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Using solar-powered refrigeration for vaccine storage where other sources of reliable electricity are inadequate or costly in Nigeria

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ABSTRACT

Large areas of Nigeria have no grid electricity. This is a serious challenge that threatens the continuity of the vaccine cold chain. The main alternatives to electrically powered refrigerators available for many years—kerosene - and gas-driven refrigerators—are plagued by problems with gas supply interruptions, low efficiency, poor temperature control, and frequent maintenance needs. There are currently no diesel- or gas driven refrigerators that qualify under the minimum standards established by the World Health Organization (WHO) Performance, Quality, and Safety (PQS) system. Solar refrigeration was a promising development in the early 1990s, providing an alternative to absorption technology to meet cold chain needs in remote areas.

Devices generally had strong laboratory performance data; however, experience in the field over the years has been mixed. Traditional solar refrigerators relied on relatively expensive battery systems, which have demonstrated short lives compared to the refrigerator. There are now alternatives to the battery-based systems and a clear understanding that solar refrigerator systems need to be designed, installed, and maintained by technicians with the necessary knowledge and training. Thus, the technology is now poised to be the refrigeration method of choice for the cold chain in areas with no electricity or extremely unreliable electricity (less than 4 h per average day) and sufficient sunlight. This paper highlights some lessons learned with solar-powered refrigeration, and discusses some critical factors for successful introduction of solar units into immunization programs in the future including: Sustainable financing mechanisms and incentives for health workers and technicians are in place to support long-term maintenance, repair, and replacement parts. System design is carried out by qualified solar refrigerator professionals taking into account the conditions at installation sites. Installation and repair are conducted by well-trained technicians. Temperature performance is continuously monitored and protocols are in place to act on data that indicate problems.

Introduction

Using sunlight to produce cooling is a long-sought goal. Intuitively, the need for cooling is proportional to the solar intensity, thus nearly matching the time of peak cooling demand with the time of maximum sunlight. Given this close coincidence between resource and need, it is no wonder then that considerable effort has been devoted to producing economical solar cooling technologies. Large areas of Nigeria have no grid electricity. The International Energy Agency estimates that 1.3 billion people lacked access to electricity in 2010, more than one-fifth of the world's population (IEA, 2012). Some 85 percent of those without electricity live in rural areas, where there is no distribution grid for electricity, nor prospects of the grid reaching them in the near future. This is a serious challenge that threatens the continuity of the vaccine cold chain.

Alternatives to electrically powered refrigerators have been available for many years, but diesel- and gas driven "absorption" refrigerators have not kept up with the new, more stringent WHO PQS requirements while solar-powered electric compression-type refrigerators have continued to innovate and do meet standards established under the WHO PQS system. For the last 35 years, areas with insufficient power supply for electric refrigerators have been mostly supplied with absorption-type refrigerators, the majority of which burn diesel or bottled liquid petroleum gas to drive the cooling cycle. These fuels are polluting and suffer from supply interruptions due to numerous reasons including poor planning, fuel shortages, diversion for other uses, and theft.

