EFFICIENCY FOR ACCESS

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# REFRIGERATORS

## Solar Appliance Technology Brief

**JUNE 2021**

EFFICIENCY FOR ACCESS COALITION

## CONTEXT

**This refrigerator technology brief is one in a series of insight briefs developed to synthesise the latest market intelligence and chart the pathway to commercialization for some of the off- and weak-grid appropriate technologies most relevant to catalysing energy access and achieving the Sustainable Development Goals.**

The first iteration of the LEIA Technology Summaries was published in 2017 to help the newly established Efficiency for Access Coalition navigate a nascent market. At the time there was limited data and research available on market trends and off/weak-grid appliance performance. This refrigerator brief updates and expands on these summaries, bringing together the latest insights on market and technology trends, consumer impacts, and pathways to scale for fans. You can access briefs on all technologies that are a part of this series here.

This brief was developed by CLASP and Energy Saving Trust as part of the Low Energy Inclusive Appliances programme, a flagship programme of the Efficiency for Access Coalition. It is a catalyst for change, accelerating the growth of off-grid appliance markets to boost incomes, reduce carbon emissions, improve quality of life and support sustainable development.

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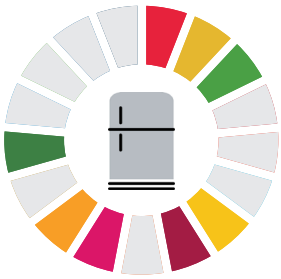
## SDG INTERLINKAGES



**REFRIGERATORS**

**SDG 1:** No Poverty
**SDG 2:** Zero Hunger
**SDG 3:** Good Health & Wellbeing
**SDG 7:** Affordable & Clean Energy
**SDG 8:** Decent Work & Economic Growth
**SDG 10:** Reduced Inequalities
**SDG 11:** Sustainable Cities & Communities
**SDG 13:** Climate Action

Refrigeration provides a wide range of lifestyle benefits, from improving human health and productivity to reducing the domestic burden on women and children, who are usually responsible for food gathering and preparation. Outside of home use, refrigeration is indispensable in hospitals and clinics – especially for vaccine storage – and enables income-generating activities for small retailers through the sale and storage of drinks and perishable items.

# Introduction

Refrigerators have the potential to unlock an array of social and economic benefits for consumers living in off- and weak-grid areas, from reducing food waste to enhancing income through new business opportunities. Prior to 2016, the off-grid refrigerator market was mainly focused on donor-supported specialised uses, such as vaccine refrigerators. Since then, more refrigerator manufacturers have started expanding into the mass market to target off-grid households and small businesses. This new class of efficient off-grid appropriate refrigerators holds promising potential to provide cooling services to more users. Although refrigerators can also serve the small-scale agricultural market and health clinics, this technology summary covers refrigerators intended for domestic and light commercial use only.[1]

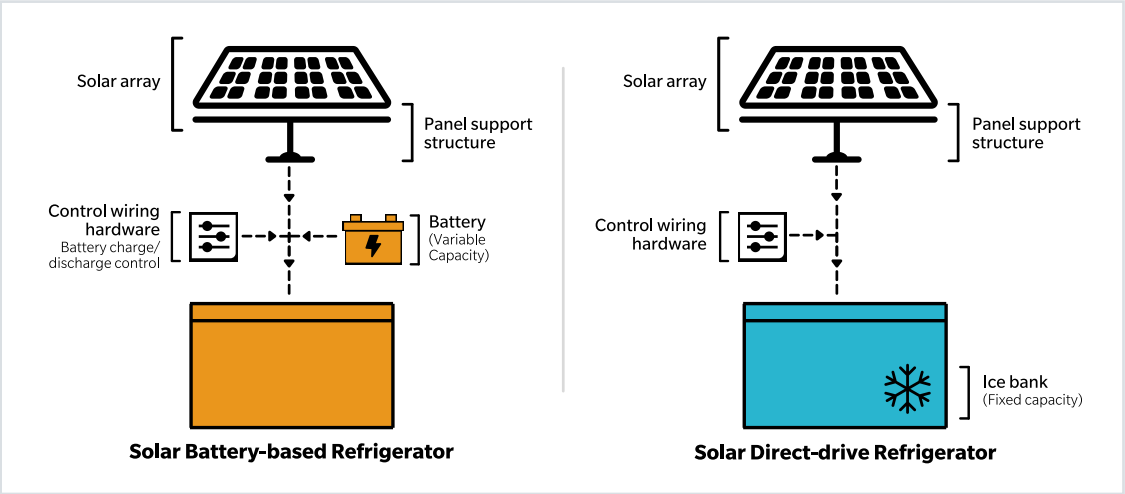
There are various types of refrigerators suitable to operate in energy-constrained conditions (Table 1). With the growth of the solar market, compressor-based refrigerators have prevailed as the most popular and viable technology, and this brief therefore primarily focuses on these products. Compression refrigerators utilise a compressor to circulate a refrigerant and change it from liquid to gas. This process, called evaporation, cools the refrigerator compartment.[2]

