Cold Chain Equipment Market landscape

UNICEF presentation

Discussion document
Oct 2nd, 2013
Contents

▪ Underlying issues
  ▪ Market segmentation
There are 4 critical cold chain equipment gaps that cap immunization coverage

Total health posts targeted for CCE

**Thousands**

<table>
<thead>
<tr>
<th>Equipment Gap</th>
<th>Count</th>
<th>Current Challenges</th>
</tr>
</thead>
</table>
| Unequipped facilities | 23 | Many facilities that should have cold chain equipment (based on government plans) are **not equipped today**  
  - **Nigeria**: <20% of 11,500 target facilities currently equipped |
| Non-functional equipment | 23 | Much of equipment which does exist is **non-functional or not installed** (e.g., due to poor maintenance) |
| Undesirable technology | 56 | Significant portion of installed base is absorption, solar with battery, or domestic refrigerators with significant issues:  
  - **Expensive to run**  
  - **Unreliable**  
  - **Inadequate holdover**  
  - **Risk to efficacy of vaccines** due to poor temperature control (e.g., freezing, etc.) |
| Acceptable, but sub-optimal technology | 32 | Smaller portion of installed base are ILRs and SDDs that:  
  - **Do not meet facility needs** (e.g., 50% of facilities need <15L capacity, but most too large)  
  - **Are of some risk to efficacy of vaccines** (risk freezing if user does not pack refrigerators correctly) |

1 Extrapolated data from 7 countries representing >50% of GAVI birth cohort
These gaps are caused by 4 underlying issues

<table>
<thead>
<tr>
<th>Issue</th>
<th>Description</th>
</tr>
</thead>
</table>
| 1 | Poor understanding of cold chain needs | ▪ No understanding of real user-needs and how these vary within and across countries  
▪ No view on how segments will evolve in coming years |
| 2 | Inadequate supplier engagement | ▪ No clear articulation of target product profiles  
▪ Conflicting messaging to suppliers  
▪ No real engagement to improve designs or lower costs |
| 3 | Poor country decision making | ▪ Countries don’t have fact base to make decisions  
▪ Focus on capital cost rather than total system cost  
▪ No maintenance networks, leading to high failure rates |
| 4 | Fragmented and ineffective F&P | ▪ Significant funding gap until 2020  
▪ No incentive to purchase high-performing devices  
▪ Not leveraging combined scale to shape market |
## Expected Outcomes: Ambitious but Realistic

<table>
<thead>
<tr>
<th>From . . .</th>
<th>To . . .</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>System cost</strong></td>
<td></td>
</tr>
<tr>
<td>Percent of vaccines lost to heat:</td>
<td>▪ 1-3%</td>
</tr>
<tr>
<td>Equipment price variation:</td>
<td>▪ &gt;60%</td>
</tr>
<tr>
<td>Total spend requirement through 2020¹:</td>
<td>▪ ~$1,150M</td>
</tr>
<tr>
<td>Costly absorption fridges:</td>
<td>▪ &gt;35%</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td></td>
</tr>
<tr>
<td>Facilities equipped with CCE:</td>
<td>▪ ~33%</td>
</tr>
<tr>
<td>Non-functioning equipment:</td>
<td>▪ ~20%</td>
</tr>
<tr>
<td><strong>Efficacy</strong></td>
<td></td>
</tr>
<tr>
<td>Freeze exposure at health post:</td>
<td>▪ 20-25%</td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
<td></td>
</tr>
<tr>
<td>Cold chain equipment inventory and performance</td>
<td>▪ Limited, ad-hoc</td>
</tr>
</tbody>
</table>

¹ New funds necessary to fill gaps, but assumes procurement improvements made
² In-line with best practices, e.g., Village Reach in Mozambique
Findings were based on extensive research and analysis

**Interviews with global experts on cold chain, health systems, and country infrastructure**

- Global institutions
  - World Health Organization
  - UNICEF
  - GAVI Alliance
  - The World Bank

- Other partners and NGOs
  - PATH
  - JSI
  - John Snow, Inc.
  - VMI
  - Clinton Health Access Initiative

