Making a 10-year-lifetime solar eCooking battery for rural Africa

Customizing lithium titanate (LTO) for low-income households

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Background: Some Basic Parameters for Off-grid Solar eCooking in Malawi

- Households in Malawi cook an average of 5 dishes per day:
  (a) Two *nsima/ugali*,
  (b) A root starch (i.e. potatoes or cassava),
  (c) A vegetable (i.e. greens), and
  (d) A protein (fish, soy, beans, or meat)
- Cooking energy intensity is 150 to 350 watt-hours per kg of cooked food
- People eat ~2000 calories/day
- On average cooked food has a caloric content of about 1 calorie per gram or 1000 calories per kilogram
- People in rural Malawi eat about 2 kg of food per day.
- The cooking energy requirement for a household of 5 is about 2.5 kWh/day
- A 700 watt-peak battery-free off-grid solar eCooking system provides about 1 kWh of cooking energy per day.

Off-grid Solar eCooking can be started with an Inexpensive Battery-free System

2 x $50 = $100 Bulk Procurement Cost

Two 72-Cell Solar Panels

+

Maximum Power Point Tracking (MPPT) 600W Controller

$30 Bulk Procurement Cost

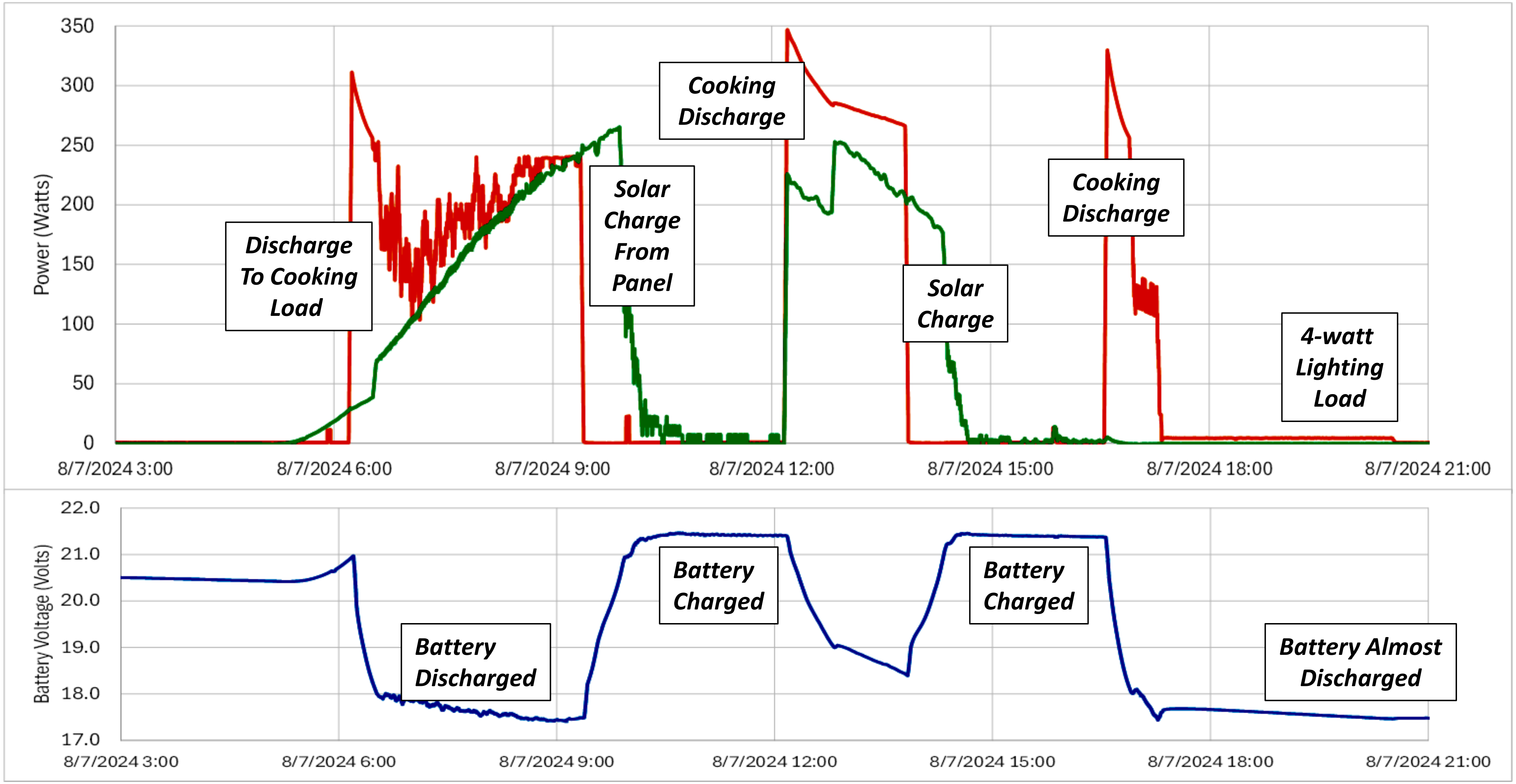
+

$30 Bulk Procurement Cost

DC Insulated Electric Pressure Cooker

Battery-free System Procurement Cost is $160

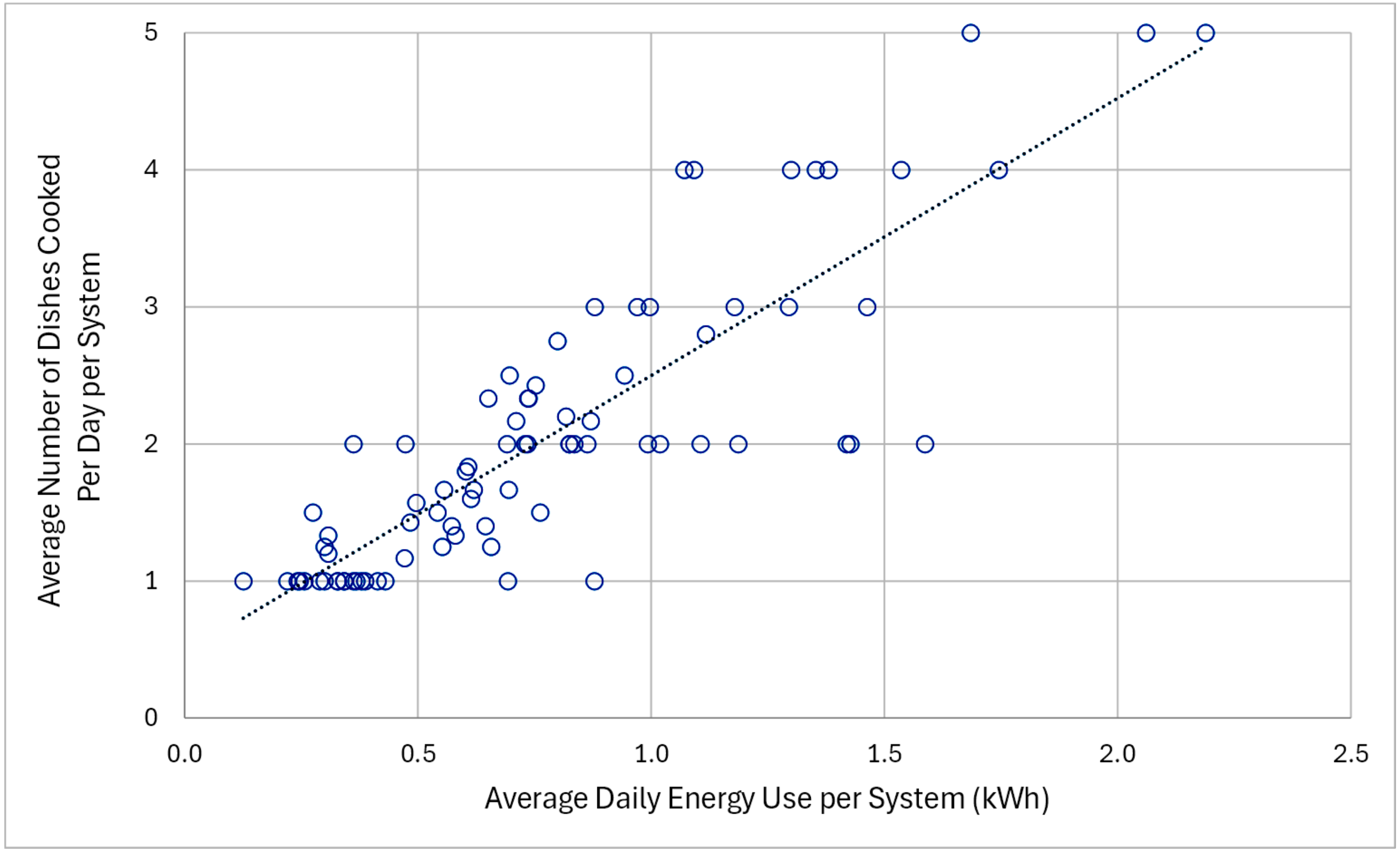
An Off-grid Solar Electric Cooking System (OGSECS) operates better when a battery added



How much does the battery cycle?
Statistics of System Energy Use vs. Dishes Cooked

Key conclusions:

- 2 to 3 dishes are cooked per day for a 1 kWh/day system
- There is one battery cycle per dish cooked for a small, affordable battery
- Total energy use is typically ~0.5 kWh per dish
- A larger solar panel will lead to more dishes cooked per day and more frequent battery cycling



LTO has Lowest per-kWh Battery Cost

when the battery cycles multiple times per day

Battery Cost per kWh = [AnnualizedBatteryCost]/[kWhPerYear]

AnnualizedBatteryCost = BatteryInvestment x CapitalRecoveryFactor (CRF)

