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Health Impacts of Fuel-based Lighting

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The Lumina Project—an initiative of the U.S. Department of Energy’s Lawrence Berkeley National Laboratory—provides industry, consumers, and policymakers with timely analysis and information on off-grid lighting solutions for the developing world. Lumina Project activities combine laboratory and field-based investigations to ensure the formation of policies and uptake of products that maximize consumer acceptance and energy savings. For more information, visit <http://light.lbl.gov>

Executive Summary

The challenges of sustainability often intertwine with those of public health, revealing opportunities in both arenas for disenfranchised populations. A fifth of the world's population earns on the order of \$1 per day and lacks access to grid electricity. They pay a far higher proportion of their income for illumination than those in wealthy countries, obtaining light with fuel-based sources, primarily kerosene lanterns. The same population experiences adverse health and safety risks from these lighting fuels.

Beyond the well-known benefits of reducing lighting energy use, costs, and pollution (which has its own health consequences), off-grid electric light can yield substantial health and safety benefits and save lives. While knowledge of these benefits can enhance the business case for conversion to more efficient and less dangerous technologies such as LED lighting, proponents often lack accurate information. Statements confusing lighting with the more widely known health impacts of cooking are a particularly common problem.

A large but specialized medical literature identifies an array of risks associated with fuel-based lighting, including: burns caused by a wide variety of factors, indoor air pollution, non-intentional ingestion of kerosene fuel by children, suppressed visual health, and compromised health services and outcomes in facilities lit with fuel-based light. Each risk factor results in illness, and most in mortalities. Lighting is the dominant and sometimes only use of kerosene (referred to as paraffin in some parts of the world) in rural areas, although kerosene plays a large role for cooking in urban areas or areas without solid fuel supplies. Lighting-only statistics are provided in this report whenever possible.

There are few national-level assessments of health impacts associated with off-grid lighting. A survey of 3,315 users of kerosene lighting across five sub-Saharan Africa countries found 26% to have health concerns related to the kerosene lighting. Many studies report that accidental ingestion of kerosene is the primary cause of child poisoning in the developing world. In South Africa alone, over 200,000 people are injured or lose property each year due to kerosene-related fires, in addition to 79,750 very young children unintentionally ingesting kerosene (in 3.6% of all households), of which 60% develop a chemically induced pneumonia. In Bangladesh, kerosene lamps are responsible for 23% of infant burns. Three multi-year reviews of admissions to Nigerian hospitals attributed ~30% of all burn cases to kerosene. Even higher burn rates (~40%) are attributed to kerosene lamps in Sri Lankan homes, with 150-200 lives lost and an associated cost of \$1M each year to for medical care.

Most studies are based on hospital admissions, which vastly underestimate incident rates in the broader population, particularly among the poorest segments and other groups less likely to have access to or seek hospital care. This report's review of 85 published reports spanning 27 countries indicates the pervasiveness of impacts and potential solutions:*

- **Fuel-based lighting is a significant cause of structural fires and severe burn injuries, with particularly high death rates (24% on average) in cases where kerosene is adulterated with other fuels, resulting in explosions.**
 - For context, more than 95% of deaths worldwide from fire and burns occur in the developing world, and the mortality rate is 5-times higher in low- and middle-income populations in Africa than in high-income countries in Europe.

* https://docs.google.com/a/lbl.gov/spreadsheet/ccc?key=0Avq_VXuy99CEdFVMAHJySWVsNnVvZkF2Nm4tN2pqMXc#gid=5

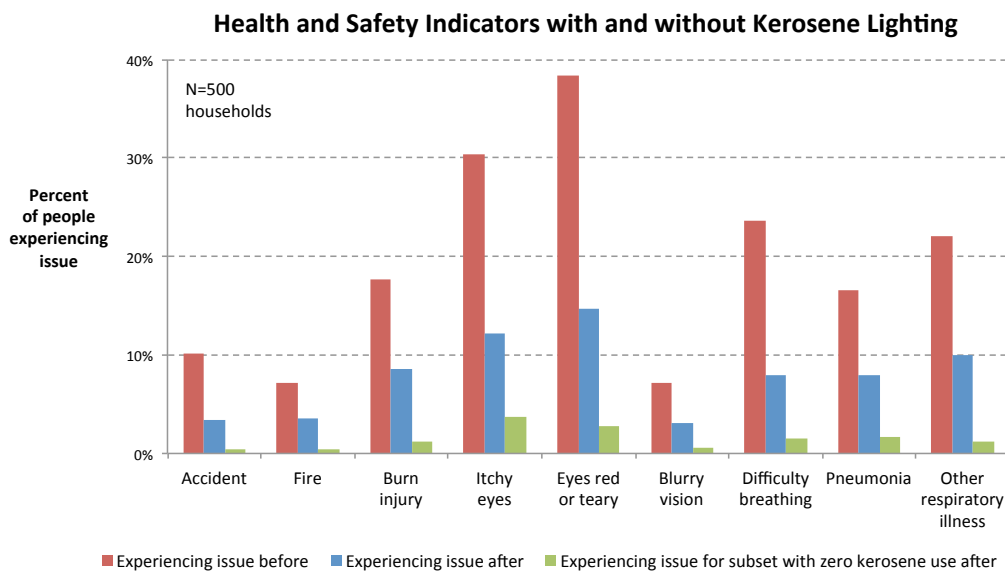
- Lamp and candle incidents cause structural fires, which can spread in tightly crowded slums, with a single event burning hundreds to thousands of homes.
- Deliberate and non-intentional adulteration of kerosene with other more volatile fuels has caused many reported explosions in kerosene lanterns and stoves, resulting in hospitalized patients with burns over large percentages of their bodies and mortality in many cases. There is a 24% average mortality rate for the studies of hospital admissions attributed to kerosene explosions. In the worst documented event, 2,500 people were injured.
- Mortality rates (all ages, excluding kerosene-adulteration explosion cases) for hospital studies averages 3%. Children are disproportionately affected.
- One long-term study found that lantern-related burns cause nearly 10% of injury-related mortalities among children in southern India.
- **Indoor pollutants from fuel-based lamps include multiple hazardous materials, with concentrations of particularly unhealthy particles an order of magnitude higher than health guidelines. Correlations with cataract and tuberculosis have been observed, but require further study.**
 - Individuals using simple wick lamps in indoor environments will likely be exposed to dangerous PM2.5 particle concentrations that are an order of magnitude greater than World Health Organization ambient health guidelines. Less-polluting hurricane and pressure lamps may not exceed guidelines, but cause pollutant levels about 5-times greater than outdoor ambient conditions.
 - Kerosene combustion products appear to be correlated with higher incidences of tuberculosis and cataract conditions, but the causal links with lighting fuels are not confirmed. In the only study to examine the lighting dimensions of the risk, researchers found the odds of having TB in Nepal were more than nine times greater for women using kerosene than those using electric light.
 - Females and children spend a larger proportion of their time indoors and thus experience a greater exposure to pollutants than males.
 - The available literature focuses on emissions from kerosene, with little attention to unique emissions from other fuels when used for lighting, or hazards from wicks made with lead cores or lantern mantles made with radioactive thorium.
- **Unintentional ingestion of kerosene is a risk unique to children, and is typically the primary cause of child poisoning in developing countries, with an average mortality rate of 7% for the studies reviewed.**
 - Kerosene ingestion is the primary cause of child poisoning reported in most hospital studies. The consequences are severe, including mortality rates ranging from 0% to 25% for those visiting hospitals in the larger studies reviewed.
 - A form of pneumonia (chemical pneumonitis) occurs in 12% to 40% of the cases. Central nervous system impairments also result.
- **Poor illumination levels from fuel-based lanterns are only 1% to 10% of those recommended by lighting authorities in industrialized countries. Users complain of vision-related problems and irritation, but the impacts are not well quantified.**
 - Multiple studies find complaints about insufficient lighting and eyestrain from users of fuel-based lighting (particularly high-output pressurized lanterns), and an increased incidence of visual health problems (including near-sightedness).
- **Inadequate lighting in clinics poses barriers to the delivery of quality healthcare, discourages patients from seeking care, and compounds the risks of adverse outcomes such as maternal and infant mortality as well as infections due to the difficulty of maintaining sanitation in low-light conditions.**

