EVIDENCE BRIEF

Solar direct-drive vaccine refrigerators and freezers

Solar direct-drive (SDD) refrigerators and freezers can be a good option for vaccine storage in areas without reliable electricity, and many models are now WHO-prequalified. But with little information on SDD field performance currently available, making a case for investing in this new technology can be difficult.

This evidence brief provides supply chain managers in low- and middle-income countries with a summary of how recent SDD projects have performed, highlighting problems encountered and the steps that were taken to resolve them. An overview of how SDD technology works, and how to make sure that SDD technology is the right choice, is also provided.

Solar panels on the roof of Pelewa dispensary, Kenya. Photo: Catherine Silali.

The need for off-grid cooling options

For many years, refrigerators powered by gas or kerosene (known as absorption refrigerators) were considered the most appropriate option to store vaccine in areas without reliable electricity. However, various drawbacks with these devices have made keeping temperatures within the safe range for vaccines of +2°C to +8°C both difficult and expensive.

+ Ensuring a regular supply of gas or kerosene is expensive for immunization programmes in the long term.
+ Supplies of gas or kerosene are subject to interruption, and once on site they are vulnerable to diversion for other purposes.
+ Absorption refrigeration is less efficient than the compression-cycle technology that is used in electric refrigerators.
+ Keeping the temperature within the acceptable range of +2°C to +8°C for vaccines is difficult in absorption refrigerators.[1] There is a high risk of exposing vaccine to freezing temperatures.
+ Gas and kerosene refrigerators require frequent maintenance to keep them operating well.
+ Operating gas and kerosene refrigerators contributes to local air pollution and an increase in global greenhouse gas emissions.

In the 1980s, battery-powered solar refrigerators were introduced as a solution to these problems. But the batteries they rely on required frequent maintenance, had a lifetime of just three to five years, and quality replacements were expensive and often difficult to obtain.

[1] See: UNICEF. Compression and absorption type refrigerators and freezers for vaccine storage (http://www.unicef.org/supply/files/Compression_and_Absorption_Type_Refrigerators_and_Freezers_for_Vaccine_Storage.pdf).