**Table 1. Off-Grid Refrigerator Types [3]**

| Refrigerator Type | Definition | Appropriate Power Source |
|---|---|---|
| **Absorption Refrigerators:** Operate on heat cycle which requires fuel or electric heat source | | |
| Gas or propane refrigerators | Use gas or propane as their primary energy source and have no moving parts. These products consume a high amount of energy and pose potential fire and health risks from particulates. | Gas or propane fuel |
| **Compression Refrigerators:** Operate using compression cycle which requires electricity | | |
| DC household refrigerators and refrigerator-freezers | Designed to be used with a solar energy system and typically feature more efficient design considerations, such as highly efficient compressors and motors, or thicker insulation.[4] | Solar system including PV panel and battery, or generator |
| SDD refrigerators | Connect directly to a PV panel, and generally include an integrated thermal and/or electric battery to allow for autonomous operation at night or on cloudy days when there is no solar power (Figure 1). SDD technology uses solar energy to freeze water packs or other phase change materials. These ice packs keep the refrigerator cool. | PV panel |
| Conventional AC refrigerators | Intended for use with a grid power supply, but may be used with a solar system through an inverter. On average, they are less efficient than DC refrigerators, but are currently the most readily available option for most off-grid consumers. | Grid electricity, generator, or solar system with an inverter |
| **Evaporative Refrigerators:** Utilise water and evaporative effect to cool without a power source | | |
| Evaporative refrigerators | A simple design that utilises water and a porous membrane to cool through evaporation. Evaporative refrigerators are only effective in low-humidity areas and can only cool 10-15°C from the ambient temperature. Handmade clay pot coolers are one of the most common designs, but some companies have developed designs for the mass market, using an internal reservoir filled with water and lightweight membranes as insulation. | No power source needed |

1. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.
2. Danfoss, The fridge-how it works, n.d.
3. Alternative Energy, Cooling Off-Grid Energy Options, n.d.
4. For more information on the types of refrigerants off-grid refrigerators utilise, please read Efficiency for Access' Phasing Down HFCs in Off- and Weak-Grid Refrigeration.

**Figure 1.Solar Battery-Powered Refrigerators vs. SDD Refrigerators**




## State of Play

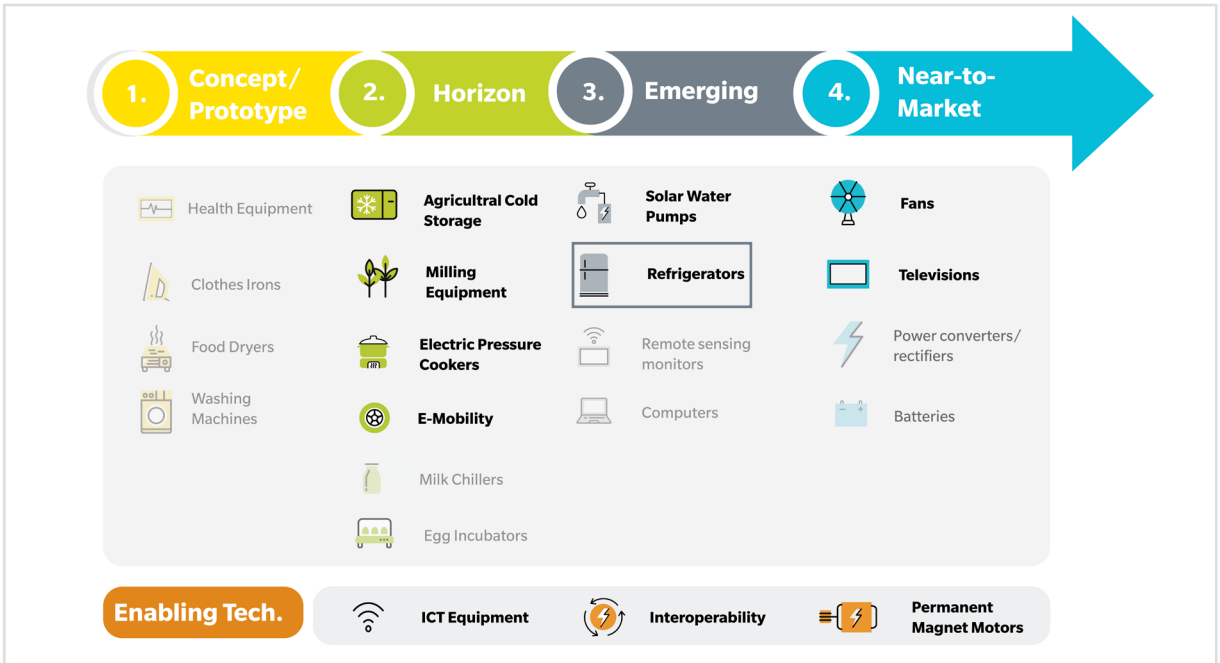
Refrigerators are an emerging appliance with high demand but low market penetration (Figure 2). In 2020, household refrigerators ranked fourth for perceived consumer demand and third for impact potential among other off-grid appliances in a sector survey.[5] As the off-grid solar industry continues to mature, the number of companies developing refrigerators designed for use with SHSs has grown, but sales volumes remain small.