- 30+ expert interviews

**Furthered country research to understand health system structure and evolution, assess user needs**

- Primary country research
  - Visited India and Tanzania, team in Nigeria

**Enhanced database & modeling of facility catchment and electrification & cold chain inventory**

- Cold chain inventories
  - Detailed cold chain data
  - CCEM data in 6 countries, incl. India
  - UNICEF cold chain inventory data in Nigeria and DRC, Tanzania MoH facility data

- Electrification
  - Infrastructure expert perspective on evolution of electrification
  - World Bank data on country access and outages
  - Country data

**Interviews with in-country officials and experts**

- Donors
  - Canada
  - John Snow, Inc.
Contents

- Underlying issues
  - Market segmentation
    - Small off-grid
About 50% of facilities are expected to remain functionally off-grid in the foreseeable future

Historically, access to electrification has increased at ~1% per annum . . .

Household electrification rate
Percent


Nigeria
Zimbabwe
All SSA
Ethiopia
Tanzania
Malawi

. . . if that continues a significant portion of facilities are expected to remain off-grid through 2020

Projected electrification status of facilities in 2020
Percent

Off-grid
- No mains access

~50% functionally off-grid

Minimal mains
- <8 hours of electricity per day, or power cuts >48 hours

Moderate mains\(^3\)
- 8-22 hours of electricity per day, power cuts <48 hours

Reliable mains
- >22 hours of electricity per day

~50% on-grid

Countries currently investing in generation capacity\(^1,2\) rather than distribution

1 Multiple country EPI officers, National energy policy makers, and infrastructure experts in Ethiopia, Kenya, Congo, Pakistan, Bangladesh, Tanzania, Nigeria, and India
2 Other sources included past electrification trend data and infrastructure investment reports
3 World Bank data surveyed firms in Nigeria, Zimbabwe, Uganda and Tanzania
There is a clearly preferred technology for on-grid facilities, but multiple options exist for off-grid facilities

<table>
<thead>
<tr>
<th>Segment</th>
<th>Current technologies</th>
<th>Emerging technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-grid</td>
<td><strong>Domestic refrigerator</strong></td>
<td><strong>Next gen ILR</strong></td>
</tr>
<tr>
<td></td>
<td>▪ Poor temperature control</td>
<td>▪ User independent “no-freeze”</td>
</tr>
<tr>
<td></td>
<td>▪ No-holdover</td>
<td>▪ Moderate to extended hold-over</td>
</tr>
<tr>
<td></td>
<td><strong>1st gen ILR</strong></td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Risk freezing vaccines</td>
<td></td>
</tr>
<tr>
<td></td>
<td>▪ Limited</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Absorption fridge</strong></td>
<td><strong>Next gen SDD</strong></td>
</tr>
<tr>
<td>Functionally off-grid</td>
<td>▪ Expensive to operate</td>
<td>▪ Affordable, low maintenance</td>
</tr>
<tr>
<td></td>
<td>▪ High risk of freezing</td>
<td>▪ User independent “no-freeze”</td>
</tr>
<tr>
<td></td>
<td>▪ Prone to gas shortages</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Solar with battery</strong></td>
<td><strong>Passive devices</strong></td>
</tr>
<tr>
<td></td>
<td>▪ Very expensive</td>
<td>▪ Cost effective for low capacities</td>
</tr>
<tr>
<td></td>
<td>▪ High risk of failure</td>
<td>▪ Minimal install and maintenance</td>
</tr>
<tr>
<td></td>
<td>▪ High maintenance requirement</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>Thermo-electric</strong></td>
<td><strong>Thermo-electric</strong></td>
</tr>
<tr>
<td></td>
<td>▪ Cost effective for low capacities</td>
<td>▪ Cost effective for low capacities</td>
</tr>
<tr>
<td></td>
<td>▪ Very low maintenance</td>
<td>▪ Very low maintenance</td>
</tr>
</tbody>
</table>
Two of the three off-grid technologies do not easily scale above 15L in storage capacity