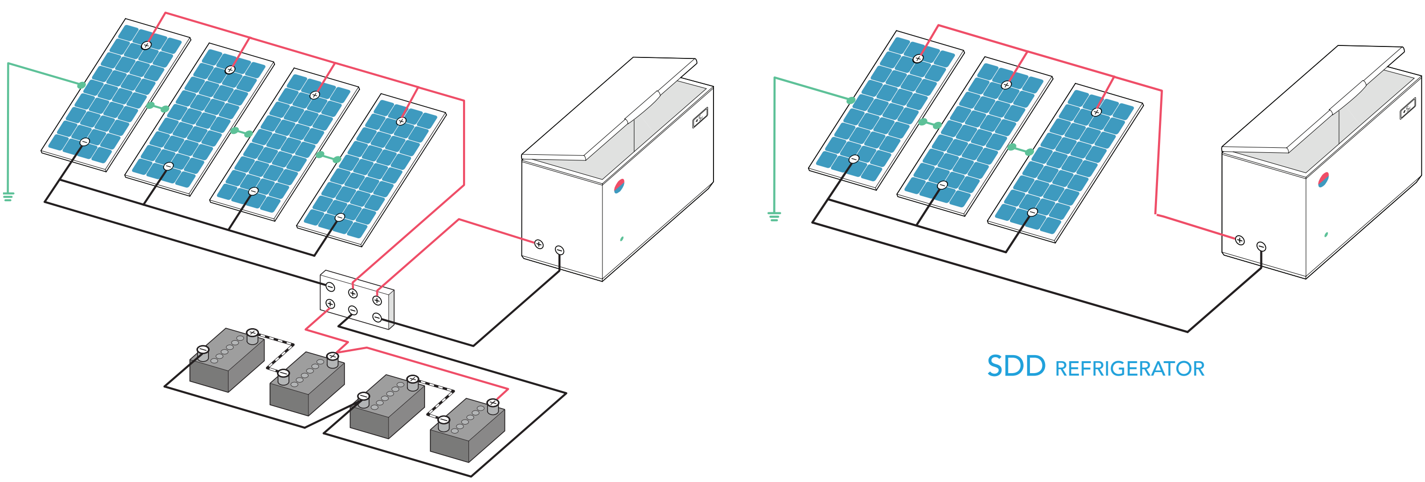
New solar technologies offer a solution

A new approach to solar refrigerator design has emerged, eliminating the need for expensive (and problematic) energy storage batteries used to power solar refrigerators. SDD technology uses solar energy to directly freeze water or other cold storage material and then uses the energy stored in the frozen bank to keep the refrigerator cold during the night and on cloudy days. These appliances include refrigerators, water-pack freezers and combined refrigerator water-pack freezers and are called solar direct-drive because they are wired directly to the solar array. This new technology has the potential to resolve many of the problems of off-grid vaccine refrigeration, enabling national immunization programmes to extend the cold chain into areas in the "last mile" that might otherwise be underserved.

Figure 1 illustrates the differences between solar battery-powered (left) and SDD (right) refrigerators.

FIGURE 1.

Differences between battery-powered and SDD refrigerators[2]



Reducing costs with solar technology

Because batteries are usually the most vulnerable component, and the most expensive part that needs regular replacement, removing them has the potential to increase the long-term success of solar vaccine refrigeration. Also, depending on the future cost of electricity and other key inputs, SDD refrigerators can compete with other types of refrigerator in terms of total cost of ownership.[3]

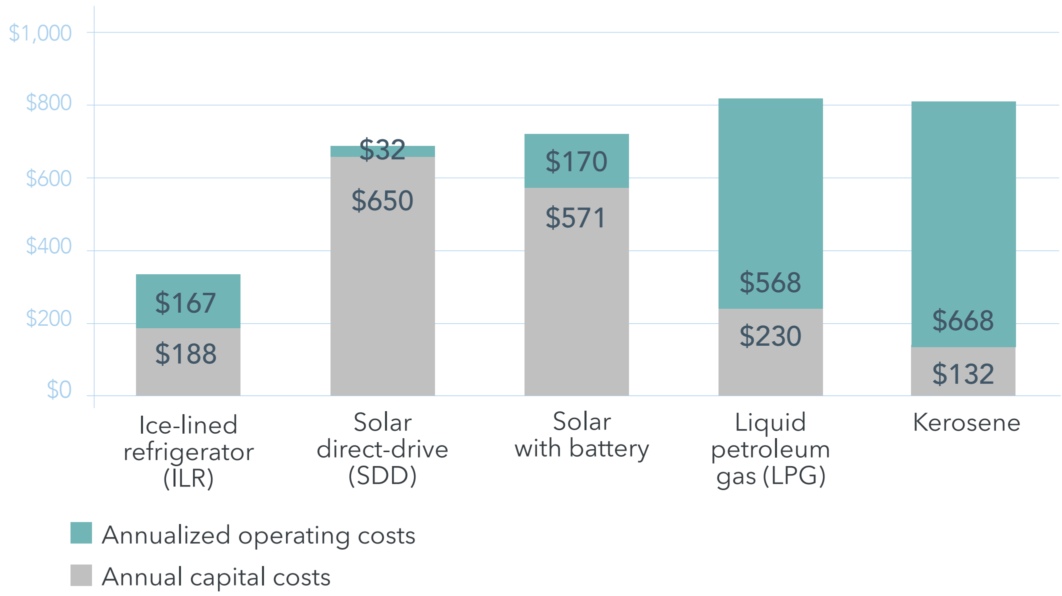
This is illustrated in Figure 2, which provides an example of how the annualized total cost of ownership of vaccine refrigerators may be compared, factoring for both capital costs and operational costs.[4] In this example, the mains-powered ice-lined refrigerator has the lowest annualized total cost of ownership, while the kerosene-fuelled absorption refrigerator has the highest annualized life-cost.

