EFFICIENCY 4 ACCESS COALITION

A campaign to drive universal energy access beyond lighting

Low-Energy Inclusive Appliance Technology Summaries

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CLEAN ENERGY MINISTERIAL
Accelerating Transition to Clean Energy Technologies

Global LEAP
Lighting and Energy Access Partnership

UKaid
from the British people

Introduction

Appropriately-designed, highly energy-efficient, cost-effective appliances are essential to delivering modern energy services to underserved communities around the world at the lowest possible social, economic and environmental cost. Because of this, they are an essential tool in scaling and accelerating global energy access and sustainable development efforts. Just as super-efficient LED technology has unlocked modern lighting for tens of millions of un- and under-electrified businesses and households, super-efficient appliances promise to unlock life-changing modern energy services—like telecommunications, cooling, mechanization and refrigeration—for millions more. But a great deal of technical progress and market development will be needed to realize this.

Low-Energy Inclusive Appliances (**LEIA**) is a new research and innovation programme supported by the United Kingdom's Department for International Development (DFID) that aims to double the efficiency and halve the cost of a suite of appliances that are well-suited for energy access contexts. LEIA will support a slate of research, innovation and market scaling frameworks that will enable entrepreneurs, policymakers, investors and other partners working in energy access to better utilize appliances to improve the lives for the world's poorest people.

About This Document

In developing LEIA through late 2016 and early 2017, DFID engaged CLASP—an international appliance energy efficiency policy and market transformation NGO—to research and advise upon the programme's proposed scope.

Through an extensive literature review, data and market analysis, a market survey, and expert consultation process, CLASP and DFID identified appliance products and technologies that LEIA may emphasize in its programmes and research:

- **Near-to-Market Products** – appliances for which the demand is strong and clear, but efficient products are only available in low volumes and at relatively high cost
- **Horizon or Enabling Technologies** – early stage technologies which may be disruptive to existing dominant appliances. These technologies may create opportunities to leapfrog in terms of efficiency or cost, with implications poten¬tially for a whole range of products.

Among these, four near-to-market products are identified: ***refrigerators***, ***televisions***, ***fans***, and ***solar water pumps***. These products make up a substantial portion of near-term consumer demand in off- and weak-grid settings and technical improvements and market scale-up can be expected to support stronger market fundamentals and improved access in the short-run.

Also identified in the research were five cross-cutting horizon and enabling technologies: ***brushless DC motors***, ***advanced electric cooking***, ***advanced refrigeration technologies***, ***interoperability & compatibility***, and ***connectivity & internet of things***. These technologies emerged from the market analysis and consultation as potentially transformative and—like the LED—could provide step-changes in the affordability, delivery and impacts of modern energy services, if properly supported and deployed.

This document is a summary and distillation of CLASP's research into these products and technologies. CLASP's research was as thorough as possible—however, as this is an emerging market, data, literature and market intelligence is limited. CLASP's research relied heavily on the papers, studies and tools cited in this document's endnotes, as well as resources made available by the Global Lighting and Energy Access Partnership (Global LEAP).

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Technology Overviews: Near-to-Market Products

REFRIGERATORS

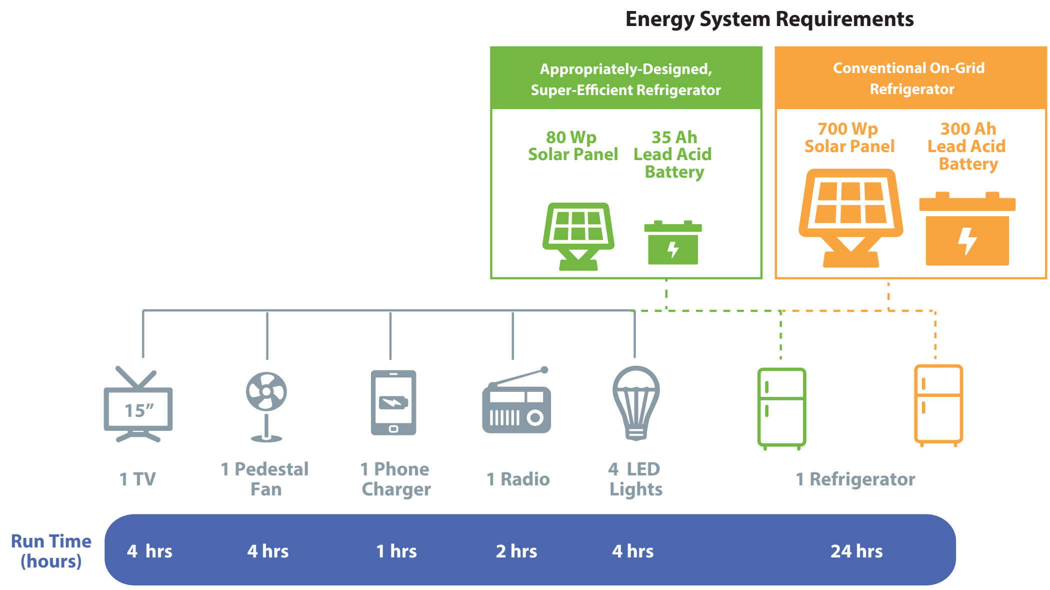
Technology Overview

The marketplace for refrigerator products explicitly designed for use in off- and weak-grid settings is nascent. The conventional AC compressor refrigerators typically found in these areas require a significant amount of power, which makes them incompatible with intermittent grid connections and the limited amount of electricity provided by off-grid energy systems.

The energy consumption of an average conventional compressor refrigerator can range from 1 to 2.5 kWh per day.[i] To support such a product an off-grid solar system would need at least a 700 Wp solar panel and a 300Ah battery—much larger than the largest commonly-available systems. Smaller, conventional refrigerators, defined here as products with less than 100L capacity, tend to consume between 0.5-0.7 kWh per day. This level of energy consumption is still beyond the capacity of the most common small- to mid-size off-grid clean energy systems.

However, an emerging class of super-efficient refrigerators designed explicitly for use in off- and weak-grid settings consume significantly less energy than conventional products, some as low as 0.1 kWh per day.[1]

FIGURE 1. ENERGY SYSTEM REQUIREMENTS TO POWER A CONVENTIONAL AND SUPER-EFFICIENT REFRIGERATOR[2]



1. The "Appropriately-Designed, Super-Efficient Refrigerator" consumes 0.1 kWh per day and has an 80L capacity. These figures are based on rated performance data from the most efficient product nominated for the 2016-17 Global LEAP Awards Off-Grid Refrigerator Competition. The "Conventional On-Grid Refrigerator" consumes 1.75 kWh per day and has a capacity of 691L. This level of energy consumption and size reflect the median of the range found in the CEE data cited above which reflects typical developed world consumer preferences and, thus, typical product offerings. This illustrates the inappropriateness of commonly-available refrigerators for off-grid and weak-grid settings.
2. CLASP analysis based on preliminary findings from 2016-17 Global LEAP programmes.

Figure 1 compares the off-grid energy system requirements to run a conventional refrigerator as compared to a currently available, appropriately-designed, super-efficient refrigerator. This suggests that cutting-edge refrigerator design technology is approaching a level of efficiency that would make refrigeration viable for a much larger proportion of the global off- and weak-grid population.

However, despite rapidly improving electrification rates and appropriate technologies on the horizon, penetration of refrigerators remains extremely low in many developing countries. Overall market penetration is below 40% in Nigeria and 30% in India. Rural market penetration is even lower, just 6% in Bangladesh (the world's largest national off-grid market) and 1% in Kenya.[ii]

Development & Market Impacts

Refrigeration is central to agricultural value chains and Base of the Economic Pyramid (BoP) livelihoods. 28% of food produced in the developing world is wasted, and nearly a quarter of that loss could be avoided if there was improved access to cold chain technologies.[iii] This has significant livelihood consequences for smallhold farmers and fishermen. It also negatively effects consumers, particularly female household members, who are most often responsible for food preparation and shopping. Refrigeration also enables income-generating activities for small retailers and other value chain actors, such as sale of cold drinks or storing milk, food, and other perishable items for later sale.