### Device capacity

<table>
<thead>
<tr>
<th>Technology option</th>
<th>0</th>
<th>&lt;5L</th>
<th>10L</th>
<th>15L</th>
<th>20L</th>
<th>...</th>
<th>50L</th>
<th>100L+</th>
</tr>
</thead>
<tbody>
<tr>
<td>Next gen SDD</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive device</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermo-electric devices</td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

### Implications

- Off-grid facilities requiring <15L can use all off-grid technologies including SDDs
- Facilities > 15L can only use SDDs
- Important to understand what portion of off-grid facilities require <15L capacity

1. >15L Passive device loses mobility and ability to easily access vaccines
2. >15L TE devices not cost competitive with SDDs
Due to technology size limitations it is important to understand which facilities require <15L fridge capacity, a function of three main factors:

<table>
<thead>
<tr>
<th>Factors</th>
<th>VFIC</th>
<th>Facility catchment population</th>
<th>Vaccine delivery frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume per fully immunized child (VFIC)</td>
<td>Number of target children immunized annually by a facility</td>
<td>Number of times vaccines are shipped to a facility</td>
<td></td>
</tr>
</tbody>
</table>

**Key drivers**

- **Vaccine program design:**
  - Vaccination schedule, and buffer stock
  - Additional space required to allow for effective fridge packing

- **Immunization program architecture:**
  - Number of health facilities
  - % of facilities with cold chain equipment

- **Supply chain:**
  - Resupply schedule of vaccines and reliability of resupply

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1 Fridge capacity as noted is max capacity required, not average
Volume per fully immunized child (VFIC) is driven by future immunization schedules and immunization program design.

Vaccination schedule including future vaccines:
- 400 cc
- 125 cc

Other program factors, including buffer stock, wastage, and non-vaccine commodities:
- 400 cc
- 105 cc
- 130 cc

Additional space required to allow for effective fridge packing:
- 40 cc

Expansion in the local catchment area due to population growth:
- 40 cc

Vaccine volume per fully immunized child (includes secondary packaging) cc:
- 84-173 cc
- 19 cc
- Others
- TT, MR, JE/Men, YF, Typh, BCG
- Most likely volume is 125 cc

VFIC:
- 400 cc
- 125 cc
- 105 cc
- 130 cc
- 40 cc

Rota
- 34 cc

PCV
- 14-47 cc

Penta
- 8-39 cc

HPV
- 7-23 cc

IPV
- 2-10 cc

Others
- 19 cc

Total
- 84-173 cc
Other volume drivers: facility catchment size varies widely, but target delivery frequencies are very consistent

- Number of children immunized at the facility annually varies dramatically between and within countries based on immunization program structure
  - E.g., # of health posts, % of health posts with CCE

**Distribution of current facility catchment populations**

<table>
<thead>
<tr>
<th>Facility catchment population</th>
<th>Vaccine delivery frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fridge capacity</td>
<td>VFIC</td>
</tr>
</tbody>
</table>

- Target delivery frequency is **1x / month** for most facilities

**Delivery frequency of vaccines to facilities**

<table>
<thead>
<tr>
<th>Percent of facilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipped facilities =</td>
</tr>
<tr>
<td>1,000+ children</td>
</tr>
<tr>
<td>500-1,000 children</td>
</tr>
<tr>
<td>&lt;500 children</td>
</tr>
</tbody>
</table>

- **Equipped facilities** = ~28,000, ~1,500, ~5,000
- **India**
  - 1,000+ children: 27%
  - 500-1,000 children: 49%
  - <500 children: 24%
- **Nigeria**
  - 1,000+ children: 36%
  - 500-1,000 children: 18%
  - <500 children: 46%
- **Tanzania**
  - 1,000+ children: 5%
  - 500-1,000 children: 93%
  - <500 children: 90%

**Examples**

- **ESTIMATE**
  - > Monthly: 10%
  - Monthly: 90%
~60% of functionally off-grid facilities will need <15L of fridge capacity in 2020