Refrigerators are one of the most difficult products to optimize for energy efficiency while maintaining prices that off-grid consumers can afford. Off-grid refrigerators can range significantly in size and power consumption (Table 2).

Although the overall efficiency of refrigerators has improved since the 2017 LEIA technology summary, most products sold in retail markets still have a ways to go to catch up to best-in-class products.

To enable consistent product comparisons and identify the best performing products, Global LEAP published its Off-Grid Refrigerator Test Method and launched the first Global LEAP Awards competition for off-grid refrigerators in 2017, with a second competition in 2019. Winners of the 2019 Global LEAP Awards demonstrated an 18% improvement in energy efficiency over 2017 Winners. Products sampled from local retail markets also improved by 36% over the same period. However, there is still a 64% gap in efficiency between high performing Global LEAP Awards products and samples procured from markets in off-grid areas.[6]

**Figure 2. Relative Maturity of Select Appliances**




5. Efficiency for Access Coalition, Off-Grid Appliance Market Survey, 2020.
6. Efficiency for Access Coalition, Appliance Data Trends, 2021.

**Table 2. Overview of Refrigerator Metrics Based on VeraSol-Tested Data**

| Metric | | Refrigerator | SDD Refrigerators | Refrigerator-Freezer Combination Unit |
|---|---|---|---|---|
| Fresh Food Compartment Temperature (°C)[7] | | 4 to 12°C | 2 to 8°C[8] | 4 to 12°C |
| Freezer Compartment Temperature (°C) | | N/A | N/A | 0 to -18°C |
| Size (Total Volume in L) | | 15 to 240 L | 30 to 290 L | 45 to 270 L |
| Average Autonomy (Hours) | | 3 | 133 | 1 |
| Average Daily Energy Consumption (kWh/24h) | | 0.5 kWh | 0.6 kWh | 1 kWh |
| Price Range[9] (USD) | 25th Quartile | $352 | $620 | $212 |
| | Median | $531 | $1,384 | $315 |
| | 75th Quartile | $866 | $2,403 | $464 |

# Market Insights

With greater affordability and increased efficiency, we estimate that the cumulative global market potential for refrigerators will grow by 10% each year, tripling from US$4.4 billion in 2018 to US$14.3 billion by 2030.[10] Demand for off-grid refrigerators is particularly high for households that have already experienced some of the benefits of energy access via basic SHSs. For example, a large-scale survey of off-grid households across 10 countries in Sub-Saharan Africa revealed that on average, 14% of households ranked refrigerators as the first appliance they would purchase upon gaining access to electricity.[11]

There is also evidence to suggest the diversity of brands and models available on the market has increased. Just five years ago, a handful of off-grid refrigerator brands were active in the market. By 2017, 11 refrigerator manufacturers with 20 products participated in the Global LEAP Awards, and by 2019, 21 manufacturers submitted 39 products for the Awards—with 67% of manufacturers being first time participants.[12] This growth in brands and models means increased competition and choices for consumers.

However, refrigerator ownership in off-grid areas is extremely low. In rural Africa, approximately 4% of rural households own a refrigerator and even in middle income countries such as India, only 16% of rural households have refrigerators.[13] GOGLA sales data shows that sales of solar refrigerators are relatively low, with GOGLA affiliates selling approximately 8,200 refrigerator units in 2019 (Figure 3).[14] For comparison, affiliates sold around 470,000 solar TVs in the same time period. The sales figures for solar refrigerators are even lower when compared to conventional AC refrigerators sold across Sub-Saharan Africa and South Asia, which is estimated at over 22 million units in 2019.[15]

When looking at sales of refrigerators by region (Table 3), East Africa holds market dominance, which may be due to several factors, including higher disposable incomes, a more developed off-grid solar market, and sales of products through donor-funded subsidy programmes, such as the results-based financing available for winners of the Global LEAP Awards.[16] In East and West Africa, refrigerators were the only appliance that did not see a decrease in sales in 2020, demonstrating a latent demand for these products despite challenges from COVID-19.[17]

