# Solar Thermoelectric Refrigeration:

## An Off-Grid Solution to Vaccine Storage

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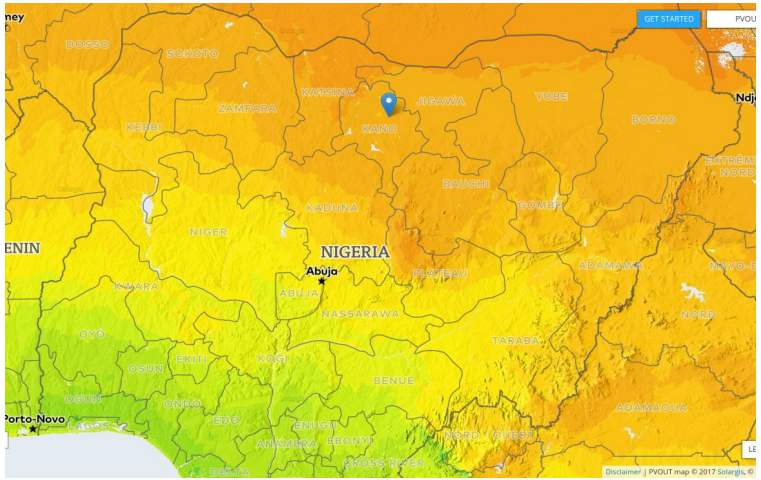
# Motivation

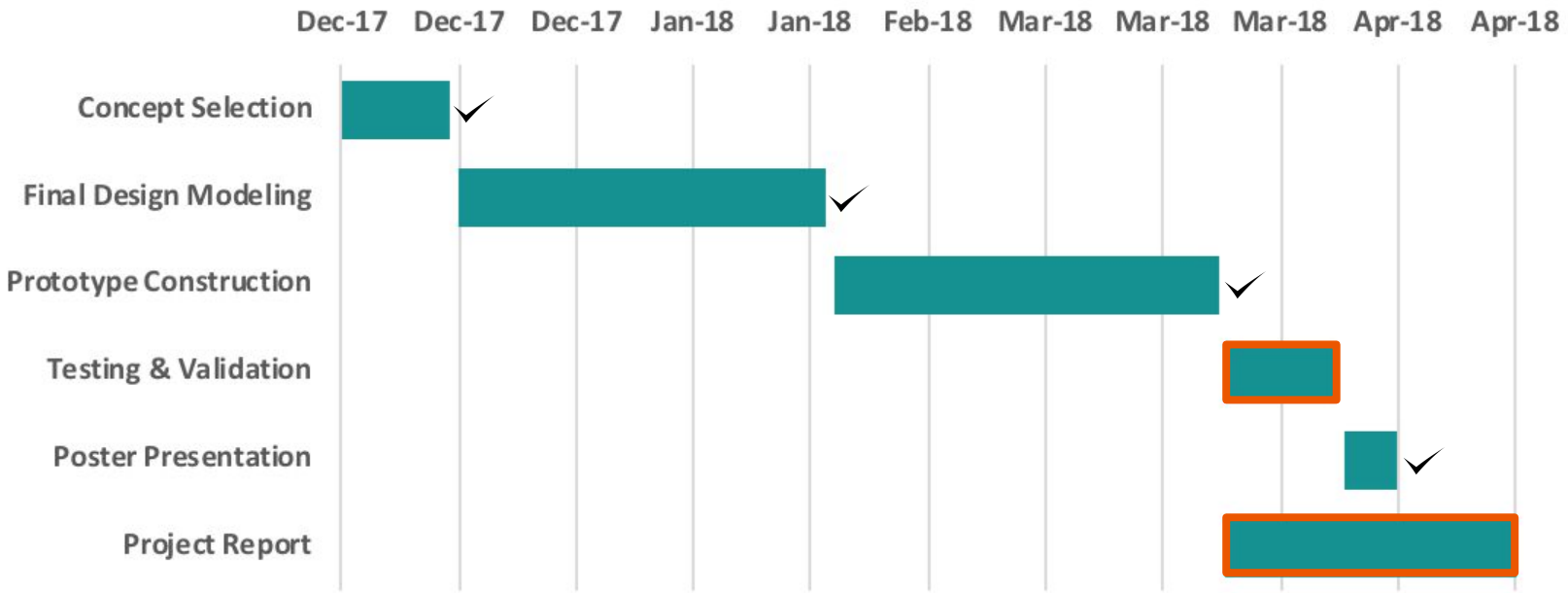
**Every day 16,000 children die globally from preventable diseases, totalling nearly 6 million per year**

