How to get the lowest-cost solar electricity to the lowest-income communities in rural Africa?  
Answer: SOLAR HOME SYSTEMS WITHOUT BATTERIES  

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*Kuyere! means “Let there be light!” in Chichewa, the language of Malawi
The Problem: SHS electricity can cost >$10/kWh

For example, the standard 8Wp Mkopa system costs $0.48/day For about 24 Wh/day = ($0.48/0.024kWh) = $20/kWh.

<table>
<thead>
<tr>
<th>Products</th>
<th>Deposit</th>
<th>Daily Payment</th>
<th>Number of Days</th>
<th>Total Price</th>
<th>Cash Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-KOPA 5 Classic</td>
<td>Ksh 2,999</td>
<td>Ksh 50</td>
<td>420 Days</td>
<td>Ksh 23,999</td>
<td>Ksh 18,999</td>
</tr>
</tbody>
</table>

What is in the box:
- 1 8W Solar Panel
- 1 Rechargeable FM/USB Radio
- 1 M-KOPA 5 Control Unit with Lithium Battery
- 4 Bright 1.2W LED Bulbs
- 1 5-in-1 Phone Charge Cable
- 1 Custom Charge Cable
- 1 Rechargeable LED Torch
AND YET: SOLAR PANELS ARE REALLY INEXPENSIVE!

$0.20/Wp = $0.02/kWh

Amortized Over 10 years of Electricity Production

(Original figure copyright: Massachusetts Institute of Technology, 2018)
Why are low-income Africans paying Solar Electricity Prices that are 100 to 1000 times the minimum Cost?

1. **Economies of Scale**: Very small systems spread system costs over very few kWh

2. **High Overheads and Mark-ups**: Import, sales and distribution in rural Africa can be expensive for imported products

3. **Short-lifetime Chemical Batteries**: Batteries last only a few years, so system costs are spread over fewer kWh
1. **Include Cooking for Solar Home Systems**: 90% of African household energy use is for cooking. Including cooking increases electricity output by 10X.

2. **Africa-assembled Solar Systems and Components**: Importing components and assembling in Africa avoids many import, and distribution costs, overheads, and mark-ups.

3. **Use super-capacitors and thermal materials for energy storage**: Super-capacitors and thermal phase change materials can last 10 to 20 years allowing solar costs to amortized over many more years of electricity production.
A 150W SOLAR SYSTEM WITH COOKER IS NOW AVAILABLE IN MALAWI FOR A COST OF ~$200

<table>
<thead>
<tr>
<th>Component</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>150 Watt solar panel</td>
<td>$ 65</td>
</tr>
<tr>
<td>Solar electric cooker with accessories</td>
<td>$ 25</td>
</tr>
<tr>
<td>Charge controller</td>
<td>$  5</td>
</tr>
<tr>
<td>Super-capacitors (15 Wh)</td>
<td>$ 25</td>
</tr>
<tr>
<td>Lights, switches and wiring</td>
<td>$ 20</td>
</tr>
<tr>
<td>Installation</td>
<td>$ 20</td>
</tr>
<tr>
<td>Overhead and profit</td>
<td>$ 40</td>
</tr>
<tr>
<td><strong>Total Cost</strong></td>
<td><strong>$200</strong></td>
</tr>
</tbody>
</table>

(Note we should soon be able to upgrade to a 250W system at no incremental cost)
“THERMAL BATTERIES” have the same first-cost as SEALED LEAD-ACID BATTERIES (but last longer!)

Sealed Lead-acid Battery

Price: $0.70/Ah at 12V
Energy Density: 43.2 kJ/Ah at 12V
Storage Capacity Cost: $23/MJ at 70% cycle efficiency

Erythritol:

Price: $3.55/kg delivered to Malawi
Energy Density: 316 kJ/kg
Storage Capacity Cost: $22/MJ at 50% cycle efficiency

Magnesium Chloride Hexa-hydrate

Price: $1.60/kg delivered to Malawi
Energy Density: 167 kJ/kg
Storage Capacity Cost: $19/MJ at 50% cycle efficiency
PER-CYCLE, SUPER-CAPACITORS CAN HAVE COSTS COMPARABLE TO SEALED LEAD-ACID BATTERIES

<table>
<thead>
<tr>
<th>Super-Capacitor:</th>
<th>Sealed Lead-acid Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price:</strong></td>
<td><strong>Price:</strong></td>
</tr>
<tr>
<td>$4.50 ea delivered to Malawi</td>
<td>$0.70/Ah at 12V</td>
</tr>
<tr>
<td><strong>Energy Density:</strong></td>
<td><strong>Energy Density:</strong></td>
</tr>
<tr>
<td>9 kJ/ea</td>
<td>43.2 kJ/Ah at 12V</td>
</tr>
<tr>
<td><strong>Cost/kWh:</strong></td>
<td><strong>Cost/kWh:</strong></td>
</tr>
<tr>
<td>$0.18 for 10,000 cycles</td>
<td>$0.12 at 500 cycles</td>
</tr>
</tbody>
</table>

(But businesses won’t pay to put supercapacitors in an SHS because customers won’t pay for the extra 5 to 10 years of lifetime)
1. Non-battery energy storage can be as cheap as lead acid batteries, but lasts much longer.

2. Solar panel electricity is VERY INEXPENSIVE. Therefore; we minimize the electricity cost with system designs that maximize direct-use of solar panel electricity.

3. There are little or no toxic chemicals in no-battery systems.

4. Solar Home Systems can now last 10 to 20 years or more if built right!
Many potential funding sources could support development of long-lasting no-battery systems

- **GEF**: Global Environment Facility
- **GCF**: Green Climate Fund
- **Beyond the Grid Fund for Africa** (e.g. funding for Burkina Faso and Liberia)
- **ROGEP**: Regional Off-Grid Electrification Project
- ...
INNOVATIVE VALUE-CHAIN IDEA:
SOLAR-ELECTRIC KITCHENS w/ WORKSHOP

Commercial solar-electric kitchen/restaurant:
Has 0.5 to 3 kW of solar panels and cooks 5-25 meals/day

Solar panels paid for with climate credits:
Because each kWh of cooking electricity saves a kg of wood

Next door is a workshop that pays the kitchen for electricity:
Workshop can use equipment that requires >1kW of power because it stores electricity in long-lasting capacitors that can discharge energy rapidly supply high-power equipment the during the day

Win-win-win-win-win-win proposition:
This a win for the environment, a win for women’s empowerment a win for the shop-owner, a win for the solar panels supplier, a win for the national economy and a win for donors