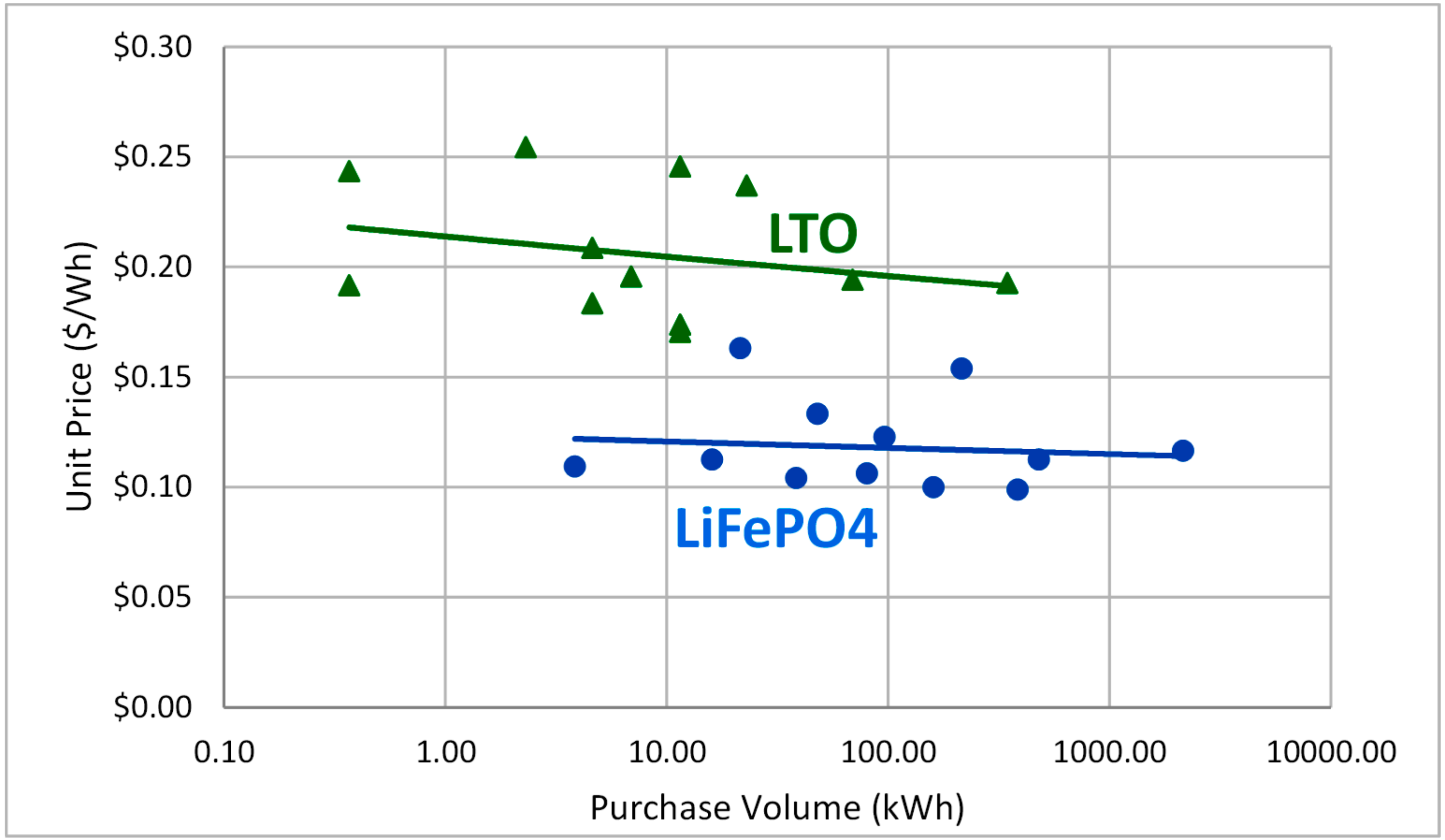
$$CRF = \frac{i\,(1+i)^n}{(1+i)^n - 1}$$

Chemistry	Retail Price/Wh	Cycle Life	Cycles/year	Lifetime (*n*)	Interest Rate (*i*)	CRF	$/kWh
Lead-Acid	$0.20	500	913	0.55	4%	1.88	**$0.41**
LiFePO4	$0.40	3000	913	3.29	4%	0.33	**$0.14**
LTO	$0.80	10000	913	10.96	4%	0.11	**$0.10**

Comparing the Cost of LTO and LiFePO4 at the Factory Door

Key observations:

- LiFePO4 battery cell factory door prices cells are about 40% less than LTO
- This is about $0.08/Wh.
- But the cost of the better LTO battery chemistry is small compared to the other costs of providing a battery
- It is easily worth it to have an LTO battery that can last 10 years rather than LiFePO4 which will last <5 years

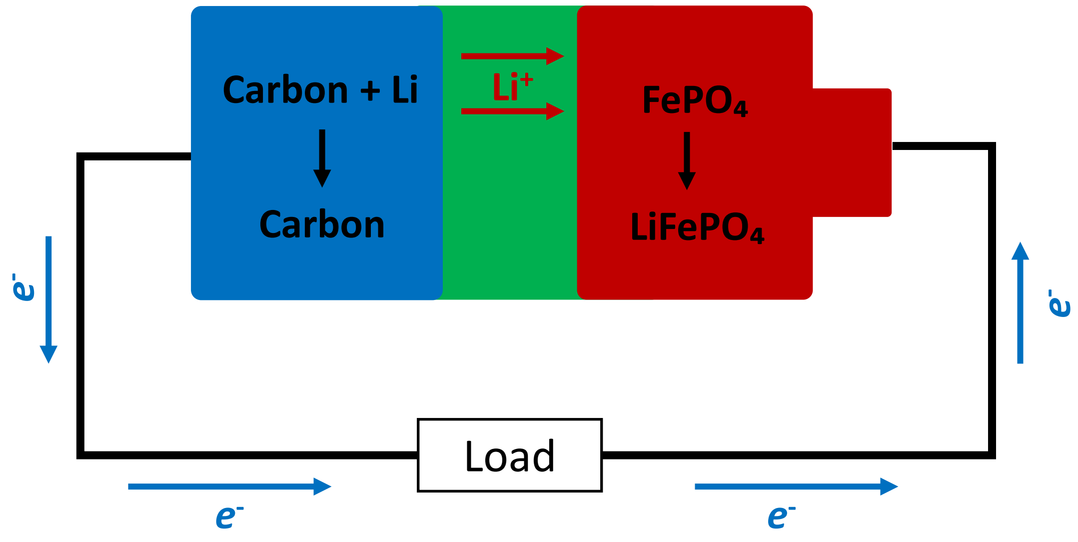


How to Make an LTO Battery for a Solar Home Cooking System

Intro to Lithium-Ion Batteries

Discharging LFP Battery

Negative Anode Electrolyte Positive Cathode



Anode Reaction:

$LiC_6 \rightarrow C_6 + Li^+ + e^-$

Cathode Reaction:

$FePO_4 + Li^+ + e^- \rightarrow LiFePO_4$

Don't care about this

Cathode Material Options:

- LCO (Lithium Cobalt)
- LMO (Lithium Manganese)
- NMC (Lithium Nickel manganese cobalt)
- LFP (Lithium Iron Phosphate)
- NCA (Lithium Nickel Cobalt Aluminum)

Anode Materials Options:

- Carbon (Graphite)
- LTO (Lithium Titanate) = $Li_4Ti_5O_{12}$

Need to address this

Cons of LTO:

- LTO batteries will be more expensive because graphite is basically free
- LTO batteries take up more space because lower cell voltage

Pros of LTO:

- Lasts more cycles because LTO deforms less during charging/discharging
- Higher power capacity because of rapid Li-Ion kinetics

Making and Protecting a Battery

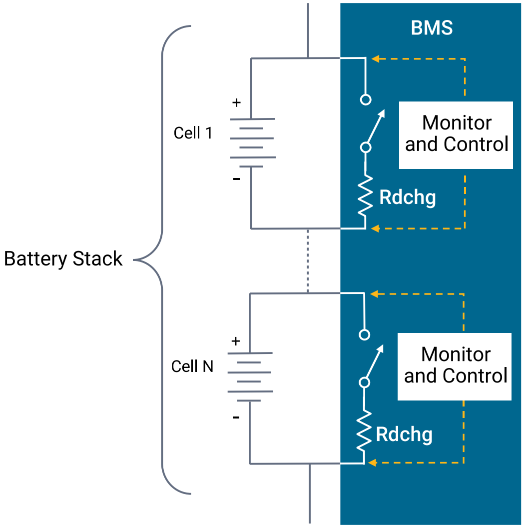
Physical Protection

Outer case & Encapsulation

- ✓ Water induced corrosion
- ✓ Shock

Electrical Protection

Battery Management System



- ✓ Over-charge
- ✓ Under-voltage
- ✓ Cell balancing
- ✓ Over temperature
- ✓ Short circuit