Increasing the availability and reliability of refrigeration for clinics in off-grid and weak-grid settings can be expected to drive a variety of public health outcomes as well. Refrigeration is critical for the safe transportation and storage of medicines, vaccines, and other items (e.g., blood for transfusion). Research estimates that 151 million vaccines, valued at nearly $750 million, are lost each year due to improper refrigeration.[iv]

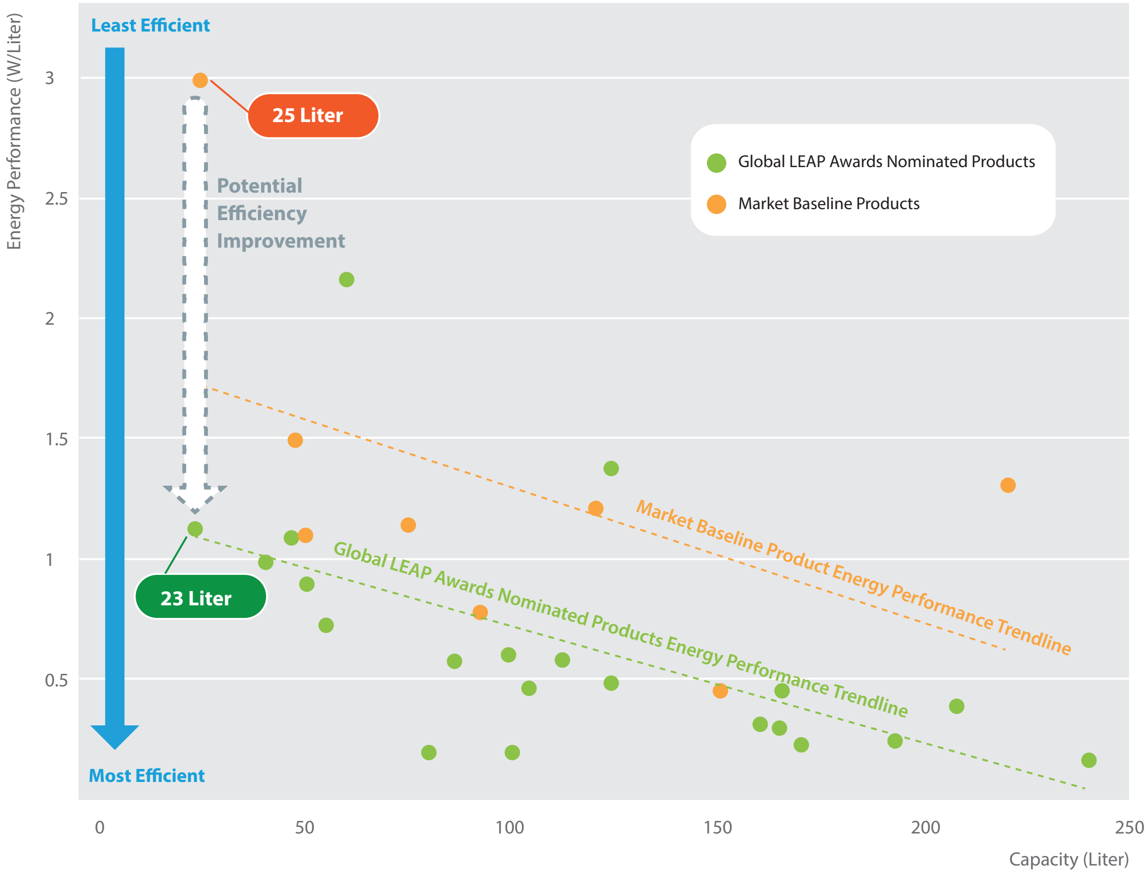
However, while some macro-level research and anecdotal data exists, there is notably little reliable research on the quality of life and livelihood improvements brought to BoP households and businesses by refrigeration.

Opportunities

Despite low penetration, latent demand for refrigerator is significant. Global LEAP estimates that current annual spending on refrigerators by off- and weak-grid households is approximately $75M. If efficient, appropriately-priced products become accessible to all households that have the purchasing power to buy a refrigerator, spending could increase to $1.1B by 2020—a 38% compound annual growth rate—despite lower per unit costs.[v]

Continued improvements in compressor and insulation technology, and scaled-up deployment of refrigerators that already incorporate design improvements in these areas, would increase the number of appropriate products available on the market. Figure 2 compares the energy performance of a set of generic, widely available products sold for use in off-grid and weak-grid

FIGURE 2. ENERGY PERFORMANCE OF SELECT OFF-GRID APPROPRIATE REFRIGERATORS[vi]



markets with a set of products recently deployed, or on the cusp of commercialization, by companies that specialize in off-grid and weak-grid appropriate products.[3] Many of the products in the latter set incorporate advanced compressor and insulation technologies, which decrease energy consumption significantly.

Pricing is a significant barrier to scaling up the supply of refrigerators appropriate for off-grid and weak-grid markets. The 23L product in Figure 2 consumes approximately 60% less energy than the 25L product. However, it also costs 25% more with a wholesale price of $360 compared to $270. Table 1, next page, shows an indicative set of cost versus efficiency trade-offs associated with various technology and design improvements.

3. Data on these products came from Global LEAP market baseline testing efforts and nominations for the 2016-17 Global LEAP Awards Off-Grid Refrigerator Competition. Please note that testing for the Competition is underway, and as such the data should not be considered final.

TABLE 1. INDICATIVE ENERGY-EFFICIENCY IMPROVEMENT OPTIONS FOR SMALL REFRIGERATORS[vii]

Energy Efficiency Improvement Option		% Energy Savings		Incremental Cost ($)	
		50L	100L	50L	100L
Insulation	Increasing insulation thickness (+2 cm)	18	25	10	15
	Increasing insulation thickness (+ 6 cm)	34	40	30	45
	Use of vacuum insulation panels	10	20	24	36
Compressor Technology	Use of a higher-efficiency compressor[4]	20	20	15	15
	Use of a DC variable-speed drive compressor	23	23	27	27

Challenges

A severely constrained supply of energy-efficient, appropriately-designed and -priced products is a primary barrier to market growth (and resulting price and design improvements due to competition and efficiencies of scale). Distributors exploring entry into the off- and weak-grid refrigerator market often struggle to find suppliers or OEM manufacturers that produce high-quality products at an affordable price. This creates a dynamic where appropriate products remain too expensive for market players to purchase at volumes that would in turn drive down costs.

Off- and weak-grid product distributors also struggle with supply chain logistics necessary to bring refrigerators to market. Distributors incur higher costs for refrigerator warehousing, shipment and inventory management than for other products, due to their size, mechanical complexity and value.

Insufficient R&D funding and the lack of an innovation ecosystem that supports product testing and component-level innovation make it difficult to transfer currently available refrigerator technology advancements to the off and weak-grid refrigerator market. Most leading refrigerator manufacturers and component suppliers remain exclusively focused on mainstream, developed world markets.

Lack of certainty regarding off- and weak-grid customer preferences and user needs are another inhibitor to product design and innovation. Feedback from early-movers in the market reveals contradictory understandings of fundamental design considerations. Stronger market research and intelligence on consumer behavior and preferences is needed to complement technical innovation focused on improvements in energy performance.

4. Higher-efficiency compressors are defined here as having a coefficient of performance (COP) of 1.7, while standard compressors are assumed to have a COP of 1.4.

