is used for cooking and not heating. In Kalinga households in the Philippines, residents of a new concrete and metal house moved the biofuel hearth outside to an attached shelter (Beck 2003). Similar solutions have been employed in Odisha, India (Khandelwal et al. 2022). In both places, the residents expressed more concern about soot in the main house than air quality; the Kalinga informant described the outside shelter as her "dirty kitchen" (Beck 2003).

Given the importance of ventilation, it might seem that special ventilation features such as chimneys would be welcome additions to houses with biofuel hearths. Households may resist adding chimneys for a variety of reasons, however. For example, hearth smoke is useful for food preservation and for creating "ash stalactites, a substance used for traditional remedies for respiratory illness in Kenya" (Rhodes et al. 2014, 10320). In India, new chimneys on rural homes had marked drawbacks: water entering the stove during the rainy season, snakes entering the home, and thatched roofs going up in flames (Chandrashekhar 2015; Khandelwal and Lain 2017; Sarin 1986). Finally, a chimney changes the use of interior space by changing which parts of the structure are comfortable. Based on her experimental reconstructions of Tudor hearths, Goodman (2016, 5) describes how a biomass hearth on the floor relates to heating the space and the use of furniture:

> These central hearths [as used in Britain before 1500] were good at heating the indoor space, with none of the energy being lost up a chimney … Hearths were also convenient for cooking upon, allowing 360-degree access. However, the smoke did tend to hang in the air. The higher up you were, the more smoke there was. Spend time in such a building with the fire lit and you'll soon notice that there is a distinct smoke horizon below which the air is clean and breathable and above which it is not. Life, then, must be lived beneath the smoke layer. Furniture that raises you up is not helpful; you are better off living on the floor, so that floor needs to be warm, dry, and comfortable to sit and sleep upon.

Presumably, "living on the floor" was more important in a one-story home with an open hearth, as the two-story height of a Wealden house's central hall would have raised the smoke horizon substantially. After replacing the open hearth with a fireplace and chimney, sleeping on the floor would be less comfortable in cold weather because chimneys "draw the smoke up and out, and in doing so pull in cold air at ground level" (Goodman 2016, 8).

Hearth placement, ventilation features, roof and wall materials, and room placement changed in English Wealden houses as open hearths were replaced by fireplaces. In efficiency and room placement, central open hearths resemble three-stone hearths and fireplaces resemble built hearth structures. The hearth, initially (ca. AD 1400) in the middle of a central hall open to the thatched roof, was moved to the side and "made more effective through the use of a fireback" to reflect the heat (Brunskill 1997, 210). The smoke was directed into a "smoke bay" (Brunskill 1997, 210) through louvres (domed features with ventilation openings) or gaps in roof tiles. By ca. AD 1600, the fireback and smoke bay had become a fireplace with chimney. With smoke securely channeled from the ground floor through the roof, a floor was added in the central hall to make a second story, and lath and plaster were added to the exterior frame "which eliminated draughts" (Brunskill 1997, 210).

Indigenous Puebloan communities in the U.S. Southwest offer another example of the transition away from open hearths and related changes in the use of space. Prior to Spanish colonization, Hopi and Ancestral Hopi pueblos placed habitation rooms with hearths on the top floor of multi-story structures and storage rooms below. Habitation rooms, used for sleeping and some cooking, had door sills at or below ground level (in contrast to other room types with higher door sills). There was enough air flow near the hearth to require a deflector: a "stone set adjacent to the firepit on the door side to keep air from blowing directly onto the fire" (Adams 1983, 46). Hopi and other Puebloan communities adopted fireplaces with chimneys after Spanish colonization (Adams 1983; Cameron 1999; Cushing 1920; Mindeleff and Mindeleff 1891) and wood stoves after AD 1850, when the United States controlled the region (Adams 1982; Cameron 1999). The introduction of wood stoves led to an increase in habitation room size, because the larger space could be efficiently heated (Cameron 1999). Wood stoves are contemporaneous with the appearance of separate structures for cooking *piki* bread at Hopi Pueblo (Adams 1982) and the shift of habitation rooms to the first floor at Hopi and Zuni pueblos (Cameron 1999; Ferguson and Mills 1987).