Base case scenario

- 400cc per fully immunized child
- 67K equipped off-grid facilities based on current plans through 2020
- Vaccines are delivered monthly

Cumulative percent of off-grid facilities\(^1\) by fridge capacity required

- <8L: 42%
- <15L: 61%
- <30L: 83%
- <50L: 92%
- <250L: 98%
- >250L: 100%

1 Based on baseline volume of 400CC per FIC, and includes off-grid and minimal mains facilities

SOURCE: CCEM; NPHCDA; Tanzania MoH; team analysis
Most off-grid facilities <15L under a range of scenarios, implying a large portion of facilities can make use of new technologies
Cumulative percentage of off-facilities by capacity required

<table>
<thead>
<tr>
<th>Scenario</th>
<th>&lt;8L</th>
<th>&lt;15L</th>
<th>&lt;30L</th>
<th>&lt;50L</th>
<th>&gt;50L</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base case¹</td>
<td>42</td>
<td>61</td>
<td>83</td>
<td>92</td>
<td>100</td>
</tr>
<tr>
<td>Reducing VFIC to 150cc</td>
<td>68</td>
<td>81</td>
<td>93</td>
<td>97</td>
<td>100</td>
</tr>
<tr>
<td>Increasing VFIC to 600cc</td>
<td>31</td>
<td>49</td>
<td>74</td>
<td>87</td>
<td>100</td>
</tr>
<tr>
<td>Doubling delivery frequency (2x per month)</td>
<td>61</td>
<td>77</td>
<td>92</td>
<td>96</td>
<td>100</td>
</tr>
<tr>
<td>2x the number of equipped health posts</td>
<td>61</td>
<td>83</td>
<td>92</td>
<td>95</td>
<td>100</td>
</tr>
</tbody>
</table>

1 VFIC 400cc, monthly delivery, ~67k off-grid facilities

- The majority of equipped, off-grid facilities require <15L capacity in all scenarios
- New technologies apply to a broad number of facilities
Summary: anticipated 2020 market segmentation and key technologies

2020 GAVI health care facility segmentation
Percent, N = 134,000 facilities in 57 countries

<table>
<thead>
<tr>
<th>Capacity</th>
<th>Grid access</th>
<th>Source: CCEM; NPHCDA; Tanzania MoH; team analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;15L, off-grid</td>
<td>13%</td>
<td></td>
</tr>
<tr>
<td>&lt;15L, off-grid</td>
<td>26%</td>
<td></td>
</tr>
<tr>
<td>Off-Grid</td>
<td>Minimal mains (&lt;8 hours)</td>
<td>4%</td>
</tr>
<tr>
<td>Moderate mains (8-22 hours)</td>
<td>42%</td>
<td></td>
</tr>
<tr>
<td>Reliable (&gt;22 hours)</td>
<td>9%</td>
<td></td>
</tr>
</tbody>
</table>

Primary technology options

i. >15L, off-grid and minimal mains
- 2nd generation solar (SDD):
  - Total facilities: ~25k
  - Annual demand: 2.5k

ii. <15L, off-grid and minimal mains
- Various small devices (e.g., SDD, passive or thermoelectric):
  - Total facilities: ~40k
  - Annual demand: ~4k

iii. Moderate mains and reliable
- 2nd generation ice-lined refrigerator (ILR):
  - Total facilities: ~67k
  - Annual demand: ~6.7k

1 Based on baseline volume of 400cc per FIC, includes India
2 "Moderate mains": at least 8 hours per day, longest power cuts <48 hours
Examples facilities within each segment highlight how different facilities require very different technologies

i. >15L, off-grid and minimal mains

2nd generation solar (SDD):

Minawa Health Clinic
- Katsina, Nigeria
- Off-grid, serves ~2,400 children (~80L)

ii. <15L, off-grid and minimal mains

Various small devices (e.g., SDD, passive or thermoelectric):

Mahumbika Health Clinic
- Lindi District, Tanzania
- Off-grid, serves ~200 children (~6.5L)

iii. Moderate mains and reliable

2nd generation ice-lined refrigerator (ILR):

Fulpada Primary Health Center
- Gujarat, India
- On-grid, serves ~2,200 children (~75L)

- Countries have very different facilities and program architectures
- Countries will need technologies to match needs of various facilities
Countries vary in terms of their infrastructure and it will be critical that they make nuanced decisions based on their situation.