SOLAR WATER PUMPS

Technology Overview

Solar water pumps (SWPs) serve to move water from surface reservoirs, streams or underground wells to storage tanks or directly onto crops for irrigation. Reductions in PV prices have made SWPs cost competitive with diesel water pumps, particularly for off- and weak-grid smallholder farms.[viii] Worldwide, electric irrigation pumps consume roughly 62 terawatt-hours per year.[ix]

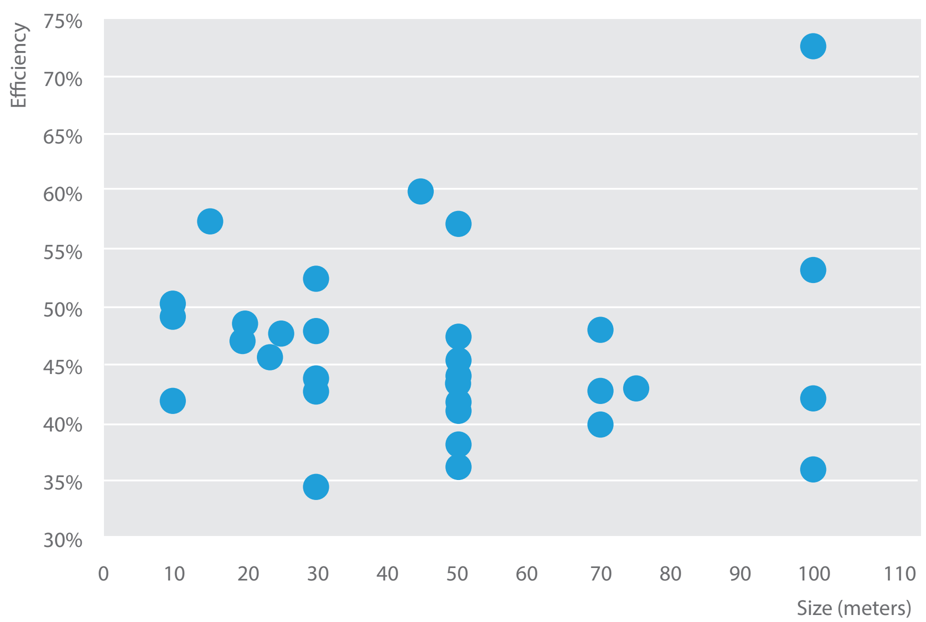
The largest potential market for SWPs is India where 19 million irrigation pumps are connected to the grid and 7 million farms use diesel pump.[x] This is a significant area of policy focus for the Indian government, which has committed to subsidizing roughly 100,000 SWPs by 90%. Figure 3 shows the wide variance (35% - 72%) in SWP efficiency found in the India subsidy program.[xi] In summary, the Indian government appears to be subsidizing some highly inefficient SWPs.

Development & Market Impacts

40% of the global population relies on agriculture as its main source of income.[xiii] Improving farm productivity has a direct impact on poverty alleviation. Only 5% of all farmland in Africa is irrigated, leaving 95% of farmland dependent on increasingly unpredictable rainfall.[xiv]

Cost reductions for SWPs will make modern irrigation more accessible and cost-effective for the nearly 500 million small-scale farmers worldwide.[xv] SWPs present a far-reaching opportunity to reduce the labor burden on women and girls in rural areas — who commonly bear the brunt of agriculture and water-ferrying work in developing countries — while increasing farm-related incomes, which have direct educational, nutritional, and economic impacts. Mech-anized irrigation allows for more planting cycles in a year by decoupling cultivation from seasonal rain patterns. For example,

FIGURE 3. EFFICIENCY OF SOLAR WATER PUMPS ELIGIBLE IN INDIAN SUBSIDY SCHEME[xii]



in Kenya crops such as kale, cabbage and beans can be harvested four times a year with mechanized irrigation, as opposed to twice a year if solely dependent of rainfall.[xvi] Studies indicate that a 10% increase in agricultural productivity for smallholder farmers in Africa leads to a 7% reduction in poverty.[xvii]

Power consumption for agricultural pumps range from <100 Watt small-scale DC systems to 200 horsepower (150kW) for commercial AC irrigation pumps. In India, where electricity tariffs are subsidized, 18% of India's total electricity consumption is used for irrigation. Moving irrigation systems from grid power to solar systems coupled with efficiency improvements will save the Indian government money on subsidies and greatly reduce strain on the electric grid. Similar government savings are possible in Bangladesh where electricity load demand and diesel fuel consumption spikes by 25% during the planting season when irrigation is required.[xviii]

Opportunities for Improvement

SWPs tailored for smallhold farmers in off- and weak-grid settings stand to make efficiency, durability and cost improvements from advances in brushless DC motors, PAYGO firmware, manufacturing materials, and power control electronics.[xix] Nascent application of PAYGO technology proven for off-grid lighting applications could make SWPs more affordable for developing world purchasers. In addition, remote system monitoring using GSM-enabled Machine-to-Machine (M2M) systems can enhance reliability of systems and speed of repair, especially in remote areas.

Further efficiency and cost reduction gains could be made in SWP design and use through better market intelligence. For example, in Kenya, the average farm size is 0.47 hectares while in India the average is 1.33 hectares, resulting in different flow-rate and system requirements.[xx] Within these countries head requirements also vary greatly depending on topography, groundwater depletion rates, and access to surface water (e.g. streams, dams). Designing and marketing SWPs with these parameters in mind—and educating farmers as to their appropriate and most effective use—could help overcome some design, cost and market scale/penetration issues.

Challenges

Only a few companies are actively designing and manufacturing SWPs for small holder farmers in off- and weak-grid geographies. Due to the highly variable environments in which SWPs must operate, it is difficult to design a SWP that meets most customers' needs. Specifications for off- and weak-grid markets often fail to meet customer requirements due to insufficient market research and data availability, leading to improper design. The high up-front cost of SWPs relative to other appliances makes financing a particularly strong barrier to scale.

FANS

Technology Overview

Fans are one of the most commonly-owned appliances in the world—over 260 million were sold worldwide in 2016.[xxi] Fans are particularly common in hot and/or humid climates; urban markets in these climates often have fan penetration rates of 70% or higher, while rural markets have much lower levels of fan penetration as illustrated in Figure 4.[xxii]

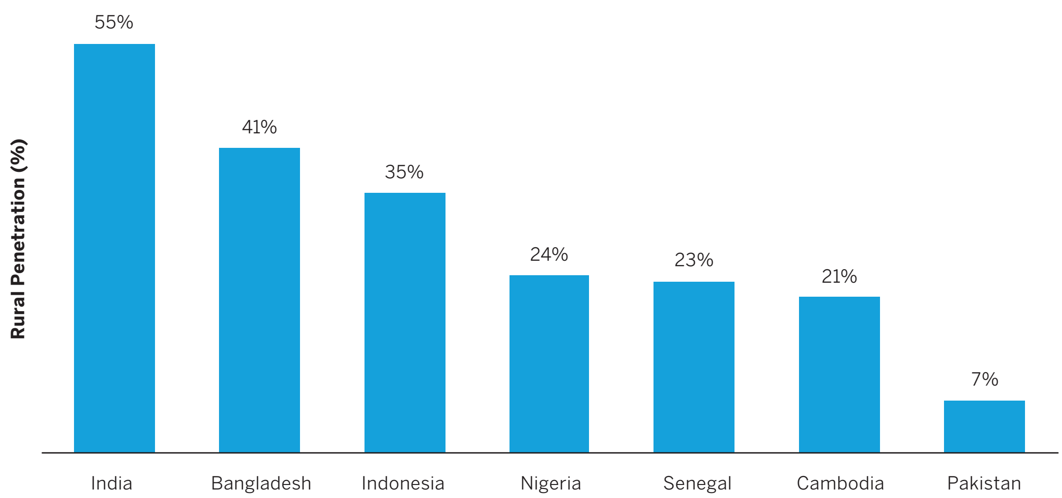
Where prevalent, fans can account for a significant proportion of energy consumption. In India, for example, it is estimated that ceiling fans alone accounted for about 6% of all residential energy use in 2000; this figure is projected to grow to 9% by 2020.[xxiv]

Development & Market Impacts

Reliable data on the impacts of fans are sparse, but a preliminary study found that "electric fans prevent heat-related elevations in heart rate and core temperature".[xxv] Another study found that access to cooling can reduce mortality and morbidity during severe heat waves.[xxvi] Fans can be expected to play a larger role in this as global temperatures rise.