**Table 3. Recent Regional Sales of Off-grid Refrigerators**

| Time Period | Global | South Asia | Central Africa | West Africa | East Africa |
|---|---|---|---|---|---|
| Jan - Jun 2019 | 2,768 | 66 | 122 | 791 | 1,159 |
| Jul - Dec 2019 | 5,388 | 1,050 | 6 | 633 | 2,474 |
| Jan - Jun 2020 | 4,445 | 188 | 52 | 1,009 | 2,586 |

Affordability is one of the biggest challenges prohibiting refrigerators from reaching off-grid consumers at a greater scale. Without financing, the cost of refrigerators can be 2.5 times higher than the annual disposable income of the poorest 50% of off-grid households[18], making them virtually impossible to pay for up front. Even with financing, only 68 million households, or roughly 15% of all off-grid and weak-grid households, could afford an average off-grid refrigerator.[19]

7. The temperature of a household refrigerator's fresh food compartment depends on the use case. Products intended for food storage should operate between 4 – 8°C, for beverage cooling between 8 – 12°C, and for freezing between -6 to -18°C. Efficiency for Access adopted these temperature targets from the EU and US standards for household refrigerators, but it can often be difficult for off-grid refrigerators to meet these requirements given high ambient temperatures.

8. As defined by the World Health Organization (WHO) for vaccine storage. VeraSol tests SDD refrigerators intended for household and small business use, and thus tests their ability to operate between 4 to 12°C.

9. Average retail price of unit without PV module or battery.

10. Efficiency for Access Coalition, The State of the Off-Grid Appliance Market Report, 2019.

11. Leo, B., et al, What Can We Learn About Energy Access and Demand from Mobile-Phone Surveys? Nine Findings from Twelve African Countries, CGDEV, 2018.

12. Efficiency for Access Coalition, The State of the Off-Grid Appliance Market Report, 2019.

13. Id.

14. GOGLA, Global Off-Grid Solar Market Report Semi-Annual Sales and Impact Data H1 and H2, 2019

15. Euromonitor International. (n.d). Market sizes [Refrigeration Appliances, 2014-2019] [Data set]. Passport. Retrieved November 23, 2020 from https://www.euromonitor.com

16. Global LEAP results-based financing is a financing programme for Winners and Finalists of the Global LEAP Awards. The programme aims to catalyse the uptake of high quality super-efficient appliances by 1) Lowering the cost to procure large volumes of best-in-class off-grid appliances for early mover off-grid solar companies, and; 2) Facilitating new business partnerships for appliance suppliers that have invested in the production of high-quality off-grid appliances.

17. Efficiency for Access Coalition, Appliance Data Trends, 2021.

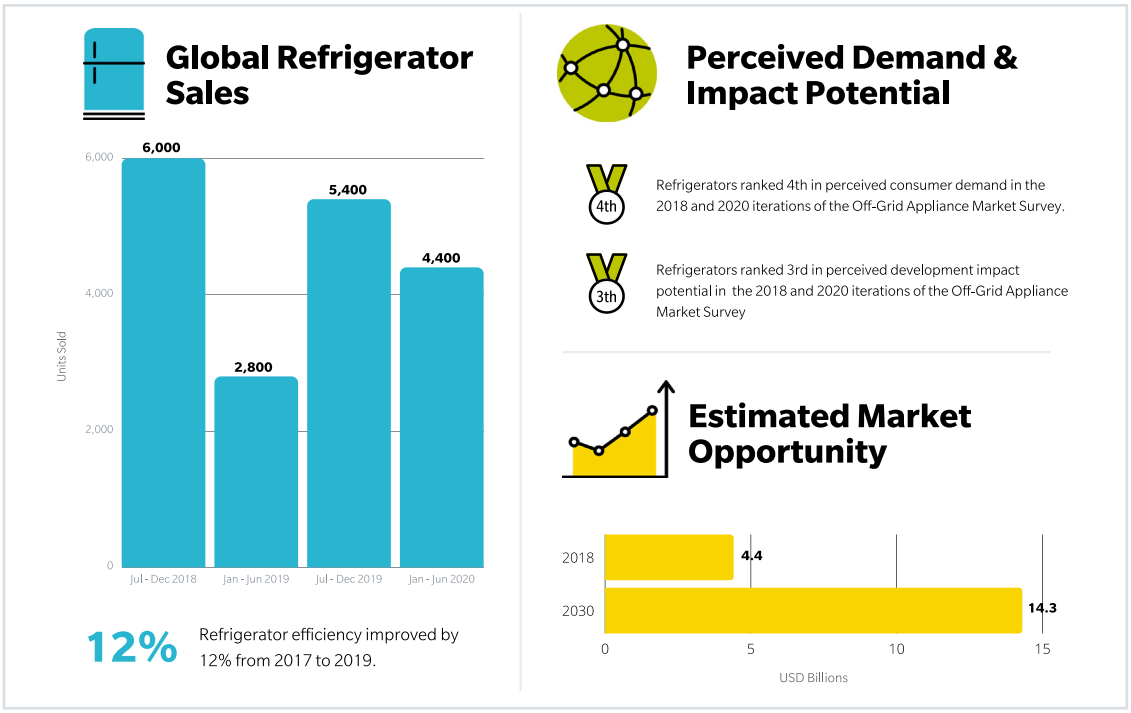
18. Id.