The SDD refrigerator would have the lowest total cost of ownership in areas with unreliable electricity and suitable solar irradiance, and where a solar service provider can be funded to provide the necessary support.

[2] Source: FGL/IM-PAHO and Solar Electric Light Fund.
[3] Total cost of ownership refers to all costs associated with owning and operating a unit of equipment over its useful life expectancy.
[4] Total Cost of Ownership Tool for Cold Chain Equipment, PATH (www.path.org/publications/detail.php?i=2576).

Example average estimated annualized cost of ownership of PQS prequalified refrigerator types (30-60L capacity)

FIGURE 2.



Protection from freezing

Vaccines are at risk of accidental freezing in the cold chain. Indeed, studies indicate that accidental freezing is pervasive and occurs across all segments of the cold chain.[5] To help address this problem, WHO now defines three grades of freeze-protection for vaccine refrigerators:

+ **Grade A** – User-independent freeze protection. The user does not need to perform any actions to protect vaccines from freezing temperatures. For example, such refrigerators do not require thermostat adjustments or storage in supplemental baskets or bins in order to protect vaccines from freezing. These refrigerators offer the greatest intrinsic protection to vaccines against the risk of freezing.
+ **Grade B** – User-dependent freeze protection. The user must perform one action to protect vaccines from freezing temperatures.
+ **Grade C** – User-dependent freeze protection. The user must perform more than one action to protect vaccines from freezing temperatures.

WHO prequalifies a comprehensive range of cold chain equipment, temperature monitoring devices, injection devices and other products needed for safe and effective immunization delivery. A catalogue of prequalified devices is available on the WHO Performance, Quality and Safety (PQS) website. For a full list of all WHO-prequalified solar-powered vaccine refrigerators and freezers, including their freeze-protection grading, refer to the PQS Catalogue.[6]

[5] Matthias DM, Robertson J, Garrison MM, Newland S, Nelson C. Freezing temperatures in the vaccine cold chain: a systematic literature review. Vaccine. 2007;25(20):3980–6. doi:10.1016/j.vaccine.2007.02.052.

[6] http://apps.who.int/immunization_standards/vaccine_quality/pqs_catalogue

Making sure that solar is the right choice

Before beginning the process of introducing solar vaccine refrigerators or freezers, the country should be sure that solar is the right choice. This can be done by asking the following questions.

Is sufficient solar energy available?

Many countries receive enough sunlight to justify the consideration of solar-powered vaccine refrigeration. However, many countries also have microclimates with limited sunlight at some times of the year. For example, most of Colombia receives sufficient solar irradiance for solar vaccine refrigeration, yet some mountainous areas and coastal regions have microclimates with prolonged cloud cover. In cloudy areas of the country, the choice of solar technology will be limited and its implementation will require careful design, like increased array size, to ensure adequate performance.

Is solar energy the most suitable option for vaccine cooling?

Continuous cooling is required for vaccine storage and, traditionally, this requires a reliable source of power for active refrigeration. When choosing a power source, various factors need to be considered. It is worth bearing in mind that even in locations with adequate solar energy, solar-powered refrigeration may not be the best choice for vaccine cooling. In addition to solar, other technologies offer solutions to the problem of unreliable electricity. Ice-lined refrigerators, for example, have long been used to provide adequate vaccine storage during extended power cuts.

More recently, passive storage containers have been developed that can keep vaccines cool without a power source like combustible fuel or electricity. The newest versions of these passive devices can provide a cold storage life greater than 30 days with a single load of frozen water-packs. Such devices offer a potential vaccine cooling option at sites with low-capacity vaccine storage needs and where no power is available.

The PQS Catalogue contains detailed guidance on selecting the most suitable vaccine cooling option based on a facility's energy source availability.

Is a solar service provider available (or will one be made available) to provide all necessary services?

