Factor[e] Appliance Workshop Webinar
05.15.2019
Introductions
The Challenge: Beyond Lights

<table>
<thead>
<tr>
<th>Tier 1</th>
<th>Tier 2</th>
<th>Tier 3</th>
<th>Tier 4</th>
<th>Tier 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Application</strong></td>
<td>Task lighting</td>
<td>General lighting</td>
<td>Tier 2 AND any medium-power</td>
<td>Tier 4 AND any very high-power</td>
</tr>
<tr>
<td></td>
<td>Phone charging</td>
<td>Television Fan</td>
<td>appliances</td>
<td>appliances</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>Min 3W</td>
<td>Min 50W</td>
<td>Min 200W</td>
<td>Min 2kW</td>
</tr>
<tr>
<td><strong>Daily supply</strong></td>
<td>Min 12Wh</td>
<td>Min 200Wh</td>
<td>Min 1.0kWh</td>
<td>Min 8.2kW</td>
</tr>
<tr>
<td><strong>Typical source</strong></td>
<td>Solar lanterns</td>
<td>Solar home systems</td>
<td>Generator or mini-grid</td>
<td>Generator or grid</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Grid</td>
</tr>
</tbody>
</table>

Moving up the energy ladder is imperative for rural economic development.

* SE4All Tiers of Electricity Access, adapted from the WHO
Diesel engines or diesel generators still remain the **primary energy source** for many rural communities.

For example, even in the communities with electricity, there is a lack of highly efficient electric appliances for agri-processing.
The Challenge: Minigrid Profitability

A “long tail” of low consuming customers hurt project IRR potential, especially if there are NO IGA or SME (small-medium enterprise) customers.

It only takes 1-2 IGA customers: who will they be?
The Challenge: Minigrid Profitability

Minigrids are often oversized for their predicted demand, convert to Actual Demand, but under-sizing a minigrid can jeopardize reliability.

In some cases, only 25% of Predicted Demand converts to Actual Demand.

* Blodgett et al. Vulcan Accuracy of energy-use surveys in predicting rural mini-grid user consumption
Solution: Connect the Largest Energy Consumers

The largest energy consumers already exist; they own and operate diesel engines when they could be using electricity.

Many are engaged in agriculture-related activities. Capturing this demand captures a meaningful share of the rural economy.

"The top 10 percent of customers generate an annual ARPU almost 5x that of the portfolio annual ARPU”

- Powering Productivity, Vulcan, Inc.
Income Generating Appliance Effect

Takeaway: business-heavy load profile results in increased IRR, reduced capital expenditures (CAPEX), operating expenditures, and LCOE values.

Cost of electricity = $0.17/kWh cheaper with “business heavy load profiles”

Project IRR = 2-4 percentage points higher with significant daytime-only load

Income generating appliances are already widely used, and could be a predictable source of daytime revenue for minigrids.
Our Approach

An informed and guided approach to appliance selection

- Draw upon experience working in-market with early stage companies working related fields
- Interviewed stakeholders: appliance manufacturers, minigrid developers, financiers
- Conducted a literature review for off-grid test methods, productive-use studies, etc.

Experience-driven insights
Identification of needs and gaps
Survey of pre-existing work
Framing the Investigation

Powering income generating appliances with remote, renewable electric power systems is not straight-forward.

Technical
- Energy consumption
- Power specification
- Efficiency
- Power system / appliance compatibility

Economic
- Value proposition
- Working capital

Supply Chain
- Global procurement
- Shipping
- Distribution

Prioritize the right appliances and the right approach.
Our Approach

Establish open-access appliance test methods and test representative appliances

Remotely monitor appliances operating under a range of conditions

Develop an interactive appliance selection tool for minigrid operators

An informed and guided approach to appliance selection
Filling Knowledge Gaps Along the Way

Characteristics
- What is the productivity?
- What is the Efficiency?
- What additional equipment is needed?

Use-Patterns
- How much solar and battery are needed?
- What time of day is the appliance active?
- What is the utilization?
High Resolution Laboratory Testing
Appliances We Sourced for Testing

Futurepump Solar Water Pump: Made in India

Informal Stick Welder: Made in Rwanda

Multi-Purpose Agricultural Mill: Made in China
Side Note: The Expense of Appliance Sourcing

Relevant appliances are manufactured globally, but they must be imported in larger quantities to spread out the costs of shipping and logistics.