19. Efficiency for Access Coalition, The State of the Off-Grid Appliance Market Report, 2019.

One pathway to better affordability is through developing specific standards for off-grid refrigerators, which can help unlock preferential tax treatments. Currently, many countries classify refrigerators as luxury goods and tax them at relatively high rates.[20] In Africa, duties for importing a fully assembled refrigerator can be as high as 50%, with an additional 10-15% VAT. Some governments are implementing policies to increase VAT and duties on imported products to incentivise local production. The Indian government, for example, recently increased customs duties on refrigerators and air-cooling appliances by 20% while also increasing duties on compressors from 7.5% to 10%.[21]

Regional standards and policies also play an important role in the distribution of high-performing products, especially in nascent markets. Even though institutions such as the International Electrotechnical Commission (IEC) and World Health Organization (WHO) have developed standards for conventional refrigerators and vaccine refrigerators, standards and policies designed specifically for off-grid household refrigerators are underdeveloped. Although there are no internationally recognised standards for off-grid refrigerators, some NGOs, such as SEforALL, have designed quality criteria parameters to help procurement agencies and financers select high quality products.

**Figure 3. Off-Grid Refrigerator Market Overview**




## Consumer Impacts

Refrigerators have the potential to unlock an array of social and economic benefits for off-grid consumers, satisfying both consumptive and productive uses. Refrigerators can reduce poverty by creating new business opportunities, improve food security by extending the shelf life of food and reducing food waste, decrease the amount of time spent food shopping and cooking, and improve health by keeping vaccines and medication viable (Technology Spotlight 1).[22]

Refrigerators can be highly impactful for small shops, who are the main customer base of off-grid refrigerator sales to date. Shop owners primarily use refrigerators to provide new services and expand product offerings, such as selling cold beverages and perishable food. In an unpublished study[23] which followed up with customers who bought refrigerators from manufacturers participating in Global LEAP results-based financing, 90% of refrigerator customers bought their product for use at their work place in order to improve their business, attract customers, and increase income. After purchasing their refrigerator, users increased their daily incomes by 2.5, on average, with half of them using their refrigerator to expand into new business lines such as food and drink sales. Another survey, which was conducted with M-KOPA customers using the Youmma refrigerator in rural Kenya, found that small businesses reported increased weekly income between US$1 to US$40 on average.[24] Despite these documented income increases, we estimate that, in most cases, refrigerator systems used for productive use only become viable at a payback period of six years or more.[25] This suggests that even when refrigerators are used for productive uses, further cost reductions are needed for customers to recover costs within a reasonable time.

20. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.
21. Efficiency for Access Coalition, The State of the Off-Grid Appliance Market Report, 2019.
22. Yasemin Erboy Ruff, How High-Performing Off-Grid Appliance Power the Sustainable Development Goals, 2019.
23. The study was unpublished due to a relatively small sample size of 121 respondents.
24. CDC Group, Innovation and product development: why some products take off and others don't, 2019.
25. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.

Research on the impacts of refrigerator ownership for households is limited, with some contradictory results arising from several initial efforts. The aforementioned study conducted with M-KOPA customers also found that households estimated saving on average US$4.82 per week from improved food storage and less time spent on trips to the market. Beyond increased savings, respondents reported a number of social benefits, including better diets, lower stress, increased convenience, and time savings estimated at two hours weekly.[26] By contrast, phone surveys conducted among off-grid refrigeration users as part of Global LEAP user surveys found that most customers did not experience notable changes in time savings or purchase volume, but the surveyed population was not exclusively focused on domestic applications.[27] These conflicting outcomes indicate that more research is needed to quantify the impact of household refrigerators.