The nature of certain types of injuries and the demographics of exposures indicate that women and children tend to disproportionately experience the impacts.

Vulnerable populations are not presented with effective or affordable alternatives. Safety information is necessary, but does not substitute for addressing the underlying role of poverty and lack of access to modern energy sources. Replacing fuel-based lighting with efficient and cost-effective off-grid electric systems provides health benefits while supporting poverty alleviation.

Replacing intrinsically dangerous fuel-based technologies is the only way to reliably eliminate the myriad risks. Grid electrification has sought to do this for many decades, but progress has been very slow. Indeed, the number of people using fuels for lighting is still increasing in some parts of the world, particularly sub-Saharan Africa. A more promising avenue for energy access are the innovative small-scale solar or grid-charged LED lighting systems, many of which provide more, better, cheaper, and safer illumination.

Available evidence indicates health-related consequences can be greatly reduced when fuel use is displaced with electric lighting. Limited surveys have documented almost complete elimination of injuries and vision-related complaints among people switching from fuel-based to off-grid electric lighting systems. Health workers and patients in clinics report improved morale and outcomes (e.g., fewer infections, more accurate blood-banking, and more successful child deliveries) when better lighting is introduced.



Changes in user-reported health and safety problems believed to be associated with kerosene lanterns before and after receipt of LED-solar replacements among 500 homes in the Philippines (Thatcher 2012).

Policies and programs targeting the most vulnerable geographical and demographic user groups will obtain the greatest benefits. Examples include improved illumination in healthcare facilities, substitutes for fuel-based lighting where housing is dense and poorly defended from fire (slums), and where fuel adulteration is particularly common due to fuel subsidy imbalances and other factors. Improved technologies for women and children will yield the greatest benefits.

Health consequences of fuel-based lighting and inadequate service levels

About 1.3 billion people throughout the developing world (~20% of global population), lack access to electricity and must rely instead on fuel-based lighting (IEA 2011). Many businesses find themselves in the same situation, and additional users on the electric grid face routine outages or energy costs forcing reversion to fuel-based light sources. Today, more people than the world's population at the time Edison introduced electricity spend on the order of \$40 billion each year to operate highly inefficient and dangerous lamps, which, in the process, releases nearly 200 million tonnes of greenhouse-gas emissions (Mills 2005).

Lighting is the dominant use of kerosene in rural areas and among the poorest populations (e.g., Rao 2012), but kerosene plays a large role for cooking in urban areas or areas without solid fuel supplies or where it is promoted as a “cleaner” alternative to solid fuels (e.g. Swart and Bredenkamp 2012). Some health-impact statistics combine both uses of the fuel. The results reported here indicate where cooking and lighting uses of fuels are combined; in many cases lighting-only data are available.

Quantifying the health impacts of fuel-based illumination practices in the developing world is of critical importance. Adverse health effects are recognized (Baker and Alstone 2011) but rarely are specifics used in making the business case for alternatives. Marshaling more information on potential health benefits will help define the value of policy and market-based initiatives to replace fuel-based lighting with grid-independent alternatives powered by electricity. With funding support from the U.S. Department of Energy in the context of the Solar and LED Energy Access (SLED) initiative, the Lumina Project (<http://light.lbl.gov>) has synthesized what is known about these adverse health effects. A database with additional detail and references has been posted online (Mills 2012).

The surprisingly extensive literature, mostly from medical journals, paints a detailed and startling picture of various risks, including: unhealthful indoor air quality, injuries, poisonings, and compromised visual health. The low quality of fuel-based illumination also has negative impacts on the delivery of healthcare. For this report, 85 reports were reviewed that presented relevant field data spanning 27 countries (Table 1).

Table 1. Summary of studies on health consequences of fuel-based lighting.

	Reports	Countries	
House fires	11	6	Bangladesh, China, India, Nepal, Philippines, South Africa
Kerosene burns	16	7	Bangladesh, India, Mozambique, Nepal, Nigeria, South Africa, Sri Lanka
Kerosene explosions	17	4	India, Nigeria, Papua New Guinea, South Africa
Kerosene ingestion	28	18	Antigua and Barbuda, Barbados, China, Ghana, India, Iraq, Israel, Jamaica, Jordan, Kenya, Libya, Malawi, Malaysia, Nigeria, Pakistan, South Africa, Sri Lanka, Zimbabwe
Indoor air quality*	4	1	Nepal
Visual health	7	8	Ethiopia, Ghana, Kenya, Nepal, Kenya, Nepal, Tanzania, Thailand, Zambia
Clinic outcomes with improved lighting	2	2	Nigeria, Tanzania
Total	85	27	

* Three studies performed in laboratory settings; one in the field.

Fuel-based light sources are intrinsically more dangerous than electric ones (although electricity is not risk-free, particularly when generated with fossil fuels or nuclear fission). The many potential health consequences of fuel-based lighting include respiratory issues from indoor air pollution (bronchitis, asthma, tuberculosis), burns and infection from direct contact with flames, injuries from explosions caused by adulterated fuels, dermatitis from contact with fuel, poisoning and pneumonia from fuel ingestion, and adverse impacts on visual health. Enormous mental and emotional injury accompanies these incidents, in addition to the costs of medical aid, lost work time, and replacing lost homes and property. Death results in all too many cases.