Shipping to Fort Collins, Colorado (a landlocked state) might be similar to shipping to a remote or landlocked part of East Africa.
Laboratory Methods and Testing

Method: modified IEC 62253 with unique test bench
Variables: flow rate, head, voltage, current, and efficiency over time
Variations: small and large pulley

Method: original to CSU
Variables: grain throughput, voltage, current, efficiency, RPM, harmonic distortion over time
Variations: coarse and fine screen size

Method: original to CSU
Variables: throughput, voltage, current, efficiency and, harmonic distortion over time
Variations: short and long arc
### Lab Test Takeaways

**Pump**

**Surface Solar Water Pump**

#### Key Applicator Characteristics
- **Manufacturer:** [Image]
- **Model Number:** [Image]
- **Inlet Size:** [Image]
- **Flow Rate:** [Image]
- **Head:** [Image]
- **Efficiency:** [Image]

#### Modes of Operation (3 panels switch off)
- **Small Pulley**
- **Large Pulley**

<table>
<thead>
<tr>
<th>Power vs Flow</th>
<th>0.5 to 0.3</th>
<th>0.3 to 0.5</th>
<th>0.3 to 0.25</th>
<th>0.25 to 0.2</th>
<th>0.2 to 0.15</th>
<th>0.15 to 0.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>4.5 to 5.5</td>
<td>5.5 to 7</td>
<td>7 to 8</td>
<td>8 to 9</td>
<td>9 to 10</td>
<td>10 to 11</td>
</tr>
<tr>
<td>Flow</td>
<td>3.5 to 4</td>
<td>4 to 4.5</td>
<td>4.5 to 5</td>
<td>5 to 5.5</td>
<td>5.5 to 6</td>
<td>6 to 6.5</td>
</tr>
<tr>
<td>Efficiency</td>
<td>78% to 82%</td>
<td>82% to 86%</td>
<td>86% to 90%</td>
<td>90% to 94%</td>
<td>94% to 98%</td>
<td>98% to 100%</td>
</tr>
</tbody>
</table>

**Stick Welder**

#### Key Applicator Characteristics
- **Manufacturer:** [Image]
- **Model Number:** [Image]
- **Inlet Size:** [Image]
- **Flow Rate:** [Image]
- **Head:** [Image]
- **Efficiency:** [Image]

#### Modes of Operation (3 panels switch off)
- **Short Arc**
- **Long Arc**

<table>
<thead>
<tr>
<th>Short Arc Characteristics</th>
<th>Long Arc Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>21.1</td>
</tr>
<tr>
<td>Current</td>
<td>5.4</td>
</tr>
<tr>
<td>Efficiency</td>
<td>77%</td>
</tr>
<tr>
<td>Arc Type</td>
<td>Short</td>
</tr>
</tbody>
</table>

**Welder**

#### Key Applicator Characteristics
- **Manufacturer:** [Image]
- **Model Number:** [Image]
- **Inlet Size:** [Image]
- **Flow Rate:** [Image]
- **Head:** [Image]
- **Efficiency:** [Image]

#### Modes of Operation (3 panels switch off)
- **Short Arc**
- **Long Arc**

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<tr>
<td>Arc Type</td>
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</tr>
</tbody>
</table>
Welder Test Overview

- **Welders CAN be powered by a minigrid** as long as batteries are exporting power to the AC bus and input current does not exceed smart meter breaker ratings.

- **Welder power consumption varies widely** and is influenced by arc strength; better welding technique could smooth out variability.

- **Power factor and efficiency of informal welders is mediocre**; if better power factor is desired, industrially manufactured welders (inverter type) may be used.
Mill Test Overview

- Smaller, electrically powered mills CAN be powered by minigrids, and appear to have similar throughput as larger, more inefficient diesel mills.
- High in-rush current from 1-phase motors must be mitigated by soft starters or 3-phase motors with a star-delta starter.
- Poor motor construction can lead to high THD (as in this case).
- This particular motor exhibited good power factor and mediocre electrical efficiency (70%) but can be switched out for a better motor.
- Milling maize into fine flour required 1.7x more energy.
Pump Test Overview

- Pumps were the most difficult and demanding to test with the most widely varying results.
- Technically, a pump of this power draw is a “friendly” load to a minigrid (however, was designed to be solar compatible).
- Small (<500W) solar pumps - if paired with a power converter - CAN operate on an AC minigrid. Value proposition is best without long distribution lines; consider other pump-minigrid business models.
- Manufacturer performance test methods vary widely, but CLASP is developing new off-grid testing methods, which will help standardize solar water pump performance ratings.
• We only purchase assets locally, because we don’t know the performance or quality of foreign machines.  
  - East Africa Minigrid Developer

• Many thanks for sharing the test results from this Chinese machine, those are some really exciting numbers.  
  - East Africa Minigrid Developer

• As a water pump manufacturer, we are really happy to see 3rd-party testing. It helps us get objective performance results that customers can trust.  
  - Appliance manufacturer

• Our inventor is interested to engage with you further on your test protocols the industry certainly needs more of this, and we will support it if we can.  
  - Appliance manufacturer
Low Resolution On the Ground Sensing