Fans have a high potential for positive technological spillover effects for other LEIA applications. There are a large number of motor-driven appliance and equipment categories (e.g. pumps, grinders, mills, hand power tools, sewing machines) that would benefit from innovation, cost reductions, and scale in the brushless DC (BLDC) motor markets. Because of their demand, existing penetration, and the high likelihood of continued demand growth, the off- and weak-grid fans market could inspire significant gains in BLDC price and efficiency—and inspire manufacturers and distributors of BLDC-motorized products to invest more heavily in the off- and weak-grid market.

FIGURE 4. ESTIMATED RURAL PENETRATION OF ELECTRIC FANS[xxiii]



Opportunities

Fans are in high demand, particularly in Southeast Asia. A recent survey of energy access professionals found that fans ranked the third and fourth among the most demanded appliances in Bangladesh and India, respectively.[xxvii] Improvements in price and efficiency can be expected to unlock and enable further demand. Experience from analogous markets, and data from off- and weak-grid markets, suggests that such improvements should be possible.

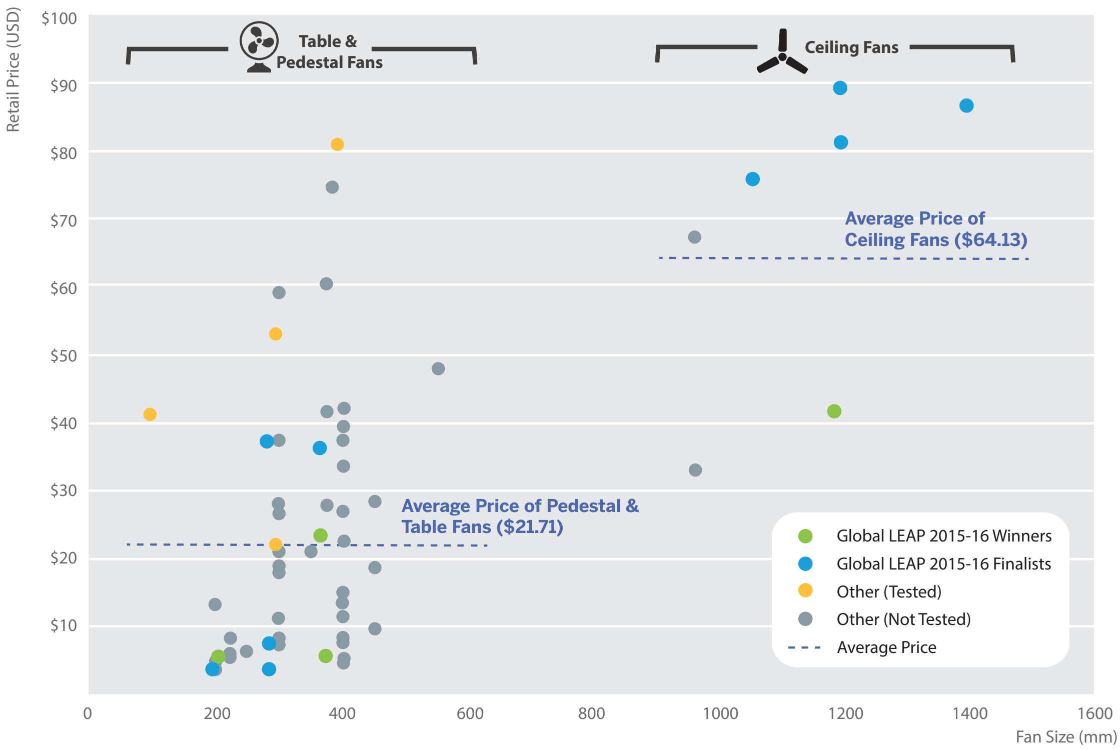
Fan pricing varies greatly based on configuration (i.e. pedestal, tabletop), features, brand, number of speeds, motor type, and market—a feature-rich 16" pedestal fan might cost $122[xxviii], while a more basic 16" pedestal fan can be purchased in Indian retail markets for less than $4.50.[xxix]

Data from Global LEAP testing efforts demonstrates that the energy consumption of fans varies greatly as well. Fans with 350-400 mm blades can consume as little energy as 9 watts or up to 33 watts. More importantly, there is significant variability in fans' energy efficiency (i.e. energy used per unit of air delivered) and substantial opportunity for improvement (see Figure 6).

Challenges

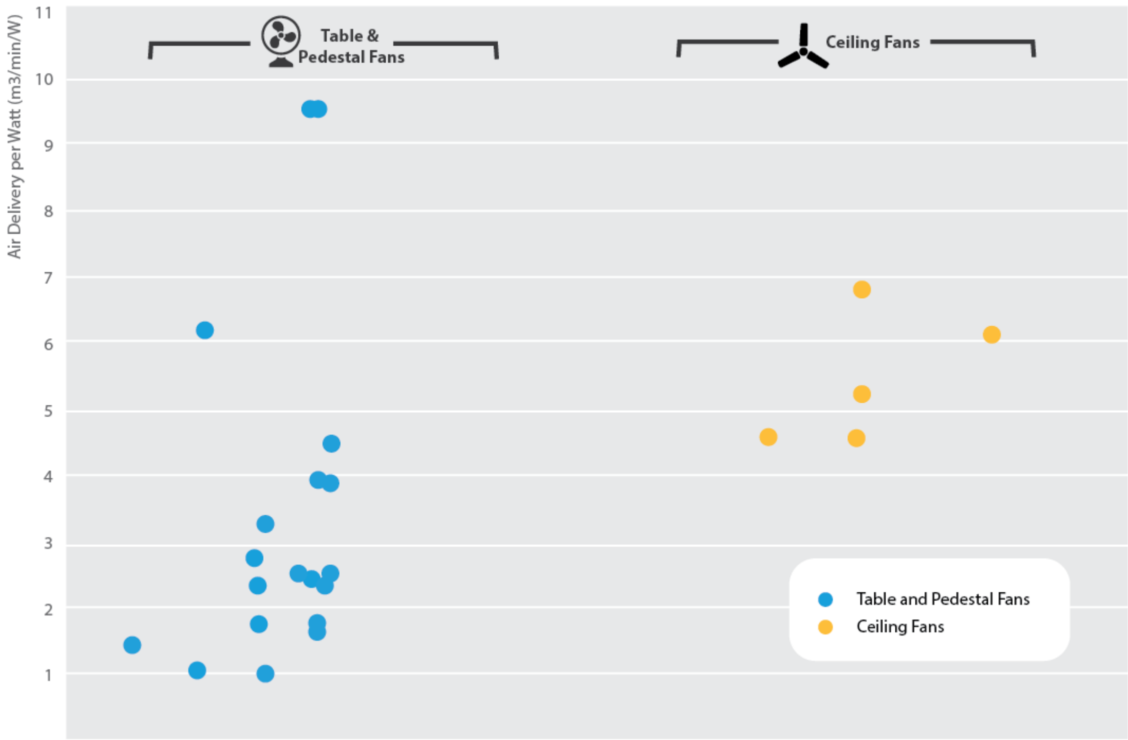
Fans are a relatively simple to design and manufacture, which has made it easy for cheap, generic products to enter and dominate the market. However, customers generally are not able to evaluate the quality or energy efficiency of their product when making a purchase, or they may not understand the impacts of an inefficient fan on their energy bill or the performance of

FIGURE 5. OFF-GRID FAN RETAIL PRICE, BY SIZE[5]



5. In 2015 and early 2016, CLASP initiated an off-grid fan market scoping exercise in India and collected retail price data for 59 products from retail marketplaces in Patna and Lucknow. See earlier footnotes regarding "retail price" estimates.