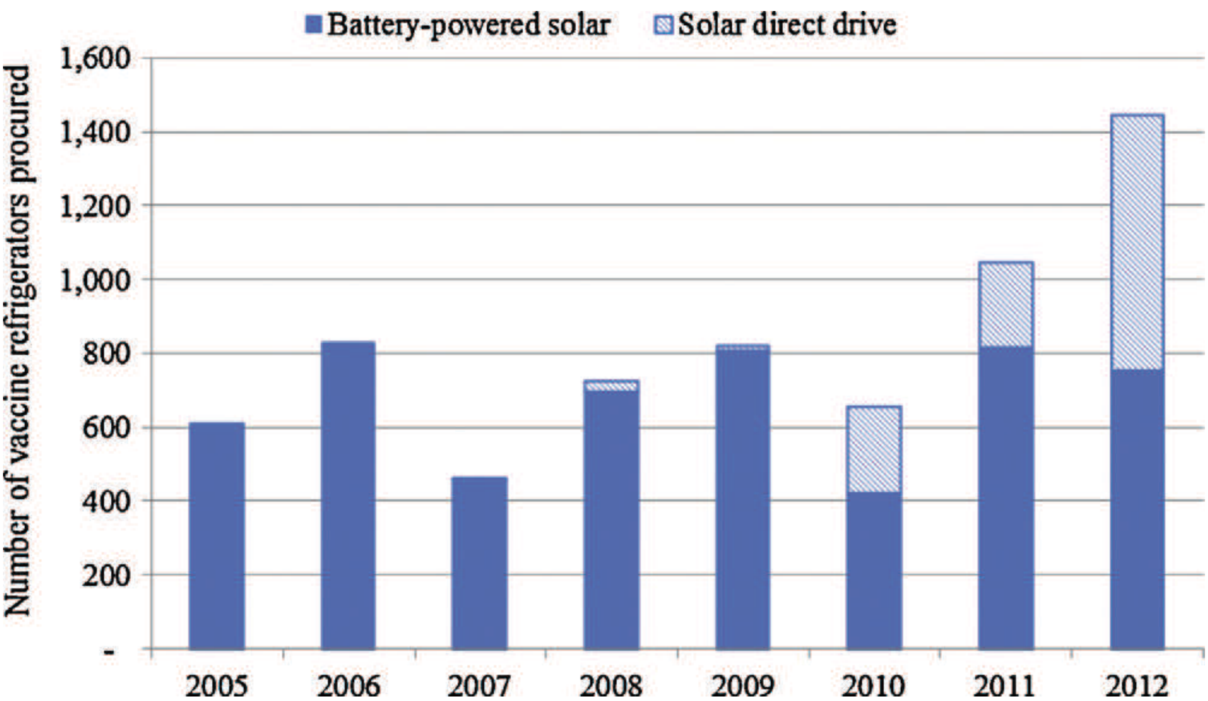

Fig. 1: Solar refrigerators supplied by UNICEF

Absorption refrigerators also suffer from low efficiency, poor temperature control, frequent maintenance needs, and limited ice-making capacity (world Health Organization, 2012). In the early days of vaccine cold chain design in developing countries, absorption devices were widely used because there were no other readily available options at a similar cost, and countries anticipated that grid electricity would soon be distributed to rural areas, providing a reliable and affordable source of energy for compression-type refrigerators. However, given the low-population densities, minimal consumer loads, and steeply rising costs associated with rural electrification, it is often not an economically viable option. As a result, absorption refrigerators continue to be used today in more than 60 percent of vaccine storage locations in spite of their shortcomings in providing safe and appropriate storage for vaccines. However, the vaccine refrigerator market has changed.

2. Review of in-state experience—challenges

Since 2005, UNICEF has supplied more than 950 solar-powered vaccine refrigerators (6048 were battery based and 119 were direct drive), with the greatest number supplied to Nigeria (see Fig. 1). There have been a number of challenges constraining the performance and reliability of solar vaccine refrigerators. Four challenges listed below are drawn from a review of Nigeria experience and are each discussed in the following sections:

•Inadequate system design and installation quality. •Maintenance and spare parts supply not addressed.

•Inappropriate use .

•Lack of feedback on field performance.

2.1. Inadequate system design and installation quality

Most of the refrigerators supplied by UNICEF have been prequalified by WHO under the PQS standards. In addition to prequalifying refrigerators, the PQS division at WHO sets standards for solar power-generating systems and identifies qualified suppliers who are recommended to supply combined refrigerator and solar power systems. Qualified suppliers must meet certain minimum levels of expertise and experience. This list of qualified suppliers is available from WHO and can be accessed by countries doing their own procurement. According to reports from the field, some of the most common problems relating to system design and installations are: designers lack data, poor system sizing and poor installation.

2.2. Maintenance and spare parts supply not addressed

Maintenance challenges have been mainly of three types:

•Failure of the users to properly care for the system, with simple maintenance tasks such as regular cleaning of the solar array and topping up battery cells with distilled water

.•Lack of local qualified electrical technicians to diagnose failures and to repair systems and funding for training over time.

•Lack of a plan or source of funding to purchase the correct spare parts, in particular to replace batteries as needed over the life time of the system.

Despite best-practice guidelines, the main cause of these solar refrigerator problems can be attributed to the lack of necessary budget and planning for long-term maintenance.