A Partnership with Minigrid Developers
Appliance Selection

- Sewing Machines
- Welders
- Diesel Mills
- Refrigerators
- Electric Mills
- Chilling Units
Sensing Approach

Rotational Speed Sensing
*Arch Systems, California*

- Low energy
- Local Bluetooth pickup

Electrical Sensing
*eGauge, Colorado*

- Cellular hotspot connectivity
- USB thumb drive local pickup
EQuota Energy: Data Disaggregation

• 20 smart meters with household and SME appliances
• EQuota uses a trained algorithm to disaggregate loads from an overall smart meter load profile
• End result will be a web-based dashboard and .csv files

Investigating lighter-touch methods of higher-fidelity appliance use-pattern discovery
Data Gathering – Use Patterns

Diesel Mill RPM Monitoring

Welder Monitoring

Sewing/Tailoring Monitoring
Sensors quietly pick up the daily habits of people in the community. This community has a market day on Mondays, which is represented in the data.
**Data Gathering: Use-Patterns**

Real data illuminates the real conditions.

With surveys, appliance owners always (20-300%) overestimated utilization.

<table>
<thead>
<tr>
<th></th>
<th>Maize Mill #1</th>
<th>Maize Mill #2</th>
<th>Rice Huller</th>
<th>Welder</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Hours in Operation (Daily)</td>
<td>1.4</td>
<td>3.36</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>Average Utilization (total waking hrs.)</td>
<td>9%</td>
<td>21%</td>
<td>12%</td>
<td>1%</td>
</tr>
<tr>
<td>Daytime Operation</td>
<td>63%</td>
<td>95%</td>
<td>91%</td>
<td>89%</td>
</tr>
<tr>
<td>Dusk/Night time Operation</td>
<td>37%</td>
<td>5%</td>
<td>8%</td>
<td>11%</td>
</tr>
</tbody>
</table>
Data Gathering: Use-Patterns

Real data, sampled and extrapolated out to a yearly load profile

Mill #1

Mill #2

Rice Huller

Welding Machine
• This sensor would be really helpful, because operators can only state their utilization for the last week, and we need better data fidelity to build our power systems.
  - India Minigrid Developer

• This tool would be really valuable to any company or organization that is trying to convince the operator of diesel-powered machine to switch to a solar/hybrid model.
  - Impact Investor

Testimonials

• We’ve met several SMEs who we want to support. For example, there is a local who operates a large (1.5kW) water pump, but we don’t have a good way to measure or estimate his energy consumption.
  - Southeast Asia Minigrid Developer
Appliance Decision Making
(Online TEA)

A Partnership with Radiant Labs
It only takes 1-2 IGA customers: Who will they be?

**Takeaway:** While minigrids are likely always going to serve Tier 1 & 2 customers, they should also power 1-2 IGA customer to help boost profits.

This customer and appliance should both be a **steady consumer of energy** as well as be fit with the technical capability of the power system.

**IRD by Customer Type**

- **IGA: 100%**
- **SME 68%**
- **Tier 3 & 4 customers**
- **Med Residential 25%**
- **Tier 1 & 2 customers**
- **Low Residential -9%**
Solving a multi-variable, multi-stakeholder problem

Costs

Energy Needs
Performance Characteristics
Ancillary Equipment
Power System

Appliance Owner
Grid Operator
ROI
Simple Payback
Technical Outputs
Compatibility

Repeatable
Comparable
Calculations
Solving a multi-variable, multi-stakeholder problem

- Energy Requirements
- Performance Characteristics
- Ancillary Equipment
- Renewable System

Economic Value Proposition

- Appliance Owner: ROI, Simple Payback
- Electricity Retailer: Additional Revenue, ROI
- Customers: Cost of service
## Incorporating Technically-Advanced Characteristics

### Ancillary Equipment

<table>
<thead>
<tr>
<th></th>
<th>Overall efficiency</th>
<th>Machine start-up</th>
<th>Safety / Protection</th>
<th>AC/DC Conversion</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Frequency Drive</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>$$$</td>
</tr>
<tr>
<td>Soft Starter</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>$</td>
</tr>
<tr>
<td>Correction Capacitor</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>$$</td>
</tr>
<tr>
<td>Inverter</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>$$</td>
</tr>
</tbody>
</table>
Repeatable Problem-Solving with an Online TEA/calculator

### Model Inputs

<table>
<thead>
<tr>
<th>Model Inputs</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Capacity Usage Factor to kW</td>
<td>2.2</td>
</tr>
<tr>
<td>Duty Cycle Derate Factor</td>
<td>1</td>
</tr>
<tr>
<td>Usage Factor Seasonal Derate Curve</td>
<td>TBD</td>
</tr>
<tr>
<td>Wholesale Electricity Cost</td>
<td>0</td>
</tr>
<tr>
<td>Unmet Load Electricity Cost</td>
<td>0.324</td>
</tr>
<tr>
<td>Retail Electricity Price</td>
<td>0.35</td>
</tr>
<tr>
<td>Units of Production per kWh</td>
<td>136.9</td>
</tr>
<tr>
<td>Revenue Per Production Units</td>
<td>0.0215</td>
</tr>
</tbody>
</table>