FIGURE 6. ENERGY PERFORMANCE OF TABLE, PEDESTAL, AND CEILING FANS, BY SIZE[6]



their solar home system. Early feedback from the field suggests that—despite being highly attuned to brand in other product categories—BoP consumers purchase almost exclusively on price when it comes to fans. Moreover, in most off- and weak-grid markets, no standards or policies are in place to help customers navigate quality and energy consumption considerations when making their purchase. Standards, affiliated import policies, and consumer education efforts should help level the pitch for manufacturers and distributors of appropriate fans.

6. CLASP has tested 13 off-grid fans submitted through the Global LEAP Awards program and 4 fans sampled from a retail market in Coimbatore, Tamil Nadu. More data points are being collected.

TELEVISIONS

Technology Overview

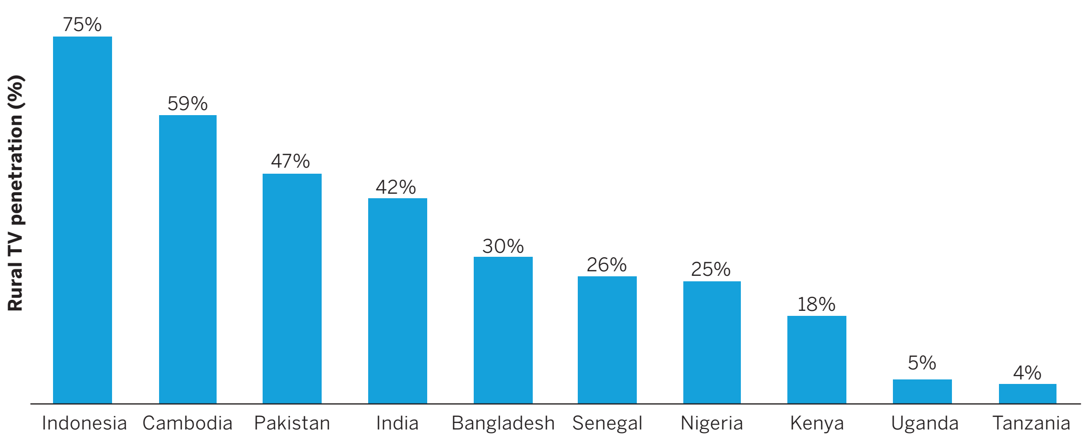
The market for grid-powered televisions is highly-developed, to the point of saturation and decline. Penetration in off- and weak-grid (e.g. peri-urban and rural) communities is much lower and demand articulation surveys of un- and under-electrified households and businesses consistently find televisions to be among the most desired appliances.[xxx] A recent Global LEAP survey found that televisions are second only to lighting appliances in terms of under-electrified consumer demand.[xxxi]

Development & Market Impacts

Recent estimates suggest that price and efficiency improvements could cause the annual global market for off-grid-compatible televisions to more than triple—from \$1.024B to \$3.126B—between 2015 and 2020, despite lower per unit costs.[xxxiii] As all indications from distributed energy service companies (DESCOs) are that demand for television is a primary driver of demand for off-grid energy, this scaling of the off-grid television market has significant implications for off-grid power system penetration.

Televisions can have significant social and economic impacts, particularly for women and children living in rural areas, as newly-introduced televisions serve as a sudden and profound conduit for previously unavailable national, regional and global information and perspective. Research has found associations with the introduction of cable television and positive changes in school enrollment, literacy, family planning, financial decisions, and health. For example, the introduction of cable television in rural India was associated with "significant decreases in the reported acceptability of domestic violence toward women and son preference, as well as increases in women's autonomy and decreases in fertility." This same study found evidence that "exposure to cable [television] increases school enrolment for younger children, perhaps through increased participation of women in household decision making."[xxxiv] Research has also found that embedding social messages in television dramas had positive impacts on financial behaviour, family planning, literacy, and health in Africa, Latin America, and Asia.[xxxv]

FIGURE 7. ESTIMATED RURAL PENETRATION OF TELEVISIONS[xxxii]



Opportunities for Improvement

TVs are in high demand by consumers, and there are many DESCOs pursuing this market due to relatively high profit margins and TVs' ability to monitor data and deliver paid- or rented-content via satellite, USB sticks pre-loaded with content, and more. However, initial research indicates that efficiency improvements in TV screens, sound systems, and receivers are achievable—improvements in backlight technology alone could reduce the total energy consumption of the average television by 20-24%.[xxxvi]

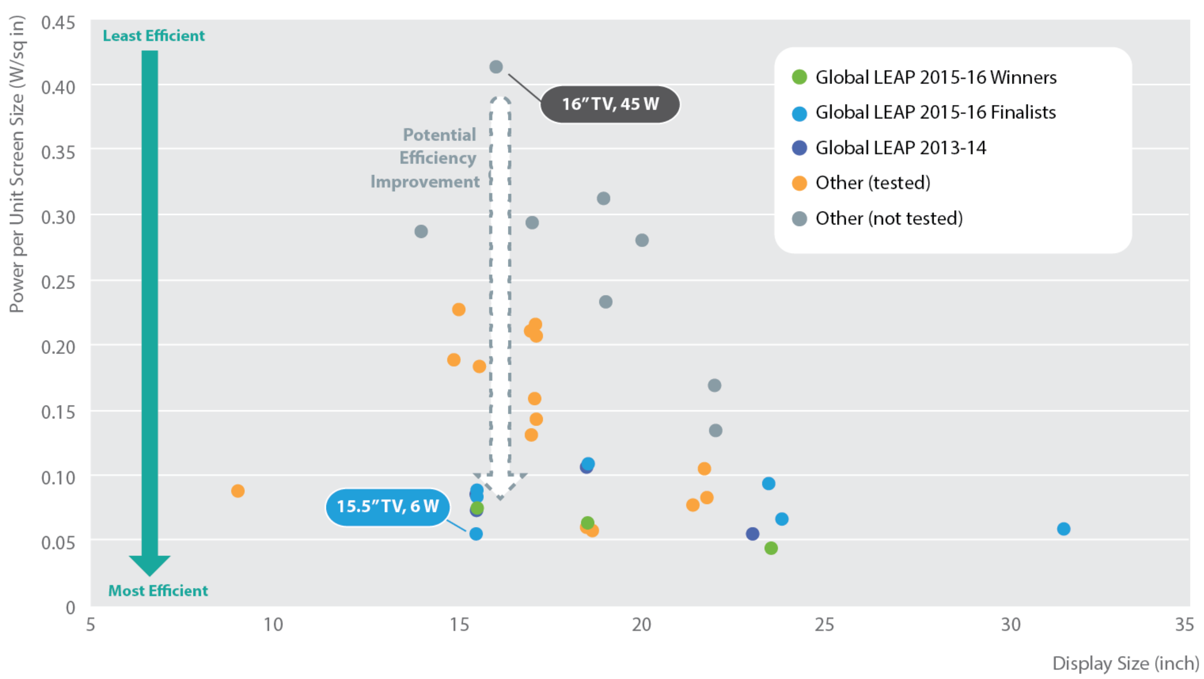
Global LEAP market testing data indicates that the price of a 19" off-grid television can range from USD $75-$207 dollars and power consumption can range from 8.7 – 48 watts (see Figure 8). Improvements are possible, and scale and competition will continue to drive down the prices and efficiency levels of products at the high end of the range.[xxxvii]

Beyond price and efficiency improvements, design improvements, including responsiveness to the (literal and technological) illiteracy of many BoP consumers and content delivery, will improve customer experience and amplify the potential socio-economic impacts.