Credit: Gavi Alliance

## TECHNOLOGY SPOTLIGHT 1

# OFF-GRID REFRIGERATION FOR LIFE-SAVING VACCINES

Refrigeration enables the storage and delivery of life-saving vaccines. During the COVID-19 pandemic, refrigeration and cold storage have become a key supply chain challenge. In areas where electricity is unreliable or unavailable and temperatures are higher, the challenge of keeping temperature-sensitive vaccines viable is even greater. While refrigerators intended for vaccine storage are not one of the main use cases for this brief, they are an important segment in weak- or off-grid regions.

The market for off-grid vaccine refrigerators operates in a highly evolved set of guidelines, with the WHO) and UNICEF formalizing the procurement processes for these products.[28] Given these design and quality requirements, the typical price can be upwards of US$2,000, but the vaccines they protect can be worth several times that amount and offer life-saving services.

For a long time, absorption refrigerators were the only option for vaccine storage in off-grid areas, but these products were unreliable and required a constant supply of fuel.[29] In the last 15 years, SDD refrigerators have emerged as a more reliable and durable option for vaccine storage. SDD refrigerators are powered directly by a solar panel without the need for a battery. This gives users in remote areas a more accessible energy source (solar) and improves durability by eliminating the need for a battery, which are expensive and typically need to be replaced every 3-5 years. They are able to maintain the temperature range necessary for vaccine storage, and can sustain those temperatures for long hours without solar energy.

26. CDC Group, Innovation and product development: why some products take off and others don't, 2019.
27. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.
28. Efficiency for Access Coalition, Off-Grid Refrigeration Technology Roadmap, 2019.
29. World Health Organization, Solar direct-drive vaccine refrigerators and freezers, 2017.

## Current Success and Remaining Challenges

Since the LEIA Technology Summary was developed in 2017, the off-grid refrigerator market has shown promising improvements in price, efficiency, and innovation, but more work needs to be done to bring these products to scale.

### Successes

**Overall product efficiency has improved by 12% in the last two years.**[30] Given their large energy requirements, efficiency is a key consideration for refrigerators to improve their affordability and environmental impact. With the falling prices of solar panels, there is some debate over the cost-effectiveness between buying more expensive, efficient refrigerators versus cheaper, less efficient refrigerators with larger solar panels. However, industry experts agree that higher efficiency, among other factors, is necessary to truly minimise purchase cost of the system.[31] Especially in countries where solar power systems are less affordable and/or taxes and duties on refrigerator appliances are low, refrigerator efficiency may be the most effective tool to reduce overall expenses.[32]

**Recent innovations in insulation, efficient compressors and better controllers are driving down prices, and improving efficiency and durability.** Efficiency improvements may be due in large part to R&D efforts and technology innovations from leading refrigerator manufacturers. These efforts are primarily done through manufacturers in-house or by donor-supported programmes, such as the Efficiency for Access R&D grant for cooling technologies.[33] Innovations such as Peltier Cooling (Technology Spotlight 2) can address key affordability and supply chain challenges, while permanent magnet motors and improved compressors are growing in scale and have the potential to improve refrigerator efficiency. For example, Youmma's Wisemotion Compressor delivers a low inrush current to help improve load management and system efficiency. Another new technology, digital inverter compressors, can increase efficiency and operate on AC or DC power, making them a viable option for households in weak-grid areas. While many of these product designs are still in development or early stages of implementation, they could be transformational for the off-grid market in the next several years as more companies adopt and adapt these technologies.

**Prices have improved for certain product segments, which could unlock more options for high performing products.** In the last two years, autonomy,[34] or the duration of time that a refrigerator can keep a sealed fresh food compartment under 12°C without input power, remained relatively constant across all refrigerator types. However, SDD

TECHNOLOGY SPOTLIGHT 2

# POTENTIAL OF PELTIER COOLING

Peltier coolers are a solid-state semiconductor that operates with no compressor, meaning that there are no moving parts with the exception of the fan. This technology offers several benefits when compared to compressor-based refrigerators. One of the main benefits of this technology is lower manufacturing costs and greater affordability due to the small number of parts. In addition, without refrigerants or a compressor, Peltier cooling refrigerators are easier to transport and can reach end-users more effectively. However, Peltier technology is less efficient than compressor refrigerators, and cooling performance is highly dependent on ambient temperatures, meaning that they're best suited for moderate climates. Efficiency for Access R&D Grantee Fosera has already started developing an off-grid refrigerator model that utilises Peltier cooling (Figure 4). More refrigerator manufacturers may adopt this technology in the coming years to drive greater affordability in the sector.