A complex array of factors contribute to injuries and health impacts, including lack of product safety labeling or warnings, illiteracy (inability to receive communications about risk), overcrowding (contributes to rapid spread of fires and peoples' proximity to lantern emissions), corruption and fuel subsidies (fuel adulteration), unsupervised children, poverty (inability to afford child-safe containers for fuels), cultural practices (e.g., keeping lamps next to young children while sleeping to ward off evil spirits (Mashreky *et al.*, 2008)), and ineffective or counterproductive folk remedies (e.g., inducing vomiting after kerosene ingestion (Adam 2012; Azizi *et al.*, 1994)) plus delay, unwillingness, or inability to seek professional care.

Some users of fuel-based lighting are aware of the risks, but most are not. The only demographic factor reported to correlate with reduced injury so far is income with wealthier individuals using safer practices (Schwebel *et al.*, 2009a). A survey of 3,315 users of kerosene lighting across five sub-Saharan Africa countries conducted by Lighting Africa found 26% to have health concerns related to the kerosene lighting, with no apparent differences in responses between men and women (Baker and Alstone 2011). For this same group, levels of concern about negative health effects were seen to vary from about half in Kenya and Zambia, one-fifth in Ghana and Tanzania, and only 4% in Ethiopia.

Burns

More than 95% of deaths worldwide from fire and burns occur in the developing world, and the mortality rate is 5-times higher in low- and middle-income populations in Africa than in high-income countries in Europe (World Health Organization 2002a). In South-East Asia, the rate is 8.3-times greater than in Europe. By one estimate, the global deaths from burns and smoke inhalation were on the order of 322,000 in the year 2002, which an authoritative source (Peck *et al.*, 2008) refers to as likely a "gross underestimate". The value was estimated at 195,000 for the year 2008 (World Health Organization 2012b). Overall burn incidence rates are substantially higher for children and the elderly.

The Paraffin Safety Association (2012a), states that 200,000 people of all ages are injured or lose property each year (400 per 100,000) due to kerosene-related fires in South Africa. According to van Niekerk *et al.*, (2004), "[b]urns are the leading cause of the global burden of disease and injury (based on deaths and disability) among children aged between 5 and 14 years." In southern India, burns are the number-two cause of injury-related mortalities among children, just over half of which are due to lanterns (9.3% of total injury-related mortalities) (Kanchan *et al.*, 2009). Approximately 40% of domestic burns in Sri Lanka are attributed to kerosene lamps, with 150-200 lives lost each year, and a cost of \$1M to the Sri Lankan government for medical care (Shepherd and Perez 2007).

Lighting-related burns can occur in many ways, including as a result of structural fires, direct contact with hot lamps or flames, and explosions due to the adulteration of kerosene with other fuels. The injuries are often complicated by infection, and can be followed by disability and psychosocial trauma. These events are pervasive in the developing world, with incidents documented in Bangladesh, China, India, Mozambique, Nepal, Nigeria, Papua New Guinea, the Philippines, South Africa, and Sri Lanka. The literature is based on studies of individuals admitted to hospitals, and thus reflects only a small subset of all cases that occur. These cases tend to be particularly severe, e.g. of the 1,368 cases studied by Jayaraman *et al.*, (1993), a third were fatal. There was a 3% weighted-average death rate for the publications reporting the data on regular burns, and 24% in the case of explosions. Table 2 provides some examples of the published research on lighting-related burns.

Statistics for burns caused by lighting fuels other than kerosene are rare. The Paraffin Safety Association of South Africa (2012), collected extensive data on injuries associated with lighting by candles. They find that candles—used as primary or secondary sources for lighting in nearly half of low-income households—are implicated in one-third of burn injuries in the country, with 58% of the injuries involving males. Females are in the majority for the 0-24 age group. They also found that 30% of the fires caused by energy-using activities are attributed to candles. Elsewhere in sub-Saharan Africa, candles are used as a source of light in non-electrified households by 79% in Zambia, 20% in Ethiopia, 19% in Tanzania, 18% in Ghana, and 10% in Kenya (Baker and Alstone 2011).

Table 2. Studies of burns associated with lamps.

Bangladesh	Survey of 171,000 households comprising 819,000 individuals. Kerosene lamps are responsible for 23% of infant burns and 11% for children aged 1-4.	Mashreky <i>et al.</i> , (2008)
India	Nearly 15% of all burns are caused by kerosene lamps, with a 7.4% mortality rate and a female:male incidence rate of 3:1.	Kumar <i>et al.</i> , (2002)
	14.2% of all hospital burn-injury admissions attributed to kerosene lanterns.	Ghaffar <i>et al.</i> , (no date)
	80% of burn victims arriving at the hospital with lamp-related burn injuries were admitted, and 47% of lamp-related cases resulted in mortalities.	Jayarama <i>et al.</i> , (1993)
Mozambique	Lantern-related burns from homemade 'xiphefo' lamps were the main cause of burn-related mortalities (44.7% of the total). Children under 10 represent 64% of the total (and 41% of the mortalities), with 79% under 5 years old.	Barradas (1995)
Nepal	Of 237 burn cases, 20% resulted from lamps.	Liu <i>et al.</i> , (1998)
Nigeria	59 burn patients, representing 3.7% of all trauma patients over a particular time period. The 20 kerosene and candle-related burns represented 33.9% of the total, of which 19 were explosions. Female:male ratio 3:1	Asuquo <i>et al.</i> , (2008)
	62 children admitted to the hospital for burns (2002-2006). 52% of burns were caused by kerosene explosions, with 6 to 50% of body area burned.	Oludiran and Umbese (2009)
	Of 36 burn patients, 7 (29%) were due to kerosene explosion in lamps or stoves. Female:male 1.22:1	Olaitan <i>et al.</i> , (2007)
South Africa	A randomized household survey found 3.9% of burns due to kerosene lanterns. Of the 188 cases, 47% were fatal (probably due to fuel adulteration).	Matzopoulos <i>et al.</i> , (2006)

Sri Lanka	41% non-intentional burns seen at Batticaloa General Hospital in the Eastern Province were caused by homemade kerosene bottle lamps. Female:male 1.2:1	Peck <i>et al.</i> , (2008)
	31% of 487 patients aged 12 years and older admitted to National Hospital in Colombo had non-intentional burns from kerosene lamps.	Peck <i>et al.</i> , (2008)
	33% of all burns in Sri Lankan homes are caused by kerosene lamps, causing 1500 mortalities each year at a cost of \$1M/year to the Sri Lankan Government.	Rolex Foundation (1998)

House Fires

Over a century ago, large fires in China, displacing 1,000 families in one case, were traced to U.S.-imported kerosene lamps. This was relayed by the U.S. President to Congress as a matter affecting foreign relations with China (Office of the President 1888). House fires in the developing world are still attributed to fuel-based lighting. When they occur in slums (Figure 1), these fires often spread rapidly due to crowding of buildings. Newspaper accounts report large fires, such as one affecting 3,000 people in a Philippine slum in 2009, killing 16 (*Daily Mail* 2009). Other examples include fires destroying 200 homes in India in 2010 (*Thaindian News* 2010), and 1,500 homes – killing 15– in Bangladesh in March 2000 (*Associated Press* 2000). Refugee camps are also vulnerable, e.g., in the case of a Nepali camp where 1,200 of 1,500 homes were burned by a fire suspected to have been started by a lantern, leaving 12,000 homeless (UCRI 2010).