Selected examples:

- **India: low density, mostly on grid**
  - Other similar countries: Pakistan, Vietnam

- **Kenya: high density, mostly on-grid**
  - Other similar countries: Cameroon, Chad, Haiti, Senegal, Zambia, Zimbabwe

- **Malawi: low density, partial grid**
  - Other similar countries: Afghanistan, Bangladesh, DRC

- **Nigeria: on grid but highly minimal mains**
  - Other similar countries: Cambodia, Ethiopia, Madagascar, Yemen

- **Tanzania: high density, mostly off-grid**
  - Other similar countries: Rwanda, Somalia, South Sudan

- **Uganda: medium density, mostly off grid**
  - Other similar countries: Pakistan, Vietnam

Countries vary in terms of their infrastructure and it will be critical that they make nuanced decisions based on their situation.

SOURCE: CCEM; NPHCDA; Tanzania MoH; team analysis
Contents

- Underlying issues
- Market segmentation
  - Small off-grid
### Small Off-grid – Multiple devices

For <15L off-grid facilities, there are trade-offs between the different devices

<table>
<thead>
<tr>
<th></th>
<th>Cost</th>
<th>Install and maintenance</th>
<th>Outreach support</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDD</td>
<td>High</td>
<td>Expensive; requires trained tech</td>
<td>Can integrate freezer (compartment or standalone)</td>
<td>High</td>
</tr>
<tr>
<td>TE</td>
<td>Medium</td>
<td>Potentially a little easier than SDD (smaller panels)</td>
<td>Can integrate freezer (compartment or standalone)</td>
<td>Medium</td>
</tr>
<tr>
<td>Passive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Passive</td>
<td>Low</td>
<td>Simple; no installation / moving parts</td>
<td>Very limited</td>
<td>Requires reliable ice delivery</td>
</tr>
</tbody>
</table>

**SOURCE:** Device teardowns; PATH; supplier and expert interviews; team analysis
Passive devices will need to overcome a set of challenges linked to ice logistics...

Supply chain reliability is an issue; although vaccine replenishment is monthly, delivery often falls behind 1-2 weeks (can be 1-2 months late in very remote locations).

Basic forms of transportation for last mile distribution (e.g., bikes); limit how much vaccine and ice can be carried in a pull system.

Ice delivery challenges; changes may be required to deliver ice at the right temperature.

Ice is required for outreach, which passive devices cannot produce:
- Outreach frequency varies by facility; larger facilities typically do more outreach.

SOURCE: Tanzania health clinic visits; interviews
Solar requires additional maintenance

- Solar panels should be cleaned every 3-4 months
- “We have found that Solar panel cleaning is often an issue . . . leading to reduced performance” – solar expert

Countries lack an adequate install and maintenance network
- Few local trained technicians due to limited solar adoption and little work
- Should naturally improve as solar adoption rates increase

Solar install costs are very high USD

<table>
<thead>
<tr>
<th></th>
<th>Passive</th>
<th>ILR</th>
<th>Solar powered (SDD, TE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>85</td>
<td>100</td>
<td>650</td>
</tr>
<tr>
<td>6-7x more costly</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Experts travel 2x per installation from a central location
  - Pre-install visit required to ensure solar will work

Small Off-grid

... and solar devices (SDDs/TE) will need to overcome challenges with install and maintenance
Because of challenges, there is potentially a role for both passive and active devices in the small off-grid segment.