*Photo credit: Fosera*

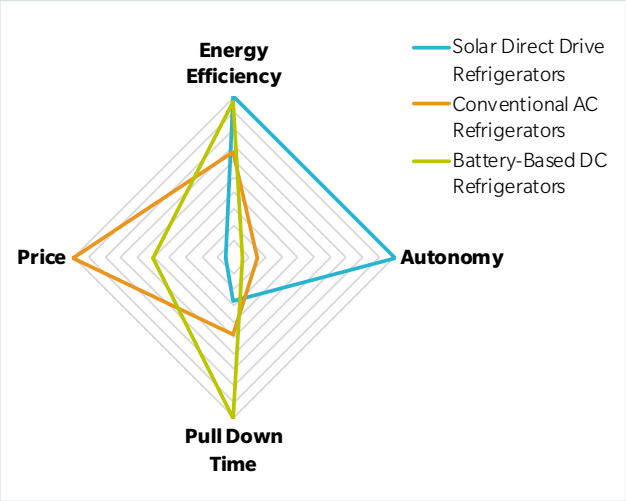
30. Efficiency for Access Coalition, Appliance Data Trends, 2021.
31. Efficiency for Access Coalition, Off-Grid Refrigeration Technology Roadmap, 2019.
32. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.
33. In 2019, the EforA R&D Fund launched its second call for applicants developing technologies and products for sustainable cooling in off- and weak grid areas, such as fans, refrigeration and cold chain. Learn more: https://efficiencyforaccess.org/cooling-call
34. Autonomy is a key metric to measure the cooling performance of off-grid refrigerators given that the power supply may be unreliable.

refrigerators performed particularly well, with an average autonomy time of 133 hours. This means that some units can cool food or beverages for roughly 5.5 days without power. Between 2017 and 2019, the average price index, or price relative to size, of SDD refrigerators decreased by 83%.[35] This is likely because in 2017, most SDD refrigerator manufacturers were designing their products to meet stringent WHO requirements for vaccine storage. Now, companies have started adapting their products for household and light commercial uses, which has helped bring down prices. With continued price improvements, more consumers will be able to access refrigerators delivering high-performing autonomy.

## Challenges

**Affordability remains the primary barrier to market growth, and requires balancing efficiency and performance in product design.** Although there have been encouraging efficiency and price improvements in recent years, and initiatives such as the Global LEAP results-based financing facility are working to deliver products at scale, manufacturers still struggle to identify the right balance between these key metrics and price. In addition, there are tradeoffs between performance, efficiency, and price dependent on the type of refrigerator (Figure 4). Given the price sensitivities of off-grid consumers, every incremental change to improve efficiency and performance, e.g. adding thicker insulation, needs to be worth the increased manufacturing and shipping costs. Refrigerators are also highly sensitive to ambient temperatures, meaning that cooling performance and efficiency are impeded by high temperatures common in off-grid regions. It costs manufacturers a significant amount to design a product capable of sustaining optimal cooling temperatures in high temperature areas, and for consumers in turn to run the product.

**Figure 4. Relative Performance and Price by Refrigerator Type[36]**




**Distribution and supply-chain challenges make it difficult to reach rural consumers.** Distributors new to the off-grid appliance market have reported having a hard time finding equipment manufacturers that sell high quality refrigerators at an affordable price. They also face difficulties bringing products into the market due to complicated supply-chain logistics. For example, many stakeholders incur high costs for product storage, shipment, and inventory management because of their size, mechanical complexity, and value.[37]

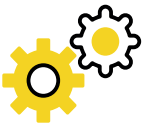
**Manufacturers face high VAT and duty rates in many countries.** Even if manufacturers bring down production costs, off-grid refrigerators cannot reach greater scale until high import duty rates are lessened. Varying duty rates across components and difficulty navigating information on local duties can also present complications for manufacturers when deciding how to ship and classify their products. For example, a refrigerator compressor shipped to Kenya could have a duty rate around 8.3%, whereas a fully assembled refrigerator could have a duty rate around 25%.[38] While local assembly could be one way to address this issue, there is limited information on the feasibility and costs associated with equipping local factories, assemblers, and technicians.

**Performance can vary significantly in lab versus field settings.** Initial results from refrigerator field testing suggest that refrigerators tested under real world conditions consume significantly more energy compared to those in a lab. In addition to refrigerator performance, limited evidence on the benefits, use cases, user behavior and viability of off-grid refrigerators makes it challenging to design products that meet users' needs and prioritize strategies for the entire sector. For example, as part of the 2017 Global LEAP Awards, Efficiency for Access installed 36 refrigerators in small retail shops across rural Uganda to monitor them in real world conditions and gather data on user behaviour and socioeconomic impacts. The results showed that 88% of refrigerators consumed more energy in the field than in the lab, with medium and large refrigerators in particular consuming on average 124% and 80% more energy respectively.[39] This was primarily due to use case and user behaviour; users tended to overload the refrigerator and frequently opened and closed the doors, thus resulting in higher energy consumption.[40] Having an accurate idea of energy consumption in the field is especially important when the rated power consumption is used to size the solar system, meaning that in reality the system would not be large enough to power the refrigerator.