Challenges

The primary barrier to technological innovation in television — with respect to energy efficiency and BoP-appropriate design — is lack of incentive and market pressure. The state of the DESCO market, its readiness to scale, and the degree to which appliance manufacturers see it as a viable opportunity are not creating the appropriate incentives for market entry by new manufacturers (and subsequent price, design and efficiency improvements). Other barriers include a lack of access to financing for appliance transactions, the cost of last mile distribution, and fickle policy environments.

FIGURE 8. POWER CONSUMPTION OF OFF-GRID TELEVISIONS, BY SIZE[xxxviii]



Technology Overviews: Horizon & Enabling Technologies

BRUSHLESS DC MOTORS

Technology Overview

Brushless DC (BLDC) Motors are a relatively new motor technology and avoid the use of a commutator and brushes to improve efficiency.[xxxix] BLDC motors have many benefits including higher efficiencies, longer lifetimes, programmable controls, and relative lightness and quiet. BLDC motors are typically between 85-90% efficient, whereas the efficiency of a traditional brushed motor is between 75-80%.[xl] The efficiency and longer lifespans of BLDCs can radically improve energy and lifecycle costs.

However, BLDCs presently have higher up-front costs and it is estimated that in 2017 they will comprise less than 1% of the total market for motors.[xli]

Development & Market Impacts

BLDCs are an enabling technology that can be applied to a wide range of residential and commercial products in high demand in off- and weak-grid contexts (see Table 2) including fans, refrigerators, pumps, hand power tools, mills, sewing machines, and grinding machines. If brought to scale, the productivity gains from cooling, mechanization, and transport could be substantial. The table below lists some of the technologies in which BLDCs are applicable and the status of integrating them into commercially available products.

TABLE 2. APPLICABILITY OF BLDCS TO OFF- AND WEAK-GRID TECHNOLOGIES[7]

Product	Status	Example of Commercially Available Product
FANS	Fans using BLDC technology are commercially available, but uptake is limited.	Superfan
REFRIGERATOR	Compressors using BLDC motors have been used in commercially available off-grid refrigerators.	Danfoss
SOLAR WATER PUMPS	Research on applications of BLDC motors in solar water pumps is available.[xlii] Products are commercially available.	Sun-Sub pumps from Mono pumps
MILLS	The market is dominated by brushed motors, but has the potential to switch to BLDC motors if there are price reductions.	Project Support Services
GRINDING MACHINE	Some research is available on the design of BLDC motors for DC operated mixer grinders.[xliii] Research on the design of efficient BLDC motor for DC operated mixer-grinder were reported in 2015.	Unknown

7. The information in this table was compiled based on input from expert interviews and desk research.

Opportunities

BLDCs are already quite efficient, but improvements in price, market scale, and off- and weak-grid application are needed for the technology to be more widely deployed.

There is an opportunity for LEIA to address inefficiencies and challenges in the supply chain for BLDCs. A common application of BLDCs is in electric and hybrid vehicles—matching off- and weak-grid distributors and product developers with relevant automotive design and supply chain experts could result in innovations and reduced costs. However, this requires further research to determine if these motors and/or the professionals working with them could be repurposed. Likewise, something like a "buyer's club" of off-grid product developers and other large purchasers of BLDCs could lower up-front costs. As a first step, more research is needed on the supply chain and the state of the market to understand the opportunity and address barriers.

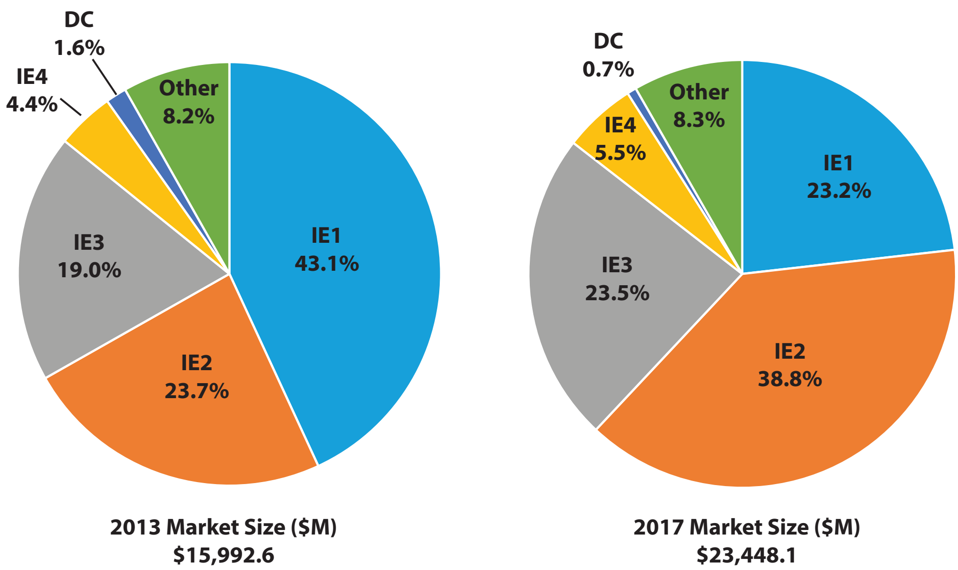
There has not been a lot of research on customizing and right-sizing BLDCs for off- and weak-grid applications. Initial research on which appliances or products would be most appropriate for adopting BLDC technology, not to mention market potential, would help in prioritizing future market scale-up efforts.

Challenges

BLDCs have many advantages over their brushed counterparts, but their market share is still small largely due to high material costs, lack of market scale, and the need for customization.

At present, the biggest challenge to broader deployment of BLDCs is likely the upfront cost. Experts indicate that the cost for a BLDC motor can be 50-100% more expensive than a comparable brushed motor.[xliv] Moreover, as Figure 9[xlv] shows, the market size for DC motors more generally is small and actually appears to be shrinking relative to other motor types, making it much more difficult to achieve economies of scale.

FIGURE 9. MARKET SHARE BY CLASS OF MOTORS[8]



8. IE1, IE2, etc refers to efficiency classes for AC motors as determined by the IEC.

ADVANCED ELECTRIC COOKING

Technology Overview

Advanced electric cooking in the context of LEIA refers to induction cooking, a technology that uses the principle of magnetic induction, in which "eddy currents are excited in a ferromagnetic cookware when in the presence of an oscillating magnetic field"[xlvi].

Induction cooking is generally considered clean, safe, fast and highly energy-efficient. The thermal efficiency of induction stoves can be as high as 90%[9], compared to about 74% for traditional electric systems and 40% for gas.[xlvii] However, as efficient as they are, induction stoves are highly energy consumptive. The typical maximum power of a single hob induction stove is around 2000W-2100W,[xlviii] far more than most off- and weak-grid energy systems can support.

Development & Market Impacts

Induction stoves do not burn fuels, eliminating the local air pollution, black carbon and CO_2 emissions that result from other traditional cooking methods, thus reducing the health risks for women and children, as well as climate impacts.

Induction stoves can reduce the expense of solid fuels and the amount of time women and children spend cooking, collecting fuel, and building fires. Women and children spend up to five hours a day collecting fuel.[xlix] In regions of conflict women and girls are vulnerable to gender-based violence when collecting firewood.[l] Where electric cooking is common, induction cooking holds the potential to shave grid and energy system peak demand significantly and improve reliability, government subsidy costs, and more.