**Segmentation of small off-grid facilities**

<table>
<thead>
<tr>
<th>Reliability of monthly supply chain</th>
<th>Frequency of outreach</th>
<th>Technology options</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1x month</td>
<td>&lt;1x month</td>
<td>1 Small SDD</td>
</tr>
<tr>
<td>&gt;1x month</td>
<td>~15L segmentation; ~40,000 facilities</td>
<td>2 Thermoelectric</td>
</tr>
<tr>
<td>Reliable delivery</td>
<td>Active device + freezer (~50%)¹</td>
<td>3 Passive</td>
</tr>
<tr>
<td>Unreliable delivery</td>
<td>Passive device + central delivery of ice (~50%)¹</td>
<td></td>
</tr>
</tbody>
</table>

1 Based on sample of interviews with EPI managers in Vietnam, DRC, Nigeria, Ethiopia; 2 Active is still a viable option; 3 Passive may be feasible if alternatives for ice procurement are possible, such as purchasing ice from local store or delivery from an adjacent facility with a freezer.

**SOURCE:** EPI and expert interviews
**Small Off-grid**

Both types of small off-grid facilities often exist within the same country

Through our visit, we learned SE Tanzania has many small off-grid facilities....

**Lindy Rural District**
- Majority of facilities\(^1\) off-grid
  - 25L absorption fridges; \(~$300-700 ~\text{year}\)
  - Typically vaccinate \(\sim 15-20\) kids per month (6-7L)
  - \(\sim 80\%\) coverage rate

...but not all the locations have a supply chain that can support a passive device

**Locations with a reliable supply chain (~70%+ of facilities), are ideal for a passive device**

**Mchinga Health Dispensary**
- Off-grid, \(\sim 200\) children, <30 km from district, 1 day re-supply trip with semi-paved road access
- **Ideal for a passive device**, supply chain can reliably provide ice and vaccines every 30 days

**Passive devices are not viable at facilities with an unreliable supply chain (~30%+ of facilities)**

**Mahumbika Health Clinic**
- Off-grid, \(\sim 200\) children, \(\sim 180\) km from district, resupply \(\sim 5-6\) weeks
  - Unpaved road access, unreachable in rainy season, at end of 2 day resupply trip
- **Passive device not viable**, supply chain cannot consistently provide ice or vaccines every 30 days

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:\(^1\) Denotes Facility

147 immunization sites, 49 facilities serving 132 villages

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GAVI partners are aiming to provide active targeted support for the most critical countries, and also develop tools for all countries.

**Active support for critical countries**

- Where partners are already providing cold-chain support today, efforts will be coordinated and enhanced as appropriate
  - Ethiopia, Tanzania, Nigeria, Ghana
- Support for others will need to be established
  - DRC, Uganda, India

**The Task Team has developed a roadmap across 5 areas critical for cold chain**

- Creating a cold chain equipment inventory / baseline
- Assessing and segmenting current and future facility needs
- Evaluating and selecting various equipment types (e.g., total system cost comparison by technology)
  - Including expert equipment reviews, online country feedback
- Applying for funding and procurement support
- Establishing effective installation and maintenance systems
All devices should provide user friendly vaccine fridges that overcome common challenges at health posts

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Description</th>
</tr>
</thead>
</table>
| Vaccine freezing           | - Although many devices claim to be no-freeze, poor packing often leads to **vaccine freezing** due to technology constraints  
                             - **Ice packs** used in vaccine carriers are **rarely pre-conditioned**, anecdotally happens ~50% of time |
| Simple, intuitive to use   | - Refrigerator can be **intuitively operated** by a **single health post worker**, a role that is faced with high turnover  
                             - “Solar fridges were sent with the panel disconnected from the fridge, but it was not intuitive for end users that they needed to plug in the solar panel”…PATH cold chain expert  
                             - **Loose vial storage support**: Vaccines are often removed from secondary packaging before being stored |
| Reliability                | - Devices and components are **often not designed to last 10 years**  
                             - Solar battery refrigerators **require battery replacement**  
                             - ILRs fail to protect against **voltage spikes** from the main grid |
| Installation & maintenance | - Substantial fraction of solar fridges are never installed, or installed incorrectly |
| Adequate temperature warning | - Vaccine fridge temperature is only recorded twice daily in a log book, **potential to miss temperature excursions** without some type of warning signal |