## The Hearth as an Assemblage: A Case Study in Contemporary India

Home cooking energy can be considered an "assemblage'" of different elements that are contingent on each other and unpredictable in how they come together (Day and Walker 2013). In southern Rajasthan, India, the hearth assemblage includes diverse elements such as house construction materials, the carbon that blackens cooking pots and the walls of homes, supplies of firewood and alternative fuels such as gas, government policies and infrastructure, and preferences for the taste of wood-firing in bread.

We have observed hearth use and IC projects in Rajasthan since 2014 (Khandelwal et al. 2017, 2022; Khandelwal and Lain 2017). India has been a primary site for research, development, and distribution of ICs since the 1940s when organized efforts to improve stoves began in earnest. The Hindi word *chulha* describes hearths fueled with unprocessed or minimally processed biomass; in a *chulha*, cooking utensils are placed directly over a fire supported by stones, bricks, or earthen walls. The U-shaped mud enclosure helps to retain the heat, while the opening allows for biomass of various sizes and shapes, from logs to twigs to wood shavings, to be added easily and for air to be pulled in to fan the flame (Kumar, Kumar, and Tyagi 2013). Today, LPG is the most common cooking fuel in urban India and for people who can afford to purchase and refill their LPG cylinders in small towns and villages. For many rural and poor people, however, the traditional *chulha* remains common despite a massive government program launched in 2016 to bring “clean” cooking fuel to all Indians (Khandelwal et al. 2022; see Figure 2).

Hearths are a gendered technology—specifically, a feminine technology (McGaw 1996)—in India. Cooking is almost always coded as feminine because women and girls are so strongly identified as household cooks (Devasahayam 2005). The symbolic feminine connection of women to cooking often extends to the hearth itself. The hearth is a place of family rituals and negotiation. In India and elsewhere, this is where labor, status, and resources are contested and displayed, and where family and kin attachments are reinforced (Devasahayam 2005; Fuquan 2001; Ghertner 2006). As described by Khare (1976) for Hindu households, the everyday practices of cooking food and using hearths are actions which contribute to the maintenance of the moral order of society. Women not only use the hearth, but build, repair, and fuel it.

Our ethnographic research in Rajasthan (Khandelwal et al. 2017, 2022; Khandelwal and Lain 2017) suggests that people prefer cooking with wood for economic, aesthetic, and social reasons. Wood can be collected without spending money, and it also imparts a unique smoky flavor to food. A bread griddle becomes hotter over a wood fire than an LPG stove, important for correctly preparing *roti* bread. The time spent collecting wood is not always seen as a problem, particularly when the trip serves multiple purposes. For example, wood collection may be combined with livestock grazing (Khandelwal et al. 2022). In the village of Semad in southern Rajasthan, for example, women who had to walk far to collect fuelwood often took their livestock along for grazing, thus combining tasks. Families who had their own land were able to harvest fuelwood near their homes and cut fodder for their livestock instead of taking them for grazing.

Rural villagers make charcoal only to sell (Khandelwal et al. 2022). The Forest Department bans charcoal production with the exception of charcoal from an invasive species, *vilayati babul*, which can be legally cut and burned. In a remote location 100 km from Udaipur city in southern Rajasthan, we (Khandelwal et al. 2022) visited a small charcoal-making operation of one woman and two men. The landowner allowed this family group to cut the *vilayati babul* to keep it from taking over his land; they lived in his field and supported themselves by growing wheat and selling charcoal.

Many households used “stove stacking,” combining a wood-burning *chulha* with an LPG stove (Figure 10). One middle-aged grandmother we interviewed had LPG in the new part of the house built of cement, but then led us around to the back of the house to a dark room with mud walls, a clay tile roof, and her old mud *chulha* built into a corner. When she first mentioned the mud *chulha* in the back of the house, she explained that they still used it for making a milk-based sweet dish (*rabadi*) for heating milk and for cooking porridge for their milk-giving buffalo. Most of their cooking, she implied, was done on LPG. As the conversation continued, however, it became increasingly clear that she used the traditional *chulha* for quite a bit more than just these three tasks when low on gas. The matriarch noted that she can buy more gas when she has money, but that the mud stove works even without cash.