Opportunities

Induction stoves are readily available in many on-grid markets. In China the production and market sales of induction stoves in 2012 were approximately 70 million and 37 million units, respectively.[li] Induction stoves are also gaining popularity in India. It was estimated that from 2012 to 2016 the Indian market for induction stoves would grow by 35.4% annually.[lii] This should have positive implications for the costs of induction cookers. As far as appliances go, induction stoves are relatively inexpensive—though the costs can still be prohibitively expensive for cooking in the BoP context, particularly when considering the energy costs. Initial research indicates that prices could fall further. The average price of an induction stove sold in India is $30, but some firms report working on products that would be applicable to weak-grid conditions that would sell for $20. Induction stoves can be purchased in bulk in China for as low as $8 per unit.[liii]

If prices of solar panels and batteries continue to decline and pilot projects with mini-grid systems are successful, it is conceivable that many customers could leapfrog from biomass to advanced electric cooking. However, a recent study conducted by GIZ and the Directorate General of Peru found that a 85Wp solar system is needed to support cooking with induction stoves (and

9. Thermal efficiency refers to the percentage of the energy that the stove uses that is transferred directly to heat.

cooking alone). The cost for such a system was estimated to be $1000. As it stands, induction stoves present an under-explored opportunity for weak- and edge-of-the grid settings.

Induction stoves that are used in a grid-connected household require an inverter to convert AC to DC power, but this is not necessary for stoves that would be powered from a solar panel or another DC source. Building a stove without an inverter could improve both price and efficiency.

Ecuador is piloting the use of induction cook stoves to displace LPG stoves and reduce carbon emissions. The initial pilot provided stoves to 5400 households and the results were generally positive. A survey found that 60% of the respondents were 'completely satisfied' with the induction stoves, while 39% were only 'satisfied,' and 1% were 'unsatisfied.' The most frequently cited benefits of the new stoves were their ease of use, the speed with which they cook food, and that matches were not required. The most common complaint was that users felt limited in which pots they could use, as the aluminum pots common in Ecuador cannot be used with induction stoves.[liv]

Challenges

Induction cooking is common in some grid-connected areas like China and India, but outside of the above-mentioned Ecuador example there has been little research into introducing stoves in off- or weak-grid environments. Pilot projects and consumer preference research are needed to demonstrate the feasibility of using induction stoves in weak-grid and mini-grid powered communities. The product's high power demand requires a relatively large solar panel and battery to be suitable in the off-grid context. Induction cooking also requires specialized cooking pots, and consumer research is needed to understand preferences and feasibility of deployment with different cooking styles and cultures.

An Ecuadorian woman seeling aluminum pots in a local market. (Source: iStock/marcelina1982)

ADVANCED REFRIGERATION TECHNOLOGIES

Technology Overview

Innovation in advanced refrigeration technology has the potential to create a step change in affordability, durability and efficiency for refrigeration in off- and weak-grid settings. For the purposes of the LEIA program advanced refrigeration is classified as horizon technologies that are components of refrigeration and cooling technologies, capable of commercialization in 3 -5 years, and can be organized into the follow three categories:

- **Insulation** – Minimizing heat loss improves efficiency and hold-over time during periods of intermittent energy availability. Types of promising new insulation materials are Vacuum Insulated Panels (VIPs) which consist of a gas-tight enclosure surrounding a rigid core and aerogels which constitute a range of materials that exhibit extremely low levels of thermal conductivity and high porosity.
- **Thermal Energy Storage** – Intermittent power availability is often a problem in off- and weak-grid environments; energy storage is required for the refrigerator to maintain its desired temperature. This could be a chemical battery, enabling the refrigerator to run the cooling engine when there is no external power availability. Alternatively, thermal storage in the form a phase change material can create a hold-over period, assisting in temperature maintenance when power is unavailable.
- **Cooling Engine Processes** – The processes by which the refrigerator moves heat from the refrigerator to the exterior environment has significant potential for innovation. Some of the more promising advances are in developing thermoelectric (e.g. Peltier) refrigeration, magnetocaloric materials, thermos-acoustic devices, absorption, Stirling refrigeration, brushless DC motors and variable speed drive compressors.

Development & Market Impacts

Technological improvements in advanced refrigeration could be leveraged in a variety of cold chain market segments, including household refrigerators, small business enterprise cooling equipment, agriculture cold chains, freight and transport refrigeration, and medical and clinical refrigeration equipment. The Global Cold Chain Alliance estimates that India loses 40% of its produce to waste due to inadequate cold chain infrastructure. In Sub-Saharan Africa 94% of all wasted food is a direct result of insufficient supply chains.[lv] A 2016 study found that on average 15% of all vaccines in India spoil due to lapses in the cold chain.[lvi]

Opportunities for Improvement

Further development and commercialization of refrigeration technologies that do not require a vapor compressor such as thermoelectric, Stirling engine and absorption chillers could increase durability and decrease the lifetime cost of refrigeration for off-and weak grid households and businesses.

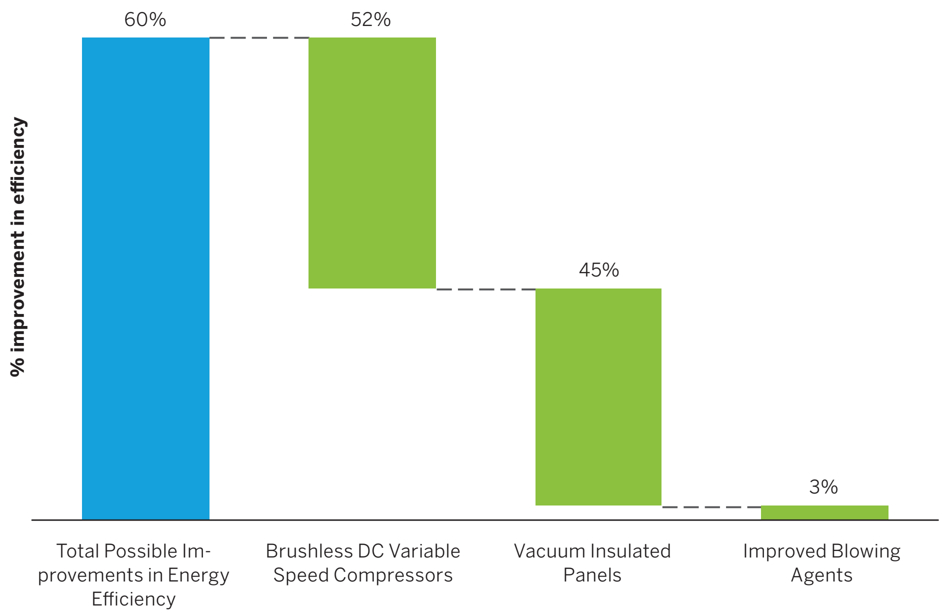
Opportunities exist to transfer promising technologies such as magnetic cooling systems, which are in the early stage of commercialization in developed economies by companies such as GE and Whirlpool, to off- and weak-grid applications. Early prototypes of magnetic cooling systems show 20-50% efficiency gains over vapor compression refrigerators, but are relatively costly.[lvii lviii]

Improving upon existing compressor technology also represents a significant opportunity to improve refrigerator performance and affordability. Use of variable speed drive (VSD) compressors coupled with brushless DC (BLDC) motors results in additional efficacy gains over standard compressors. Preliminary analysis shows that improved compressor efficiency and increased insulation thickness or vacuum insulation panels can collectively reduce electricity consumption by more than 50%.[lix]

Challenges

A primary barrier to innovation in advanced refrigeration technologies aimed at off- and weak grid applications is R&D payback uncertainty. Due to the limited application of refrigeration technologies in many developing countries very little is known about the potential downstream opportunities that R&D would generate. Funding is needed for market intelligence to better understand the needs, size and potential market segments to further de-risk and guide R&D investment.