Thermal Protection

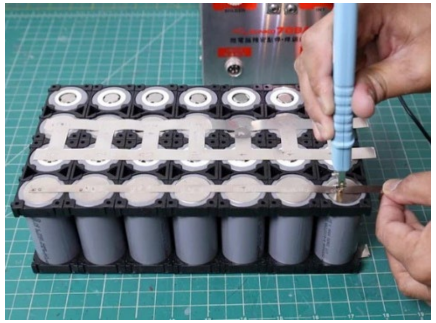
Heat sinks

Thermally conductive encapsulant

Assembly

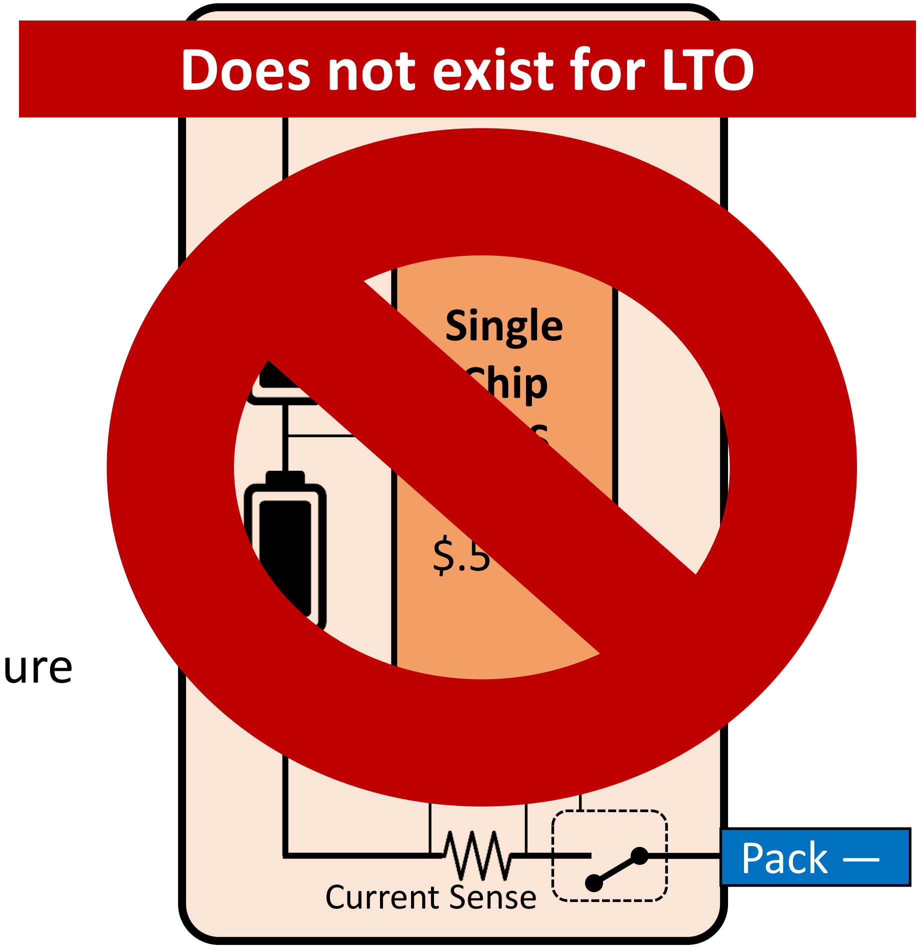
BMS and cells are done by machine

Assembly is mostly done by hand

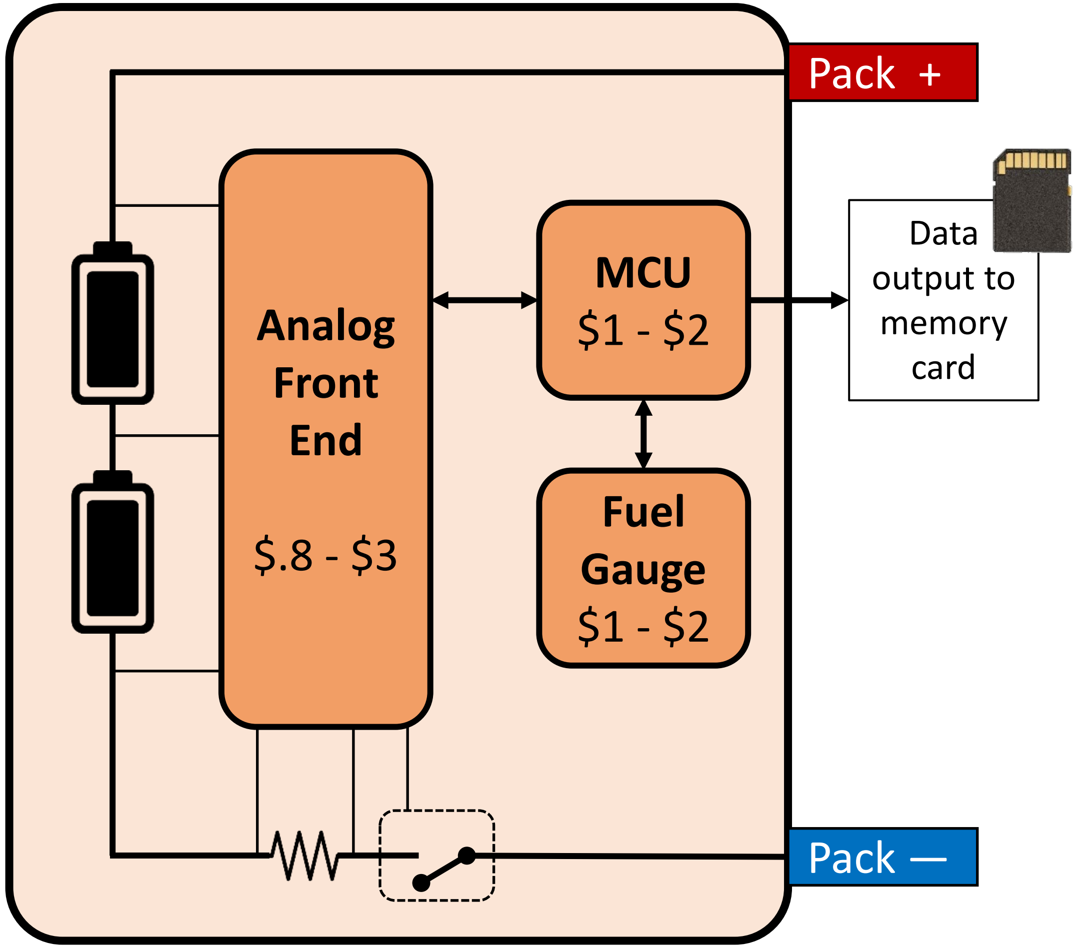


Electrical Protection: (BMS)

- ✓ Over-charge
- ✓ Under-voltage
- ✓ Cell balancing
- ✓ Over temperature
- ✓ Short circuit