This story also illustrates the relationship of the hearth to the surrounding structure. In the older style of housing in rural southern Rajasthan, roofs are typically constructed of clay tiles laid down in overlapping rows or other natural material such as thatch through which smoke can escape. Though a cement house is a sign of upward mobility, a village home built of brick and mud with a tile roof remains cooler in the summer and is

**Figure 10.** LPG stove, Rajasthan, India, 2020. This stove, occasionally used by its owners in a rural village, is stored under the bed. In this photo, the principal cook in the household has pulled the stove out to demonstrate that it still works. Photo by M. Beck.

more compatible with an indoor biofuel hearth. The smoke from a cooking fire repels insects and then escapes through gaps in the roof tiles. Households tend to have two *chulhas*, one outside and another inside for use during rainy season. If the cooking occurs outside, or inside a home with a porous roof, then smoke dissipates rather quickly. However, people who build modern, cement (*pakka*) homes know that the smoke and heat will be trapped inside (Khandelwal et al. 2022). They also want to keep their new walls free of the black carbon stains produced by burning firewood (see Figure 1). Thus, modernization of house construction is often associated with a switch to LPG cooking, though families may also keep a traditional hearth outside in a courtyard, in a separate room with a porous roof, or on the rooftop of a cement home—all arrangements that allow smoke to dissipate.

Improved Indian cookstoves in the 1940s and 50s were based on shared design principles: an enclosed fire, a chimney removing smoke, baffles for better heat transfer, and dampers permitting control of the fire (Sarin and Winblad 1989, 17). Although they served as models for improved stoves in other countries, from Bhutan to Ethiopia, they were not particularly successful in India.

After several generations of improved cookstoves, there is no evidence of their widespread and sustained use, or replacement of *chulhas,* in rural India (Khandelwal et al. 2017; Subramanian 2015). Nor is there a singular reason for this failure. For some families, the biggest barrier is cost (of purchase, repair, or fuel). Some models are technically deficient from the cook's perspective; for example, their use may depend on chopping firewood into very small pieces, or their metal parts become dangerously hot. A freestanding IC may tip over, spilling precious food and endangering people. The heat and light of *chulhas* are also important; "radiative thermal losses" (Barbieri, Riva, and Colombo 2017, 195) are bad for engineers who work to reduce fuel use during cooking, but good for people sitting in a cold room. Technical improvements that succeed on the efficiency metric sometimes create new problems and may lose features of the *chulha* that people want or need.

To abandon a biofuel hearth is also to lose autonomy, which becomes riskier the more precarious your economic position (Jewitt, Atagher, and Clifford 2020; Khandelwal et al. 2017). Modern forms of energy, such as LPG or other fossil fuels, depend on distribution through highly centralized economic and political systems. In rural India today, women commonly build and repair their *chulhas* from easily found materials and fuel them without monetary cost. This may explain the persistence of biofuel hearths, even though they require substantial traditional knowledge and effort to build and use, in households where other modern technologies such as mobile phones and motorcycles have been embraced. No matter what happens, you can always cook on a mud *chulha.*

## Conclusion

A century ago, Cushing (1920, Plate XXV) wrote of a Zuni Pueblo hearth that "[u]tensils of civilization are slowly but surely superseding those made by the natives." Contemporary anthropologists critique the term "civilization," with its embedded ideas of improvement and superiority, and recognize that nothing is sure in technological transition. To be successfully adopted, inventions or innovations must perform well in ways prioritized by users, not merely "utilitarian" functions as perceived by non-users (Hollenback and Schiffer 2010).

At the least, understanding biofuel hearths helps scholars, students, and the public understand the daily lives of the people around these hearths—clarifying basic experiences that seem foreign to some but too obvious to explain for others. More significantly, hearths and their fuels represent solutions to household needs and contemporary problems related to global inequality. Both the solutions and problems are worthy of attention, although most current research concerns the problems. Global health researchers address the short- and long-term risks of burning biofuel, as well as the challenges of providing safe and adequate cooking facilities to displaced people. Anthropologists are equipped to consider hearths as part of larger assemblages. Hearths involve human and non-human forces and interventions that come together in variable and sometimes unpredictable ways to create energy for cooking. Hearths are rich domains for archaeological interrogation because they are enmeshed within social relationships, cooking practices and tools, living spaces, economies, and the surrounding environments of women and families.

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## Disclosure Statement

No potential conflict of interest was reported by the author(s).

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