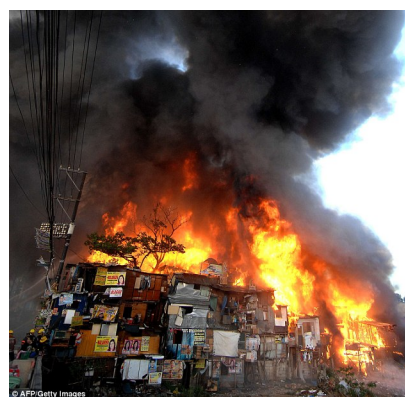


Figure 1. Slum fire such as those caused by lanterns.

A random sample of homes in South Africa found that kerosene-related fires (presumably for cooking as well as lighting equipment) had occurred in 6.3% of all households (Matzopoulos *et al.*, 2006). One fire there, attributed to a single candle, killed two people, while destroying 500 homes and leaving 2,000 people homeless (*The Mercury* 2010).

Explosions and burns resulting from the adulteration of kerosene with other fuels

Some unscrupulous oil merchants adulterate kerosene with gasoline or diesel when those fuels are even slightly less expensive, or during times of kerosene scarcity (Lawal 2011). Unintentional adulteration occurs as well, e.g., when people use the same containers for gasoline and kerosene, or upstream when mixed-use pipelines or tanks are not properly isolated or flushed. Adulteration creates a volatile mix that can ignite and explode. The lowest temperature at which kerosene vaporizes and forms an ignitable mixture in air is at least 38C, which drops to about 5C with only 10% adulteration with gasoline (Shepherd and Perez 2007). Explosions occur most easily when lanterns are refueled while lit, and the evaporating fumes ignite. The resulting injuries are severe (Figure 2), and often fatal.

Reports of exploding kerosene lanterns and stoves are particularly common from Nigeria (Table 3), where subsidies tend to keep gasoline prices lower than in much of sub-Saharan Africa (Africa Pulse 2012). Subsidies are also particularly high in Cameroon, the Republic of Congo, and Sierra Leone. The most horrendous report of adulteration identified 2,500 impacted people, of which 368 (14%) died in Nigeria's Edo region (Bernard 2011). In a particularly tragic case in one household 8 of 10 family members were killed by the explosion (Ugburo *et al.*, 2003).

These events are not rare; long-term studies find chronically high rates of hospital admissions due to explosions. Three multi-year reviews at Nigerian hospitals attributed around 30% of all burn cases to kerosene fuel explosions (stoves plus lanterns) (Dongo *et al.*, 2007; Asuquo *et al.*, 2008; Olaitan *et al.*, 2007). In the latter study, injuries to females outnumbered those to men by nearly 3:1. In another study (covering just one month), 96% of burn admissions were due to kerosene device explosions. Of those burned, 62% were children and 60% were female; the average body-area burned was 24% (with a 44% overall mortality rate) (Oduwole *et al.*, 2003). The month covered by the study followed the discovery that a petroleum storage depot deliberately adulterated the kerosene. Oludiran and Umebese (2009) found that 52% of children (half below the age of 3) admitted to a hospital for burns received their injuries from exploding kerosene lanterns or stoves, with burns covering between 6% and 50% of body area. Oduwole *et al.*, (2003) observed 100% mortality for cases with burns covering more than 18% of total body area. Another author found that half the admissions were children, with a nearly 6-fold increased admission rates at one hospital following an incident in 1984, with 47% mortalities compared to no mortalities for burns in the same month of the prior year (Grange *et al.*, 1988).



Figure 2. Burn victims of explosions of adulterated kerosene (Bernard 2011).

Table 3. Epidemic of "Kerosene Disasters" caused by fuel adulteration.

Year	Location	People injured/killed [Female:Male]	Source
1984	Lagos, Nigeria	53/30 [1.9:1]*	Grange <i>et al.</i> , (1988)
1994	Rajasthan, India	303/37	Gupta <i>et al.</i> , (1996)
2001	Lagos, Nigeria	116/18 [1.5:1]	Oduwole <i>et al.</i> , (2003)
2001	Lagos, Nigeria	59/35 [1.3:1]	Ugburo <i>et al.</i> , (2003)
2001	Madang, Papua New Guinea	38/5	NDMO (2001)
2004	Edo State, Nigeria	2500/368	Bernard (2011)
2011	Port Harcourt, Nigeria	1/5	<i>Nigeria News</i> (2011)
2011	Edo State, Nigeria	1/8	<i>Daily Independent</i> (2011)
2011	Duhbri, India	62/8	<i>The Telegraph</i> (2011)
2012	Edo and Delta States, Nigeria	11/11	Tamuno (2012)

* Ratio in month of burn disaster (March). Ratio 1:1 in earlier periods.

Reports of kerosene adulteration have emerged from India and Papua New Guinea as well. In one example from India, 72,000 liters of fuel were adulterated (*The Telegraph* 2011). Given that individuals often purchase kerosene in small quantities, hundreds of thousands of people would purchase such an amount of kerosene. An earlier event in India (Gupta *et al.*, 1998) affected 303 people. With only 10 beds available in the local hospital's emergency burn unit, many patients were turned away or referred to distant hospitals.

Health Risks from Indoor Air Pollution

Inhalation of particulates (Figure 3) resulting from indoor combustion can cause a range of adverse health effects ranging from Tuberculosis to Cancer (Bai *et al.*, 2007; Dockery *et al.*, 1993; Dominici *et al.*, 2003).

Poor indoor air quality in developing countries creates a large societal burden, both economic and humanitarian (Zhang and Smith 2007). As of 2004, an estimated 2 million deaths (WHO 2009) and 1.4 billion illnesses (Dasgupta *et al.*, 2004) occur each year from poor indoor air quality in the developing world, the primary cause of which is *cooking with solid fuels*. The consequences of lighting-related pollutants are often conflated with those of cooking (which, ironically are generally stated to be improved when the user switches to kerosene fuel for cooking). Cooking-related impacts are no doubt more severe than those of lighting, and equating the two does a disservice. However, lighting-related risks merit concern. While human inhalation of particulate matter from simple wick lamps is about 5-times less than that of cook stoves, it is also about 5-times more than from ambient air (Figure 4).

Fuel-based lanterns are often placed in close proximity to users, and emit indoor pollutants that can be inhaled deeply into the lungs. Emissions resulting from burning kerosene include carbon monoxide, carbon dioxide, sulfur dioxide, nitrogen dioxide, formaldehyde, and various VOCs (volatile organic carbons). Potentially harmful effects include impairment of ventilatory function, a rise in blood carboxyhemoglobin in people

exposed to carbon monoxide in kerosene fuel combustion products (Behera *et al.*, 1991), and a higher incidence of acute lower respiratory infection among those using kerosene and biofuels (Sharma *et al.*, 1998).