A solar service provider is an essential component in the successful implementation of a solar vaccine refrigerator or freezer system. The solar service provider is a public or private sector organization whose staff are appropriately trained, equipped and capable of supporting a solar refrigerator or freezer system by providing all necessary services, including site assessments, equipment installation, user training, maintenance, troubleshooting and repair. These services can be provided either by a public sector organization (for example, the health ministry) or by private sector organizations (for example, a solar electricity company and consulting services provider), or by a combination of both.

Is secure and ongoing funding in place for the lifespan of the equipment?

The successful implementation of a solar vaccine refrigeration system requires both financial and technical support for early-phase activities, as well as long-term planning and funding. Although solar refrigeration systems, and in particular SDD systems, can alleviate many of the performance problems encountered with traditional absorption refrigerators, they still require regular maintenance and timely repair of equipment. Therefore, supply chain managers and other stakeholders must ensure that these requirements can be met at installation sites throughout the lifetime of the system.

Children posing beside solar panels, Colombia. Photo: Alex Adams Photography

SDD CASE STUDY 1.

United Republic of Tanzania

In the United Republic of Tanzania, only 28% of immunization health facilities have access to grid electricity.[7] Approximately 70% of health facilities rely on absorption refrigerators, which often expose vaccines to freezing temperatures and are vulnerable to gas or kerosene supply disruptions.

SDD technology offers a potential solution to these problems. However, until recently this technology had not been used in Tanzania, and it was unclear whether SDD refrigerators and freezers would function reliably across the country's diverse climate zones. To find out, in May 2014 the Tanzanian Immunization and Vaccine Department, the Clinton Health Access Initiative and UNICEF initiated a 12-month pilot project to evaluate three different SDD refrigerators in 17 health facilities across five climate-diverse regions of the country.

Installation of SDD vaccine refrigerator at Matamba health facility, Tanzania. Photo: Clinton Health Access Initiative.

In terms of temperature performance, all SDD refrigerators performed reliably without mechanical or electrical problems. Surveys found high levels of user satisfaction, mostly regarding the ease of SDD operation compared with absorption refrigerators. One facility even became a storage and distribution hub for nearby facilities when a gas shortage disabled the other local absorption refrigerators.

Conducted with government involvement throughout, this pilot highlighted the benefits of scaling up use of SDD refrigerators and factors to be taken into account when considering doing so, particularly as a replacement for absorption refrigerators. Through this evidence base, the United Republic of Tanzania has been able to make more informed procurement decisions for off-grid sites and address concerns about country-specific performance. Key lessons learnt include the following:

Site assessment is critical for successful SDD installation

Ahead of a large-scale deployment of SDD refrigerators, facility-level site assessments are critical to plan for key variables such as solar array mounting options, shading, facility space for the refrigerator, and other design considerations. Without this, technicians may encounter issues on installation day which they are not equipped to address, leading to delayed or interrupted deployment.

Technicians must be empowered through resource availability

Planning activities must take into account the time, tools and resources that technicians require to properly install an SDD refrigerator. For example, during the pilot, technicians relied on district health offices to provide ladders and source key resources locally (i.e. poles, cement, additional fixtures and fasteners, etc.). Minimizing the need for such last-minute installation-related procurements – and planning for those that cannot be anticipated – will be critical for ensuring smooth deployments in the future.

There is an appetite for power beyond the cold chain

Medical officers and users expressed their desire for electricity availability for purposes beyond vaccine refrigeration, particularly lighting that could be used to extend service hours. Emerging "energy harvesting" technologies being developed by manufacturers and global partners could serve this need well, by utilizing excess energy from the SDD for other health purposes, such as lighting, cell-phone charging, etc.

[7] Comprehensive cold chain assessment led by the Clinton Health Access Initiative (CHAI), 2013.

Colombia

It is often too costly to continuously operate absorption refrigerators in remote health centres. In Colombia's northern mountains, this means that some health centres have no refrigeration, and those that do can only afford to operate the refrigerator for one week a month, meaning that immunization services are unavailable for three weeks out of four.