35. Efficiency for Access Coalition, Appliance Data Trends, 2021.
36. The closer a refrigerator type is to the edge of the matrix, the better the performance or price. To perform this analysis, we used data from refrigerators available to on-grid consumers in Kenya (data taken from EPRA in November 2020) and products included in the VeraSol Product Database as of November 2020.
37. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.
38. Id.
39. Nya Abagi et al. ECEEE Summer Study, Catalyzing Technology Innovation in the Off-grid Market through Appropriate Product Performance Testing in the Laboratory and Field, 2019.
40. Efficiency for Access Coalition, Appliance Data Trends, 2021.

## Improve affordability

Compared to TVs, fans, and other smaller appliances, up-front payments for refrigerators are too high for most off-grid consumers. PAYGo and loans through local financing institutions, therefore, are likely to be the only viable route for growing the household refrigerator market.[41] However, lenders will have to tackle important ethical and practical decisions on how to grant or deny cooling access. Cutting off power or locking the system due to inability to pay could impact food safety and livelihoods. Another way to increase affordability is to build economies of scale, where refrigerator manufacturers can utilise the same key components (e.g. insulation, compressors) across different brands and refrigerator types.[42] Building out local supply chains, especially for distributors, may also bring down costs related to VAT and duties, and transportation.[43]



## Provide after-sales support

Product failure and warranty servicing are key challenges related to refrigerator usability, especially for consumers in rural areas. Given the technical complexity of refrigerators, customers need to be able to easily access technical support to help with repairs. Training of local technicians may be one way to solve this issue. It builds local capacity, helps distributors and manufacturers address challenges on-site, and fosters refrigerator reparability. Making sure key components, such as the compressor, are available locally can also reduce the time spent on repairs.[44]

## Promote field testing

Considering the high variance in performance and user behavior, field testing is important for nascent and complicated technologies like refrigerators. Field testing can also examine the costs and benefits of refrigerators within specific geographies or use cases to provide more accurate estimates of market viability. Efficiency for Access has started field testing refrigerators in India, Uganda, and Senegal, and developed a field testing best practice guide.[45] When possible, we recommend all market actors share and publish data from field testing, which can help educate and substantiate the reputation of the industry. The data can inform product design and test methods, and fill information gaps for the sector related to user behavior, socioeconomic impact, and use cases.

## Build consumer awareness

Manufacturers selling high quality, efficient off-grid refrigerators often have to compete with low quality, cheap AC refrigerators. Awareness-raising efforts should be applied to educate customers on the benefits and cost savings of using high quality, efficient refrigerators and their value proposition for small businesses as a productive use asset. In order to promote market sustainability, companies and distributors need to expand their efforts to train consumers on how to properly use and maintain their refrigerator.

41. Efficiency for Access Coalition, Off-Grid Refrigeration Technology Roadmap, 2019.
42. Id.
43. Efficiency for Access Coalition, Use Case and Cost Breakdown of Off-Grid Refrigeration Systems, 2020.
44. Id.
45. Publication is forthcoming.

## Enhance quality assurance

VeraSol[46] has laid the foundation for QA of off-grid refrigerators through test method development, product testing, and data sharing. It is also working with the IEC to support institutional adoption of the Global LEAP Off-Grid Refrigerator Test Method, which will better enable suppliers and reviewers to publish robust and useful performance data. As the market continues to develop, a sector-wide quality standards framework will support procurement programmes and financers in selecting high quality products. Policies and standards specifically for off-grid refrigerators are a first step to help manufacturers classify these products as solar and enable them to receive preferential VAT and duty treatments.

## Advance donor cooperation

Refrigeration constitutes one of the most mature instances of donor cooperation in the sector.[47] Nevertheless, donor-supported programmes are still needed to scale the market for efficient, affordable, and quality refrigerators. Until the market can reach scale, manufacturer-led R&D efforts that focus on efficiency and durability can lead to a more expensive product, and manufacturers may not be able to reap the benefits of this innovation in the short term. This suggests that the refrigerator market needs donor support in R&D until the market reaches greater maturity.

46. VeraSol is a quality assurance framework for solar energy kits (formerly Lighting Global Quality Assurance) and off-grid appliances and productive uses. Learn more: https://verasol.org/
47. Abagi, N., Erboy Ruff, Y., Smith, J.C. et al. State of play and innovations in off-grid refrigeration technology: lessons learned. Energy Efficiency 13, 307–322 (2020). https://doi.org/10.1007/s12053-019-09783-1

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