Although particulate matter concentrations resulting from cook stoves have been extensively studied in the literature, characterization of particulate concentrations from fuel-based lighting has received minimal attention. Lighting combustion is generally poorer than in liquid-fueled stoves, and the mix of particle types and sizes will vary by fuel and even lantern type. Schare and Smith (1995) measured total suspended particulate matter (TSP) concentrations in a simulated village house.



Figure 3. Wick lamps emit more particulates than other types of fuel-based lanterns.

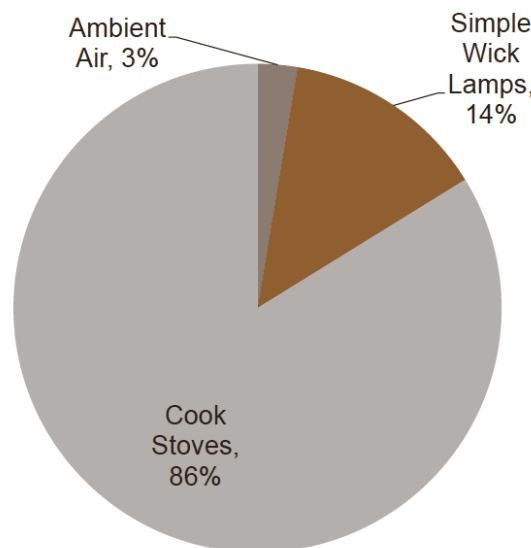


Figure 4. Relative exposures to particles from ambient air, wick lamps, and wood stoves (Poppendieck 2010).

Indoor concentrations were measured for wick and hurricane lamps. The authors did not determine the fraction of emitted particles that were in the size range (2.5 microns in diameter, aka “PM2.5”) that penetrate particularly deeply into the lungs when inhaled. In 2001, Fan and Zhang (2001) examined the emissions of a kerosene hurricane lamp but did not isolate the concentrations of PM2.5 particles.

Measurements by Apple *et al.*, (2010) demonstrated that night vendors who use a single simple wick lamp in simulated high-air-exchange market kiosks will likely be exposed to dangerous PM2.5 concentrations that are an order of magnitude greater than ambient health guidelines (WHO 2006). Thanks to more efficient combustion, using a hurricane lamp will reduce exposure to PM2.5 and PM10 concentrations by an order of magnitude compared to a simple wick lamp. Vendors using a single hurricane or pressure lamp may not incur exposures exceeding WHO guidelines for PM2.5 and PM10, but may be exposed to concentrations five-times greater than ambient air concentrations. There are no known standards regulating exposure to particulates produced from fuel-based lanterns.

One of the potential consequences of indoor pollutants from kerosene lanterns is tuberculosis (TB), a major health issue in the developing world. In 2006, there were 1.7 million TB-related deaths (from all causes) around the world. In Nepal, a remarkable 45% of the population is infected with TB, and 11,000 die each year. In the only study to examine the role of lighting, researchers found the odds of having TB in Nepal were more than nine times greater for women using kerosene lamps for indoor lighting than those using electric light (Pokhrel *et al.*, 2010). The authors do not isolate the relative risks of kerosene for cooking and lighting, but note that kerosene lamps may burn less efficiently, for longer hours, and release emissions closer to users than do stoves. The authors emphasize that more research must be done to quantify the apparent risks.

Kerosene contains known carcinogens such as benzene (American Cancer Society 2006) and probable ones such as formaldehyde (USEPA 2012), but studies have not been done on the risks associated with indoor concentrations resulting from the use of lanterns. The composition of kerosene also varies by refiner.

Studies to date on the indoor air quality impacts associated with lighting fuels have focused on kerosene. Little assessment has been made of health issues associated with lighting-related uses of certain other fuels, including diesel, animal and vegetable oils, dung, or fuel wood. Concerns in addition to fuel-combustion products are wicks made with lead cores as a stiffening agent (outlawed in the U.S. since 2003) and lantern mantles made with radioactive thorium, neither of which are accompanied with safety warnings or disposal instructions when sold in the developing world. Burning wicks have been shown to yield indoor concentrations of lead above ambient air standards as well as workplace standards (Wasson *et al.*, 2002).

Non-intentional Ingestion of Kerosene

Having an appearance and density similar to that of water, and frequently stored at floor level in ordinary beverage containers, kerosene is non-intentionally ingested by children at alarming rates. The injury is usually self-inflicted, although there are reports of mothers administering it non-intentionally to their children at night. This risk is compounded, ironically, by lack of adequate lighting. In all 36 cases (51% of all child poisonings) reported in a Malaysian study, kerosene was kept in a soft-drink bottle, typically on the kitchen floor.

According to one source (Nisa *et al.*, 2010), ingesting even 1ml of kerosene can cause complications, and 10ml can be fatal. Common complications include respiratory effects and pulmonary damage, including pneumonia. Additional impacts include gastrointestinal irritation, fever, central nervous system impairment, fever, myocarditis, and leukocytosis. A review of a broader literature identified that the chemical form of pneumonia occurs in 12% to 40% of the cases (Carolissen and Matzopoulos 2004). Sufficient dosages can lead to coma and death. There was a 7% weighted-average death rate across 19 studies reporting mortality rates, but this number is higher than the 1-2% mortality rate found in other reviews (Carolissen and Matzopoulos 2004).

Kerosene ingestion accounted for a considerable proportion of all pediatric admissions at state hospitals across South Africa, ranging from 5.5% to 16.5% of all admissions, with markedly higher rates (up to 78%) in lower-income areas where kerosene is most widely used (Carolissen and Matzopoulos 2004). The literature documents accidental kerosene ingestion in Antigua and Barbuda, Barbados, China, Ghana, India, Iraq, Israel, Jamaica, Jordan, Kenya, Libya, Malawi, Malaysia, Nigeria, Pakistan, South Africa, Sri Lanka, and Zimbabwe. Kerosene routinely represents the primary cause of poisoning related child hospital admissions (typically 25-65% of all cases) (Table 4).

Table 4. Studies of unintentional kerosene ingestion in children.