FIGURE 10. ENERGY EFFICIENCY IMPROVEMENT OPTIONS FOR REFRIGERATORS[lx]



INTEROPERABILITY & COMPATIBILITY

Technology Overview

"Compatibility" is a concept that can refer to the state of two (or more) products or pieces of equipment (e.g. systems, devices, etc.) working together satisfactorily without needing to be altered or modified. "Interoperability" is a concept that refers to the ability of two separate systems (e.g. solar home systems) to work with and/or use the parts of another system (e.g. a SHS using another SHS' TV).

In the context of energy access / LEIA product markets, these two concepts are related and relevant to one another. However, there is an important difference.

There is very little appliance compatibility across the SHS products offered by DESCOs, creating substantial challenges for the development of the appliance market, including:

- barriers to entry for new manufacturers
- reduced consumer choice (and, thus, competition)
- inhibited incentive for existing manufacturers to innovate, due to reduced scale

As for interoperability, the energy access market is destined to evolve. Mini-grids are going to show up where solar home systems were once dominant; the grid will show up and integrate with mini-grids; solar home systems may be patched together in "swarm solar" systems; etc. Absent research on enabling these transitions, and the application of the findings, a good proportion of present day energy access investments (appliances and otherwise) could be stranded.

Development & Market Impacts

Appliance price and efficiency gains due to compatibility and interoperability are hard to predict—however, these issues quickly lead to questions regarding new market entry, competition, consumer choice, and scale, which have significant implications for innovation with respect to price and efficiency.

Opportunities

For several valid reasons—including a needs to monitor data, enable remote shut-off, reduce theft and product loss, and prevent system degradation/corruption by sub-standard appliances—many DESCOs (PAYG companies in particular) use proprietary plugs/ports. A 2013 CLASP analysis of 18 SHS models found at least 14 different plugs.[lxi] Finding a "universal" plug/port that accomplishes every DESCO's needs could be revolutionary in terms of enabling competition and market entry. Moreover, it could provide an important buttress against the monopolization of energy services implied by the trajectories of vertically integrated PAYG distributor models.

There have been successful efforts to drive wide-scale interoperability and compatibility. One obvious example is in national utility/power markets (plugs, sockets), which are driven largely by top-down regulatory action rather than market forces. Another is in the (highly relevant) mobile banking industry, where there has been industry and trade-group led efforts in Tanzania and Madagascar[lxii] for all mobile money operators to have their services be interoperability—with big implications for scale-up of mobile money and financial inclusion.

Challenges

The biggest barrier to improved compatibility and interoperability is the nascent state of the market. As for compatibility, DESCOs are motivated to keep their plugs/ports proprietary, and there are no strong market/political forces to countervail that motivation. Greater activity and engagement throughout the appliance supply chain—and better education on these issues for policymakers, trade groups, etc.—should help.

An obvious intervention to address both issues is an inclusive research agenda with a policy/standardization goal line, possible working with Lighting Global, Open University, and IEC.

CONNECTIVITY & INTERNET OF THINGS

Technology Overview

Internet connectivity refers to the ability of a device to access the internet. The two most common ways to connect to the internet are through broadband and mobile networks. At the end of 2016, mobile internet user coverage worldwide reached 48%, and is expected to reach 60% by 2020, with the vast majority of users gaining access via smartphones.[lxiii] Mobile internet infrastructure is gradually shifting from 2G technology to 3G and 4G, which will increase download speeds and decrease costs for digital services and connected appliances. Off- and weak-grid communities exist at the edge of this connectivity transformation.

The connectivity of household appliances to the internet and the internet is commonly referred to as the Internet of Things (IoT).

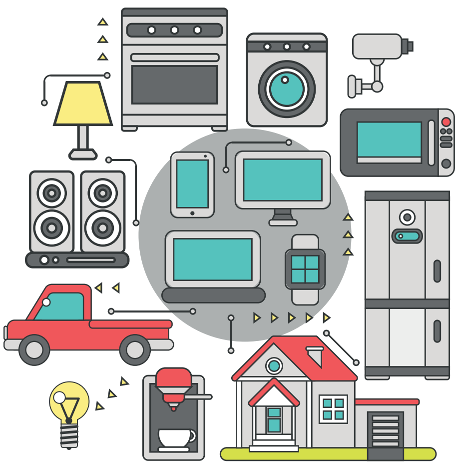
Development & Market Impacts

Internet connectivity will increase the availability of a range of digital services effecting health, economic, education and quality of life outcomes for off- and weak-grid households. Connectivity can provide access to educational materials and information at little or no cost. The non-profit Worldreader has reached 5.5 million readers across 52 countries through individual, school, and library eReader programs. Each eReader contains over 45,000 books.[lxiv] A 2014 study found that internet enabled mobile devices are playing an increasingly important role in the provision of health services to the poor in low and middle income countries. Some of these services include client education and behaviour change, sensor and point of care diagnostics, and electronic decision support.[lxv]

In addition to providing access to digital services and improving communication, internet connectivity will both enhance access to and improve the value of a suite of household appliances. Whether through greater access to finance or improved customer service, connectivity will play a significant role in the appliance value chain.

IoT can contribute to increased appliance efficiency and affordability for off- and weak-grid households in the following ways:

- **Data** – Real time appliance data allows retailers to quickly identify and respond to product issues. Remote customer service improves the utility and lifecycle costs of owning and operating an appliance.[lxvi]
- **Enhanced PAYGO Value** – DESCOs have used PAYGO technology to remotely control small solar home systems used to power lights, radio, TVs and mobile phone chargers.[lxvii] PAYGO technology increase the collateral value of an appliance, and lower the transaction cost for lending.



- **Artificial Intelligence (AI)** – Machine learning has created recent breakthroughs in speech recognition software which has the potential to improve appliance functionality for illiterate populations.[lxviii] AI is also being used to incorporate demand response features in appliances to optimize battery performance.[lxix]
- **Advanced Sensors** – Connected sensors have the potential to deter appliance theft through tracking devices and improve agricultural yields through soil moisture and temperature monitoring.[lxx]

Opportunities

Internet access and affordability can be improved in off- and weak grid areas through hardware and software efficiency optimization for Wi-Fi routers. Testing is being carried out on cost and energy efficient mesh Wi-Fi networks that allow local communities to connect at a cost lower than what is currently available through mobile telecom providers.[lxxi] Google and Facebook are exploring ways to broadcast internet to uncovered areas from helium balloons or solar powered planes.[lxxii]

IoT has the potential to improve efficiency and affordability for every appliance designed for off- and weak-grid households. Budget and energy constrained households arguably need "smart" appliances more than wealthy households who have larger disposable incomes, greater access to finance and cheaper sources of electricity. Connectivity has most successfully been leveraged by DESCOs through PAYGO technology. DESCOs are exploring ways to imbed PAYGO technologies into smart phones, refrigerators, LPG cookstoves, and SWPs. For example, the Kenya-based startup PAYGO Energy is experimenting with technology that can regulate the access to a LPG canister remotely, allowing customers to pay for incremental amounts of LPG via mobile money and avoid one large upfront payment.

Challenges

Internet connectivity for off-grid and weak grid households face technical innovation barriers to both extending access and improving the application of connectivity to appliance ownership and operation.

Providing Internet access in off- and weak-grid areas of Africa and Asia remain a challenge due to their sheer size, low population density and lack of supporting infrastructure such as roads. Internet Infrastructure design and development is typically geared towards serving more profitable urban populations. Companies trying to develop internet connectivity solutions for rural households are relative small in size and lack the adequate R&D resources needed to accelerate innovation.

DESCOs involved in designing off-grid appliances lack the R&D funding needed to develop internet-based or "smart" applications beyond PAYGO for appliances. More broadly, a better understanding of the opportunities and challenges associated with connectivity and IoT is needed, along with R&D support.

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