Examples: BQ77915

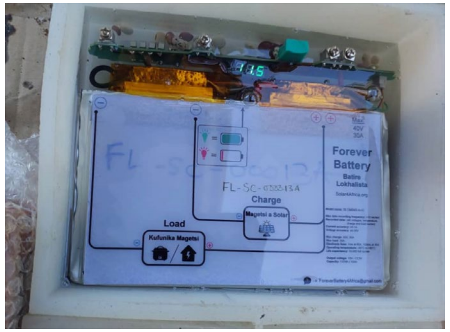


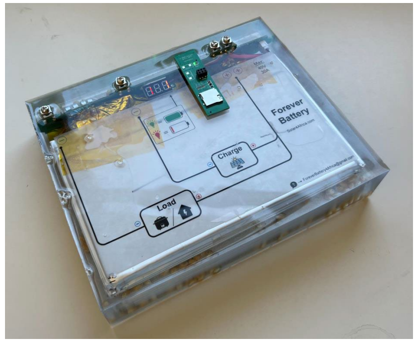
Examples: BQ76905, BQ76930, MP2797

Minimizing Cost of the Battery

Physical Protection

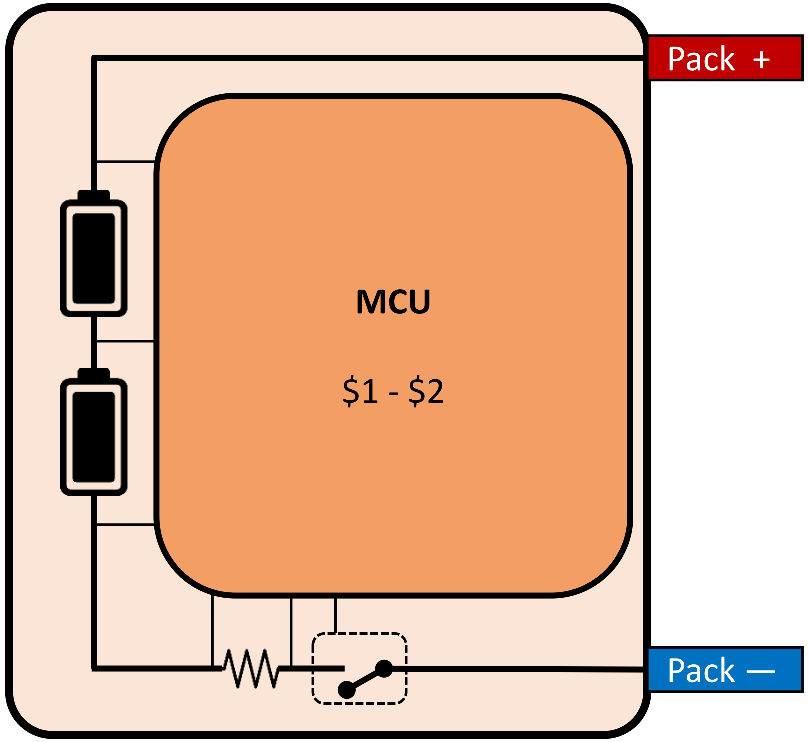
Get rid of outer case





Saves $3 to $8

Electrical Protection



Saves $2 to $8

Thermal Protection

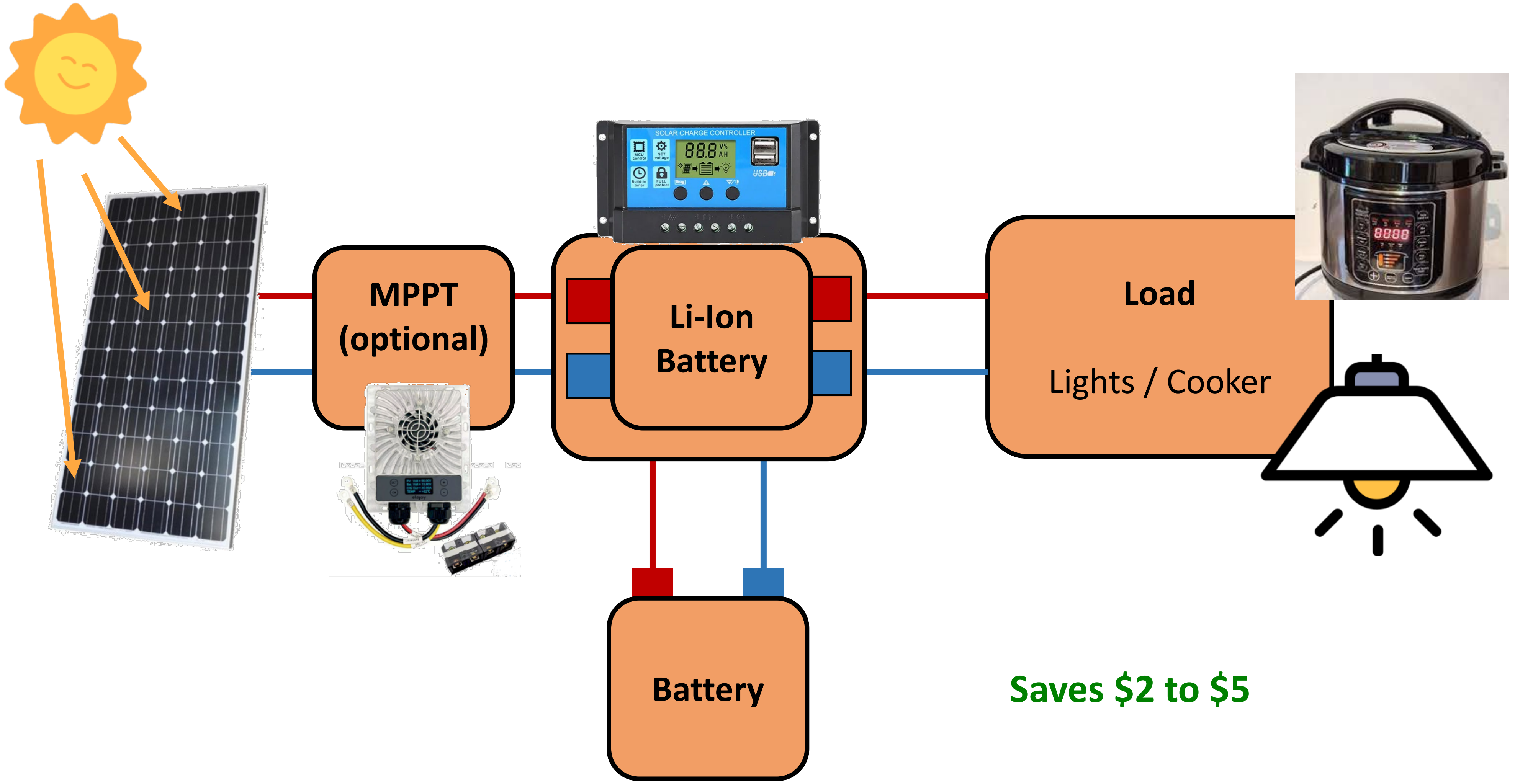
- ✓ No heat sinks
- ✓ Minimal use of thermally conductive encapsulant
- ✓ Efficient electronics