Antigua and Barbuda	39 of 255 cases (nationally), or 15.3% of all child poisonings, result from kerosene. Includes 0.6% of all children aged 0-4y.	Martin and Brinkman (2002)
Barbados	One multi-year study beginning in the mid-1970s found kerosene ingestion in 140 children aged between seven months and five years, with half of those X-rayed exhibiting pneumonia	St. John (1982)
China	13 children admitted; one mortality. Female:Male = 0.44:1	Zhang <i>et al.</i> , (ca. 2008)
Ghana	Of physicians surveyed, 79% report that unintentional kerosene ingestion is the most common cause of child poisoning; one hospital reported it as the cause of 66.7% of cases.	Arthur (2012)
India	Kerosene ingestion found to be the most common cause of poisoning of children in India.	Mohan (1986)
	Approximately 25% of all child-poisoning cases (1970-1990) were due to non-intentional kerosene ingestion, with a reduction in the rate over time (from 42% in the 1970s) attributed to a shift towards LPG fuels (Singh <i>et al.</i> , 1995).	Singh <i>et al.</i> , (1995)
	Another study found kerosene implicated in 48.8% of cases, with 40% developing into pneumonitis	Khadgawat <i>et al.</i> , (1994)
	In a three-year study at hospital in Delhi: 47% of all poisoning admissions due to non-intentional kerosene poisoning in children; 77% of these cases were in the 1-3 year age group; the mortality rate was 4.3%.	Gupta <i>et al.</i> , (1992)
Iraq	This study reviewed 103 cases in one hospital; 91% of the cases were children under the age of 5. One-third of the cases resulted in central nervous system issues. Half exhibited abnormal pulmonary conditions upon X-ray.	Nagi and Abdulallah (1995)
Israel	5-year study of admissions of children to Soroka University Medical Center, Beer-Sheva, the highest admission rates were in summer. Of those seeking care, 68% were hospitalized. One-third had CNS impairment; 43% had pneumonia.	Lifshitz <i>et al.</i> , (2003)
Nigeria	A seven-year review of emergency admissions found most frequent	Belonwu and

	age of ingestion to be 18 months; mortality rate 5.5%.	Adeleke (2008)
Pakistan	A five-year study of hospital admissions found kerosene ingestion to be the most common cause of child poisoning, with virtually all victims under the age of 6 years. Admissions were observed to be greatest during periods of high outdoor temperatures. The mortality rate was less than 1%.	Siddiqui <i>et al.</i> , (2008)
South Africa	National estimate that 79,750, or 160/100,000 (uncertainty 46,530-93,060) children ingest kerosene each year in South Africa, half of whom develop a chemical variant of pneumonia with fatality rates between 0.72% and 2.1%. Approximately 60% of all poisonings in children aged 1-2 are from ingesting kerosene. Approximately 1000 deaths accompany these injuries.	Paraffin Safety Association (2004); Carolissen and Matzopoulos (2004); (Swart and Bredenkamp 2012).
	Non-intentional ingestion accounted for 78% of acute poisonings in one hospital in 1993; nationwide, the rate of hospital admissions due to kerosene ingestion ranged from 5.5-16.5% of <u>all</u> pediatric admissions. The death rate for acute poisoning due to kerosene ingestion was 25%.	Matzopoulos <i>et al.</i> , (2006)
	Based on a random sample survey (404 households) and records of incidents in the past year representing 7759 households, kerosene ingestion by children (primarily ages 1-3) was reported in 3.6% of households. The worst-case village had 15.6% ingestion cases. As these homes were within 10km of an energy center previously disseminating kerosene safety messages, the incidence rate may be lower than in the population at large. Pneumonia occurred in 20 of 24 cases (83%) where kerosene was ingested.	Matzopoulos <i>et al.</i> , (2006)
Sri Lanka	A 10-year study at Lady Ridgeway Hospital found that 75% of victims developed pneumonitis. The Male:Female ratio was 1.67:1, with 72% under 4 years of age.	Lucas (1994)
Zimbabwe	Kerosene ingestion was the most common form of non-intentional poisoning of children at Mpilo Central Hospital. The average age of these patients was 19 months. Admissions were "uniformly" high during summer with a sharp decline in winter. Chest X-rays of 30 cases showed abnormalities in 87% of the cases. A study at eight major urban hospitals in Zimbabwe (including Mpilo) nearly four decades later (Tagwireyi <i>et al.</i> , 2002), found that kerosene was still the main cause of childhood poisonings.	Baldachin and Melmed (1964) Tagwireyi <i>et al.</i> , (2002)

Compromised Visual Health

The light levels recommended by professional illuminating engineering societies (based on visual health and eyestrain considerations) for electric lighting are often 10- to 100-times greater than the levels achieved by lanterns (Mills and Borg 1999). Insufficient illumination is one of many factors that can lead to long-term development of myopia (near-sightedness), though the research here is not conclusive (Kittle 2008; Gauna 2012).

A study of home lighting in a rural Nepali village led to recommended levels in the 5-15 lux range for general-purpose lighting, primarily for cooking and socializing, and 25 lux for reading (Bhusal *et al.*, 2007). These are far below western standards, but higher than often obtained with fuel-based lighting. The dominant baseline technology in the village was

burning *Jharro* (resin soaked pine sticks). Limited interviews of fuel-based lighting users in the field indicate that night vendors find the light levels from fuel-based lanterns inadequate, even at substantially lower levels (Alstone *et al.*, 2010).

After improving electric lighting conditions, Unitmanon *et al.*, (2006) found strong reductions in “vision problems” and “visual fatigue” among 472 workers in Thailand performing visually demanding tasks. One study (Solar Aid 2011) examined the role of lighting in the performance of school students in Zambia (where fuel-based lighting, particularly candles, is prevalent among lower income populations). Those using (brighter) solar lighting achieved Grade-7 “pass rates” of 89% versus 71% nationally. However, lower Grade-9 pass rates were observed. It is also not clear whether the improved performance was due to better lighting versus more hours spent studying or other factors, or whether longer-term eyestrain results in health problems for these students.

A study in households using solid cooking fuels noted differences in cataract incidence depending on whether a home’s light was provided by electricity or kerosene; the risk was twice as high for households using kerosene lighting (Pokhrel *et al.*, 2005). The authors further noted that the risk of cataracts is higher in developing countries and that more females than males are blind from cataracts, but causal links were not confirmed. For cataract risks, the wavelength of light is important, with UV being the most harmful, and, to a lesser degree, IR. The spectrum of kerosene mantle lanterns certainly contains IR, and some may contain UV.

In a recent set of interviews, night fishermen in Tanzania reported multi-hour periods of reduced vision after each evening’s handling of lanterns, and anecdotal claims of high rates of blindness in old age (Gengnagel *et al.*, 2012). This was reported to result from repeated periods of close proximity to pressurized lanterns (which have ten-times the output of typical wick lamps, from a mantle with very high luminosity). Eyestrain and poor eyesight caused by very bright pressure lamps are also mentioned in surveys conducted across sub-Saharan Africa (Baker and Alstone 2011). Impaired vision and visibility are, in turn, risk factors in subsequent accidents and injuries.

Adversities Resulting from Fuel-based Lighting in Off-grid Health Clinics

Good lighting is required for the delivery of health services. Many facilities in the developing world reportedly operate only intermittently at night due to fuel availability and the inability to give good care with only lanterns (Solar Aid 2012).