### Grid Operator Summary

<table>
<thead>
<tr>
<th>Grid Operator Summary</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly new appliance kWh</td>
<td>192 kWh</td>
</tr>
<tr>
<td>Yearly new appliance revenue</td>
<td>$67</td>
</tr>
<tr>
<td>Yearly new appliance electricity cost</td>
<td>$0</td>
</tr>
<tr>
<td>New appliance unmet load cost</td>
<td>$13</td>
</tr>
<tr>
<td>New appliance net revenue</td>
<td>$54</td>
</tr>
</tbody>
</table>

### Appliance Operator Summary

<table>
<thead>
<tr>
<th>Appliance Operator Summary</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yearly kWh from new appliance</td>
<td>192 kWh</td>
</tr>
<tr>
<td>Yearly Appliance Electricity Cost</td>
<td>$67</td>
</tr>
<tr>
<td>Yearly Units Produced</td>
<td>26351.881 units</td>
</tr>
<tr>
<td>Yearly Production Units Revenue</td>
<td>$567</td>
</tr>
<tr>
<td>Net Revenue</td>
<td>$499</td>
</tr>
</tbody>
</table>

### Grid Operator Summary

<table>
<thead>
<tr>
<th>Count hrs/year</th>
<th>Sum kWh</th>
<th>Percent of Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original unmet load</td>
<td>572</td>
<td>489</td>
</tr>
<tr>
<td>Additional unmet load</td>
<td>92</td>
<td>40</td>
</tr>
<tr>
<td>Total unmet load</td>
<td>616</td>
<td>529</td>
</tr>
</tbody>
</table>
Example: Evaluating an Electric Grain Mill

The tool lets a minigrid developer know how this new, large appliance will likely affect their ability to meet the new demand with their existing power system. Especially, the time of day in which the power system may fall short of meeting demand.
Example: Evaluating an Electric Grain Mill

<table>
<thead>
<tr>
<th>Minigrid System Type</th>
<th>Load Profile</th>
<th>New appliance load (kWh)</th>
<th>Net Profit from appliance load (USD)</th>
<th>Original Unmet Load (kWh)</th>
<th>Add'l Unmet Load (kWh)</th>
<th>Total Annual Unmet Load (%)</th>
<th>Grain Milled/Hulled (kgs)</th>
<th>Income (USD)</th>
<th>Net Revenue (USD)</th>
<th>Simple Payback (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline System</td>
<td>Mill #1</td>
<td>192</td>
<td>$ 74</td>
<td>489</td>
<td>40</td>
<td>7.0%</td>
<td>26,351</td>
<td>$ 567</td>
<td>$ 480</td>
<td>12.5</td>
</tr>
<tr>
<td>Baseline System</td>
<td>Rice Huller</td>
<td>1034</td>
<td>$ 448</td>
<td>489</td>
<td>55</td>
<td>7.1%</td>
<td>141,610</td>
<td>$ 3,045</td>
<td>$ 2,579</td>
<td>2.3</td>
</tr>
<tr>
<td>Baseline System</td>
<td>Mill #2</td>
<td>2560</td>
<td>$ 1,127</td>
<td>489</td>
<td>77</td>
<td>7.2%</td>
<td>350,511</td>
<td>$ 7,536</td>
<td>$ 6,384</td>
<td>0.9</td>
</tr>
<tr>
<td>Oversized System</td>
<td>Mill #2</td>
<td>2560</td>
<td>$ 1,140</td>
<td>129</td>
<td>36</td>
<td>2.7%</td>
<td>350,511</td>
<td>$ 7,536</td>
<td>$ 6,384</td>
<td>0.9</td>
</tr>
<tr>
<td>Undersized System</td>
<td>Mill #2</td>
<td>2560</td>
<td>$ 1,088</td>
<td>1173</td>
<td>199</td>
<td>14.8%</td>
<td>350,511</td>
<td>$ 7,536</td>
<td>$ 6,384</td>
<td>0.9</td>
</tr>
</tbody>
</table>

**Takeaway:** Mill #2, which has a more active daily use profile, is far more interesting as an IGA customer for a minigrid than Mill #1. Additionally, the appliance owner of Mill #1 likely doesn’t have much incentive to switch energy sources because they don’t use the machine as frequently as Mill #2.
Contact us for beta testing!
This has been done before

US electric appliance campaigns in the 1930-50
Thank You