Saves $1 to $5

Assembly

Performed in Africa

Minimizing Cost: No Solar Controller



Saves $2 to $5

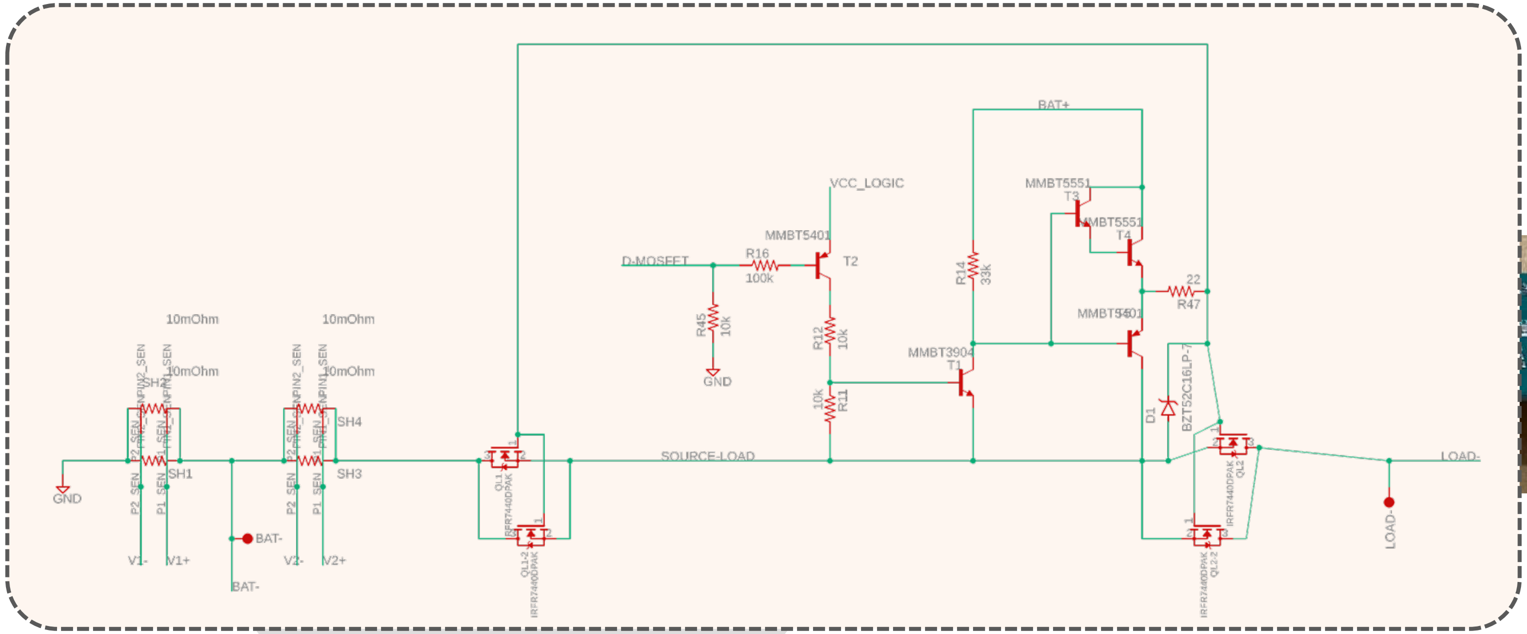
Our custom BMS

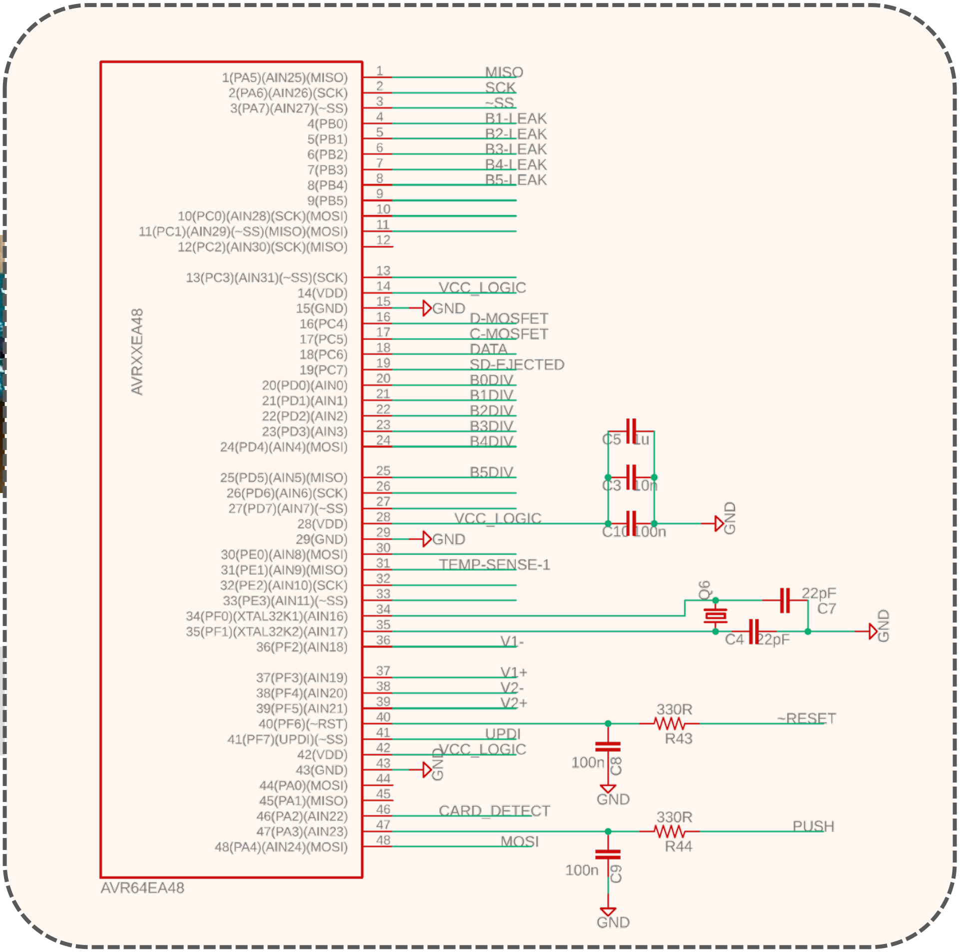
MOSFET Based Switch

Controls the current into and out of the battery.
This shows one of two switches.