About 287,000 maternal mortalities occurred in 2010, 99% of which in developing countries (WHO 2012c). Child delivery has been observed in two separate field studies to be illuminated with kerosene lanterns, and even makeshift light from repurposed cellphones (Solar Aid 2012; Stachel 2012). Lack of light keeps some populations from even attempting to visit a clinic or hospital. The cost of kerosene is a hardship for many providers. Lack of electricity also presents challenges for keeping mobile phones charged; mobile phones are a key tool for communicating with patients and staff when offsite.

Solar Aid installed 30 solar electricity and lighting systems in rural health facilities in Tanzania. Preliminary results found reduced rates of infection (including HIV); these outcomes were attributed to better illumination and associated ease of maintaining sanitation. Longer and more consistent operating hours reportedly induced more

individuals to seek health care more quickly and more mothers to give birth in the clinics. This, in turn, reduced waiting times during the day. Patients cited the benefit of not being expected to bring their own lantern and/or fuel to ensure treatment at night. The study claims a “clear increase” in safe baby deliveries at night, improved detection of postpartum hemorrhage, tears, or problems with the baby. Accounts of staff underscore the benefits:

‘Service delivery at night was very bad indeed, because staff had a low morale, the working environment was difficult with the yellowish dim light from the kerosene light or torch...The biggest challenge was using these sources of light to deliver, most of the time you are not able to see what you are doing and can only more or less guess in the progress of the mother and the child.’ (Solar Aid 2012)

In a larger trial by Solar Aid, light was brought to clinics in Malawi, Tanzania, and Zambia serving over 5,000 patients per month. Non-specific improvements to security and morale among workers and patients are reported to translate into a higher quality of service and better engagement of both staff and patients.

‘Installation of solar has also impacted on the motivation of staff because light, and the reduction of costs for charging phones, use of kerosene and frequently buying batteries for torches. For some they have been attracted to stay instead of moving to go to a place where there is electricity because we also now have a reliable source of energy.’ (Solar Aid 2012)

Many logistical problems and barriers were identified in the delivery, installation, and maintenance of custom solar systems, as well as high repair needs (Solar Aid 2011). Most of these could be addressed, and at lower cost, through use of the new generation of integrated off-the-shelf LED lighting and phone-charging systems (Solar Aid 2011).

Nigeria has one of the highest maternal mortality rates in the world. One company has completed solar lighting installations at 26 Nigerian healthcare locations (along power for cell phones and fetal monitors), and follow-up surveys have been conducted (Stachel 2012). All locations reported a higher proportion of mothers coming to clinics for delivery, particularly night deliveries. Lighting provided particular benefits for complicated cases such as patients with pre-eclampsia, hemorrhage, infections, setting IV lines, and breech deliveries. Reliable illumination allowed for an increased rate of C-section surgeries to be performed at night. Blood banking was also improved via increased ease and accuracy for testing the blood, together with refrigeration. Every site reported an improvement in health worker morale and willingness to come to work at night.

Disproportionate Impacts on Women and Children

Women and children often bear the brunt of the practical hardships of off-grid lighting (Alstone *et al.*, 2011), as well as the health consequences. For context, the rate of childhood unintentional injury deaths (from all causes) in the developing world is nearly four-times that of the industrialized world, with 875,000 affected each year (Balan and Lingam 2012), with millions more sustaining non-fatal injuries.

The preceding discussion about clinics identifies particular issues around maternal and infant health. The issue of non-intentional fuel ingestion almost uniquely impacts children, especially infants and toddlers, and is typically the primary cause of child poisoning in the

developing world. In other cases, all groups are exposed, to varying degrees. In some studies, males are more heavily represented among those arriving at hospitals for care.

To the extent that women and children spend more time indoors than men—and that children are intrinsically more vulnerable to hazards—they are differentially exposed to indoor air quality and lamp-explosion risks. A study of 55 Kenyan households (345 people) found that children of each gender aged 0 to 4 years spend roughly equal times indoors, but females for all other age groups spend more time indoors than males, varying between 1 and 4 hours more per day (Ezzati and Kammen 2002). Males spend less overall time indoors than these other groups. A major study (4,612 individuals drawn from representative locations in Bangladesh) found that infants spend the most time indoors, approximately 20h/day, which declines to about 16h/day for individuals up to the age of 60, at which time females' time indoors returns to a level of nearly 20h/day, while time spent indoors by males rises to only about 16.5h/day. All groups of females over the age of 12 spend more time indoors (1.4 to 3.2 hours more per day) than do men. The Bangladesh study (focusing on cook stoves) concluded that “young children and poorly-educated women in poor households face [indoor air] pollution exposures that are four times those for men in higher-income households organized by more highly educated women,” with half of the effect due to income and half to age and gender (Dasgupta *et al.*, 2004). Data indicating location by time of day (and use of lighting by time of day) would be needed to determine if lighting-related emissions exposures differ materially among these groups. Men and children not participating in cooking activities will receive a larger share of their indoor air pollution exposures from lamps.

Two studies of lamp explosions due to fuel adulteration found two-fold higher impacts among children than adults: 62% versus 38% injury (Grange *et al.*, 1988) and 57% versus 25% mortality (Ugburo *et al.*, 2003). Female:Male ratios were also higher in both studies.

Fire-related injury rates are higher for females in many studies (Balan and Lingam 2011). Functional, social and psychological impairment due to burns has been identified as one of the most devastating causes of child injury. Children are disproportionately impacted by lighting-related burns. Burns are reported as the leading cause of death among children in South Africa (Mrubata and Dhlamini 2008). In a nationwide study for Bangladesh, in which 171,000 households were visited, rural children were found to have a four-times greater incidence of burn than those in urban areas, and kerosene lamps were responsible for 23% of burns sustained by infants and 11% for children aged 1 to 4 years (Mashreky *et al.*, 2008). Burns were the fifth leading cause of illness among the children aged 1 to 17 years of age, and the third leading cause for children aged 1 to 4.

Solutions

Fuel-based lighting is associated with a strikingly wide array of health impacts and loss of life. The underlying drivers are many, with no single solution. Others have enumerated the causal factors, low levels of risk perception among at-risk populations, and available prevention strategies (Paraffin Safety Association 2004; Schwebel *et al.*, 2009a-b; Mrubata and Dhlamini 2008; Swart and Bredenkamp 2012).

The strategies for better understanding the risks and reducing lighting-related injuries and loss of life can be grouped into the following broad categories.