2.3. Inappropriate use

Three abuses of the system remain the most problematic. First, solar modules are susceptible to theft. Although features exist to combat theft, such as mounting modules on tall poles, fastening them with theft deterrent hardware, and/or integrating them into the roof structure, not all solar systems include these security features. Theft deterrent fasteners are required by PQS, but more effective theft proofing such as roof integration is typically expensive except in the case of new construction, and poles are not usually procured with a system as they add cost and transport bulk. Second, refrigerators have been used for personal purposes (e.g., storing food and drinks). Introduction of additional thermal mass affects the internal temperatures of the refrigerator, which may negatively affect the integrity of the vaccines stored inside

(WHO,2011). Finally, power has been diverted from batteries for other uses (e.g., lights in the facility or televisions in nearby homes).

2.4 Lack of feedback on field performance

An overarching challenge with both battery-based and direct-drive refrigerators has been the lack of funding and commitment to post-market surveillance of these products in the field. Without this information, manufacturers and other system designers cannot make improvements to their equipment that respond to the needs of users in the field. Field reports often describe only the first years of a program – there is very limited documentation on longer-term performance (WHO,2011).

3. Responding to challenges

3.1. Technology advances to improve performance

The first generation of solar refrigeration systems was designed to store energy in batteries to maintain refrigeration during the night and on days with reduced sunlight. A majority of published reports on solar powered vaccine refrigerator failure have involved the battery system (McCamey,1990 and WHO,2011). This reliance on costly, special-purpose, imported batteries that often have a service life of five years or less has presented a major parts replacement problem for countries. In addition, other major components of a typical PQS battery system such as a battery-charge regulator, electric cabling, lockable and vented battery enclosure, fusing or other over-current protection devices are also susceptible to failure.

3.2. Benefits of solar refrigeration

Solar-powered refrigeration has demonstrated four main benefits for the vaccine cold chain relative to absorption refrigeration fueled by diesel and gas. First, laboratory testing has confirmed higher performance on several critical parameters, most importantly temperature control. Second, system reliability has been adequate where WHO PQS recommendations have been respected and regular maintenance and repair service have been sustained. Third, the lifetime cost of direct-drive solar remains lower than absorption refrigeration and is increasingly competitive with grid-powered systems (Hassan et al, 2012).

3.2.1. Solar refrigerator temperature performance is superior

Laboratory testing has shown that the standard of temperature control in solar compression refrigeration is higher than kerosene or gas absorption refrigeration (WHO unpublished confidential data). Control remains within a narrower temperature range and with fewer excursions outside the recommended range. With current PQS-qualified direct-drive solar refrigerators, during periods of low sun, the autonomy of the systems (the time that the refrigerator can continue to cool the vaccine compartment under poor solar conditions such as heavy cloud and rain) is at least three days and as long as ten days in some models—considerably better than the 5 hours of cold life achieved by absorption systems when fuel is not avail-able (Nasir,2001).

3.2.2. System reliability has been adequate

Though there have been many challenges with solar equipment, on average these systems have performed adequately in the Expanded Program on Immunization system. The potential working life of solar refrigeration systems is ten years or longer. Given that there is no battery to replace, solar modules are generally warrantied for 20–25 years, and refrigerators can be made to last longer than ten years if well maintained. In the mid-1990s, experience in four states had shown an average mean time between failures
for solar refrigerators of 3.5 years. WHO expressed that although 3.5 years between failures was a good result, they hoped that time between failures would increase given the high investment costs of these refrigerators (Hassan et al 2012).

3.2.3. Annualized total cost is lower

In addition to the development of solar direct-drive refrigerators, which eliminates the cost of the battery, solar refrigerator buyers are also benefitting from the global decrease in solar module price. Between 2008 and 2011, the average cost of solar modules, measured in price per Watt peak, decreased from approximately US$5.5 per watt to $2.3 per watt (Muhammadu,2013). The assumptions was made in the cost comparison model: With typical maintenance and repair, all refrigeration units will last ten years. Total average purchase price, installation, operating, maintenance, and repair costs are amortized over ten years at a 3 percent discount rate.

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4. Conclusion

The performance of solar refrigerators is sufficient for vaccine storage even in a very hot climate, given appropriate equipment selection and proper installation. The second-generation, solar direct-drive systems are more economical to purchase and operate and may be more reliable than their battery-based predecessors due to decreased technical complexity. Solar refrigeration is also already well aligned with future policies to provide solar electrification to rural communities and health facilities in a decentralized way (Muhammadu,1998). As broader introduction of solar electrification gets underway, vaccine refrigerators could easily be connected straight into this new electric infrastructure. Thus, there are sound reasons to mainstream their use in the vaccine cold chain where there is no electricity or electricity cannot be reliably supplied.

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