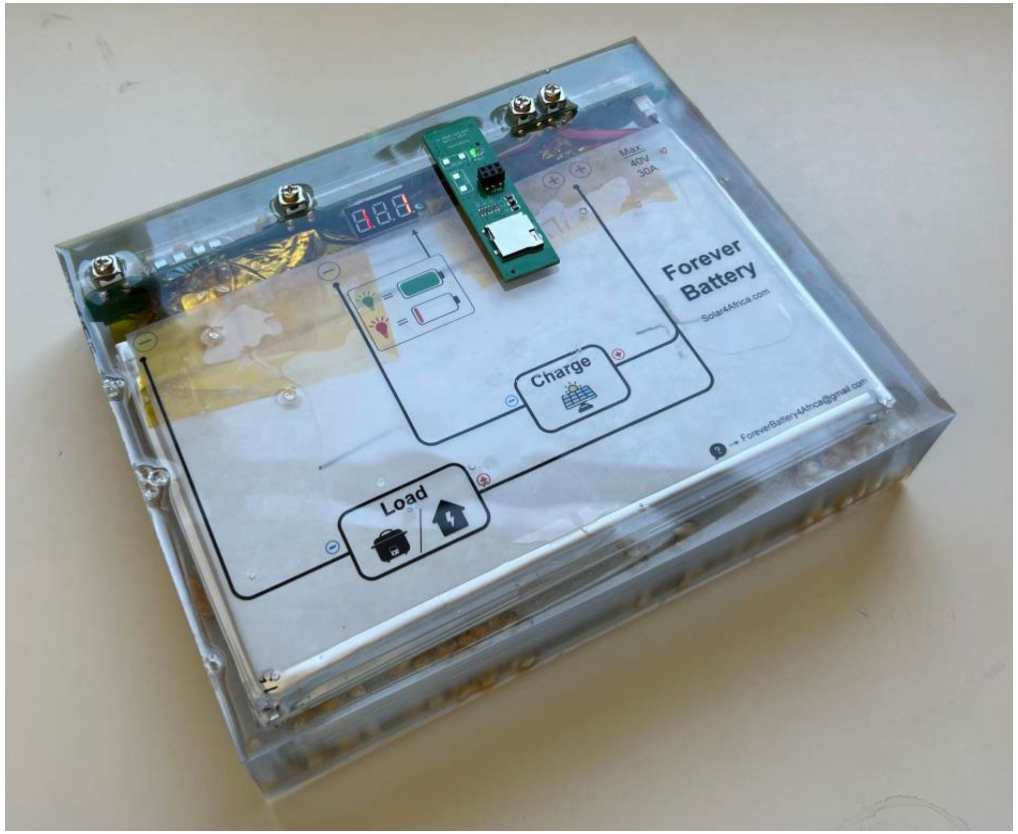
Microcontroller (MCU)

Controls all voltage, current, and temperature sensing.
Throws switches off / on. Sends data to micro-SD.





Our Product: 12V and 18V versions



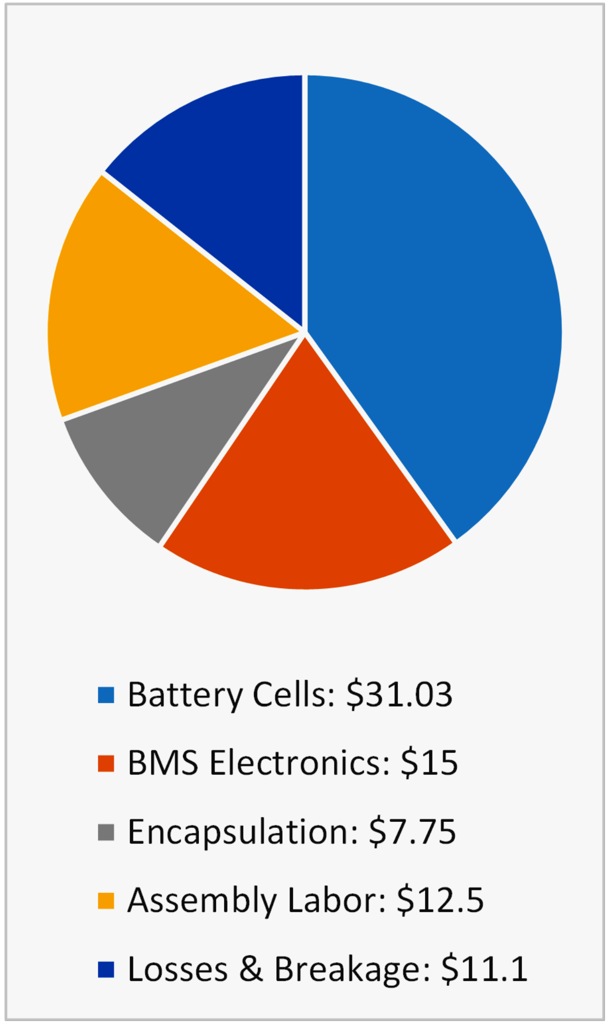
12V Version:

Max data recording frequency: >10 rec/sec
Recorded data: cell voltages, temperature, charge and load current

Current accuracy: ±0.1A
Voltage accuracy: ±0.05V
Max charge: 40V, 30A
Max load: 30A
Electronic fuse: 1ms at 60A, 100ms at 30A
Operating temperature: -40°C to +85°C
Life expectancy: 10,000 full cycles
Output voltage: 10V - 13.5V
Capacity: 110Wh / 10Ah`

Battery Assembly Costs

5-Cell, 12V Battery Cost Component	Unit	Cost/Unit Low	Cost/Unit High	Units per Battery Low	Units per Battery High	Average Cost per Battery
Pouch Cell at Factory Door	Cells	$3.28	$4.00	5	5	$18.20
Shipping of Battery Cells	kg	$3	$5	1.65	2	$7.48
Import Taxes		15%	25%	$3.20	$7.50	$5.35
BMS Electronics	Set	$10	$20	1	1	$15.00
Epoxy	kg	$5	$10	0.7	1.2	$7.75
Assembly Labor	Days	$5	$10	1	2	$12.50
Losses and Breakage		10%	20%	$4.31	$17.90	$11.10
Total Cost				$47.36	$107.40	$77.38



Next Steps/Ambitions

- Production run of 500 to 1000 batteries in Malawi
- Demonstration of applying the battery to administer per-kWh eCooking access subsidies
- Development of a capacity to export batteries from Malawi
- Create partnerships with other countries to replicate battery production outside of Malawi

Contact: info@solar4africa.org

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Modern Energy
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UKaid
from the British people

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