Installation of solar panels at Sabana Crespo health facility, Colombia.
Photo: Alex Adams Photography

In early 2013, three WHO-prequalified SDD refrigerators, three SDD water-pack freezers, and one WHO-prequalified combined SDD refrigerator-freezer were deployed at four remote health posts in Colombia's northern mountains by the Wintukwa Institución de Salud del Pueblo Indigenous, with the support of the Solar Electric Light Fund.

Three years after installation, in September 2016, all SDD devices were reported as working well. In their first six months of operation, only one high temperature alarm was recorded (after investigation, it is believed that this was caused by a lid not being closed properly overnight). These SDD appliances have provided a continuous cold chain that has satisfied health facility needs for vaccine and medicine cooling, and have also provided the necessary ice-pack freezing to support outreach activities of up to three days. The Wintukwa Institución is now planning to deploy more SDD refrigerators at off-grid sites that rely on absorption appliances or lack refrigeration.

There are several reasons for the successes of the installations to date:

+ WHO-prequalified vaccine refrigerators were used in all installations and the solar power system complied with WHO PQS specifications.
+ Quality technical information was provided by the manufacturers prior to installation.
+ Pre-installation site assessments were conducted at all health centres (see below).
+ The installation was conducted by professionals, who in turn trained Wintukwa technicians at the time of installation.
+ Health workers received hands-on training with the installed equipment.
+ Maintenance supplies and tools were provided at all sites.
+ Adequate spare parts were provided and timely repairs were conducted.

Facilities that require solar refrigerators or freezers need to be individually assessed before the solar equipment can be installed. For this reason, each health post was assessed prior to establishing the final equipment specifications. The site assessor used a solar site assessment worksheet[8] to prepare for the installation and gather the necessary information. This ensured that all the required installation equipment had been ordered and that the technicians conducting the installation were fully prepared with the proper tools and supplies. For example, two sites required a pole mount, one site was roof-mounted and another used a ground mount. A shading analysis was also conducted to ensure that the SDD refrigerators and freezers would receive enough solar insolation to provide the required refrigeration. As a result of this thorough preparation, each installation was completed in one visit.

[8] A solar site assessment worksheet template is provided in: WHO–UNICEF, Introducing solar-powered vaccine refrigerator and freezer systems – A guide for managers in national immunization programmes (www.who.int/immunization/documents/9789241509862).

Kenya

Kenya has been installing SDD refrigerators at health facilities without reliable electricity since 2009. Several hundred have already been installed, and this number is expected to rise to several thousand within the next few years.

In 2016, the National Ministry of Health brought together 46 technicians from 47 counties for a five-day cold chain maintenance workshop in Nairobi. During the workshop, equipment manufacturers conducted model-specific installation and maintenance training. Following the workshop, technicians demonstrated increased confidence and knowledge in performing SDD refrigerator maintenance. However, 46 technicians cannot manage cold chain failures in almost 6000 health facilities. Additional capacity building is required, and therefore a similar workshop is planned for 2017.

To date, health facility nurses and technicians have expressed satisfaction with the performance of the new SDD refrigerators, citing their minimal repair and maintenance requirements after installation. No major breakdowns have been reported, while the total cost of ownership for SDD refrigerators installed in 2009 and 2013 has compared favourably to the gas and electric refrigerators used previously.

An SDD vaccine refrigerator installed at Pelewa dispensary in Kadiajo, Kenya. Photo: Catherine Silali.

The installation of solar panels on health facility roofs caused various problems at multiple facilities.

+ Water was found to accumulate on some solar panels due to incorrect installation.
+ Solar panels were sometimes blown off roofs by heavy winds. Poor installation and not using the right tools and materials were identified as the causes of these failures.
+ Some solar panels were stolen from health facilities. Better training on installation techniques, utilizing secure screws, is required to prevent these losses.

In addition, solar panels quickly became dusty, and without adequate cleaning their efficiency was reduced. Key lessons learnt include the following:

Good communication between countries and manufacturers is important

A streamlined post-procurement communication mechanism should be established to enable countries to communicate directly with manufacturers, without necessarily going through procurement agencies in the country.