1. Most available data are based on hospital records, which means that they capture only those who seek and are admitted for care, live closer to hospitals, etc. Systematic national or even community-scale epidemiological information on lighting-related injuries in the developing world is rare, with South Africa making the greatest progress in this respect. More centralized statistics should be gathered.
2. Safety education is certainly a key need. For literate user groups, product labeling and other safety warnings could help reduce incidence of injury and death.
3. With one in five people in the world regularly exposed to indoor pollution from fuel-based lighting, it is a sad commentary that there are no health standards for the associated pollutants (only World Health Organization guidelines). This gap must be bridged.
4. Regulation and oversight of fuel handling, and more strict consequences for illegal adulteration, may reduce (but not eliminate) the life-threatening practice of mixing other fuels with kerosene. Energy price subsidy practices contribute to the problem.
5. Fuel-based lighting technologies can, to some extent, be re-engineered (e.g., to reduce tip-over risks or emissions). However, a very large fraction of kerosene lamps are hand-manufactured using discarded metal or glass containers, severely limiting any opportunity for a centralized solution. Cleaner-burning kerosene or propane lanterns are far more expensive to purchase and operate than standard “tin” lamps, further limiting their potential. Kerosene can be easily colored to help distinguish it from water, but this cannot be relied upon to prevent ingestion by young children.
6. More research is clearly needed to (1) better understand the emission characteristics of fuel-based lighting technologies and fuels (including biofuels, Figure 5), for varying use cases, (2) better understand the nature and epidemiology of human responses, and (3) quantify the macro-level rates of incidents and injuries, and their costs.
7. Substitution of the intrinsically dangerous fuel-based technologies is the only way to completely eliminate the myriad risks for individuals. Grid electrification has sought to do this for many decades, but in many places the rate of progress with respect to low-income populations is very slow. Indeed, the number of people using fuels for lighting is still increasing in some parts of the world, particularly sub-Saharan Africa. A far more promising avenue for energy access are the innovative small-scale solar or grid-charged LED lighting systems, many of which provide more, better, and safer light at a lower total cost of ownership (see <http://light.lbl.gov> and <http://lightingafrica.org>). A field study of 500 homes in the Philippines observed near complete elimination of health and injury issues following replacement of kerosene lanterns with grid-independent LED lanterns (Figure 6). Another study found strong reductions in “vision problems” and “visual fatigue” among 472 workers in Thailand performing visually demanding tasks.



Figure 5. Exposures to indoor pollution from the use of wood biofuel for illumination.

Health and Safety Indicators with and without Kerosene Lighting

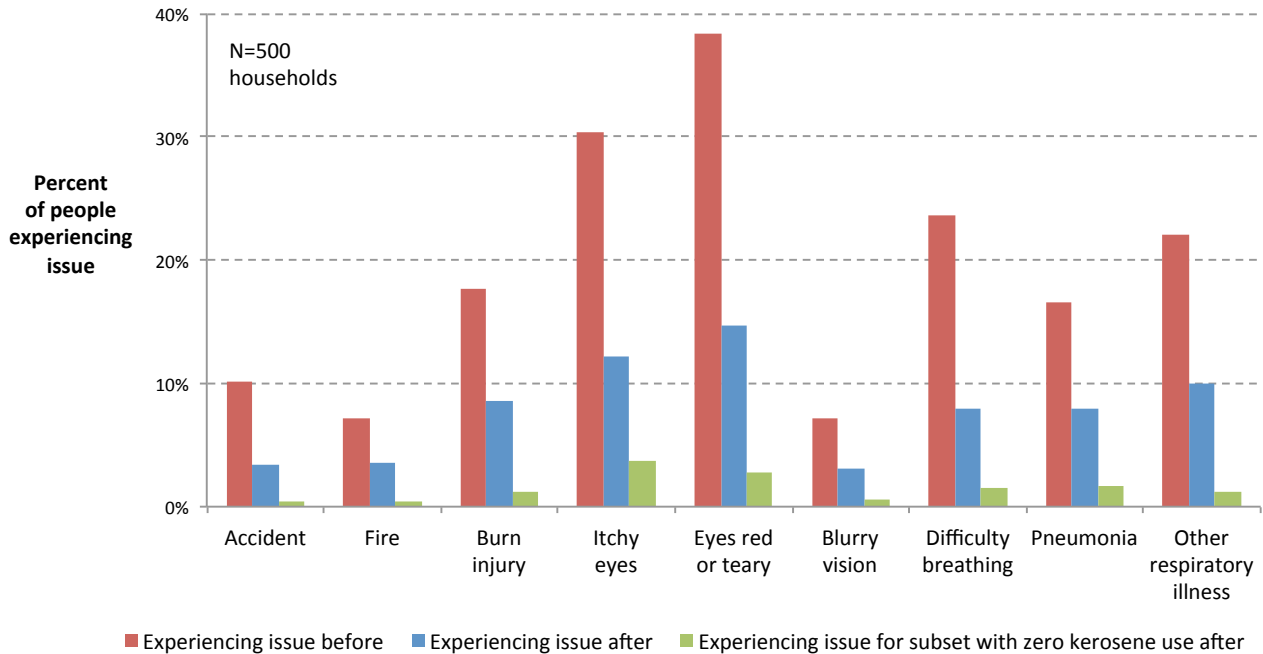


Figure 6. Changes in user-reported health and safety problems believed to be associated with kerosene lanterns before and after receipt of LED-solar replacements among 500 homes in the Philippines (Thatcher 2012). Recipients were re-interviewed one month after receiving the fuel-free lamps. Note that 66% of the homes still used some kerosene after the intervention (blue bar). Symptoms were reduced much farther among the 27% of homes that completely eliminated kerosene use.

Policies and programs seeking the greatest possible benefit should target resources toward the most impacted geographical and demographic user groups. Examples include improved illumination in healthcare facilities, substitutes for kerosene lighting where housing is dense and poorly defended from fire (slums) and where fuel adulteration is particularly common (e.g., Nigeria) due to fuel subsidy imbalances and other factors. Systems such as the mapping of fuel-related injuries in South Africa (Figure 7) could be utilized to deploy targeted programs for grid-independent electric lighting systems. Improved technologies for women and children will yield particularly large health benefits.

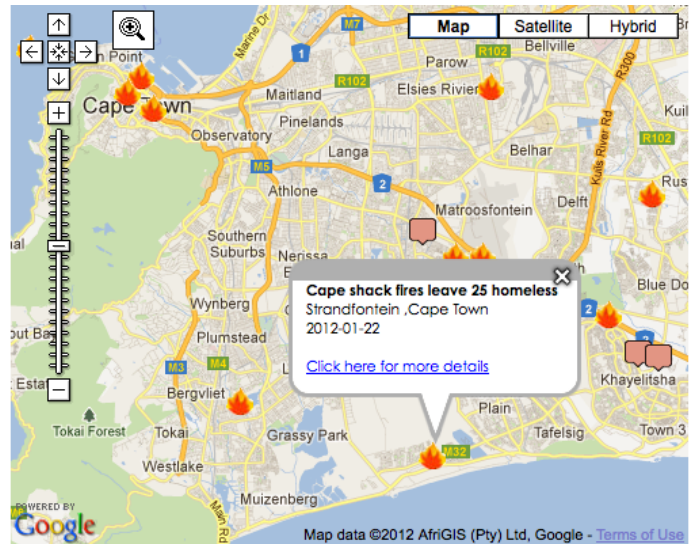


Figure 7. Geographic information system used by the Paraffin Safety Association of Southern Africa to track energy-related fires (<http://gis.paraffinsafety.org/>)

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