## Nigeria

- Lowest vaccination rate (42%)
- 3rd worst under-5 mortality (9%)
- Low electricity access (57%)
- Frequent epidemics of preventable diseases
- High solar potential



# Progress


Dec-17
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Feb-18
Mar-18
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Apr-18
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Concept Selection
Final Design Modeling
Prototype Construction
Testing & Validation
Poster Presentation
Project Report

# System Design - Approach

**Background Research** → **System Requirements** → **Prototype Development**

- Existing Cold Chain Products
- Current Refrigeration Methods on Market
- Alternative Refrigeration Methods

- $T_{interior}$ = 2˚C - 8˚C
- $T_{exterior}$ = 40˚C
- Off-grid power source
- Transportable
- Low-maintenance

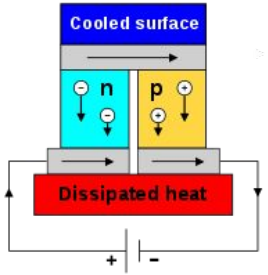
- Power requirement
- Geometry
- Materials

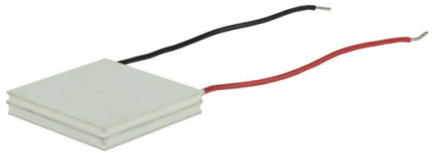
# Refrigeration Method: Thermoelectric

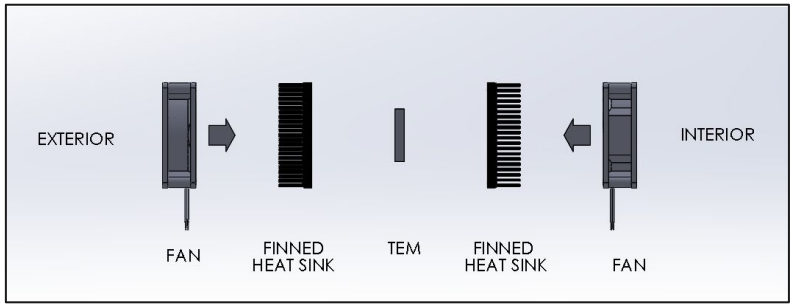
- Peltier Effect

- Pros:
  - solid state
  - small size and weight
  - quiet
  - DC power
  - no refrigerant

- Cons:
  - low C.O.P.





# Refrigerator Compartment Design

Primary Driver: Heat Removal Requirements

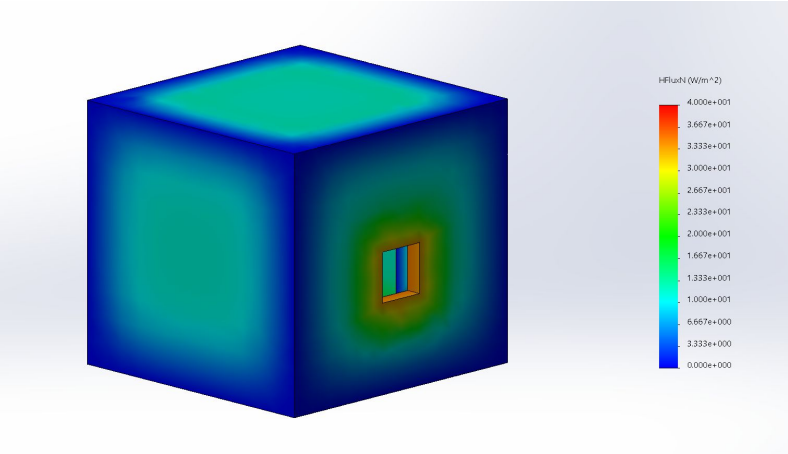
- rigid polyisocyanurate foam insulation
  - k = 0.023 W/m·K

Modeling Parameters

- $T_{interior}$ = 2˚C
- $T_{exterior}$ = 40˚C
- $t_{insulation}$ = 3 in.
- $V_{interior}$ = 0.85 $ft^3$ ≈ 25L

Modeling Results

- Q' = 8.4 W



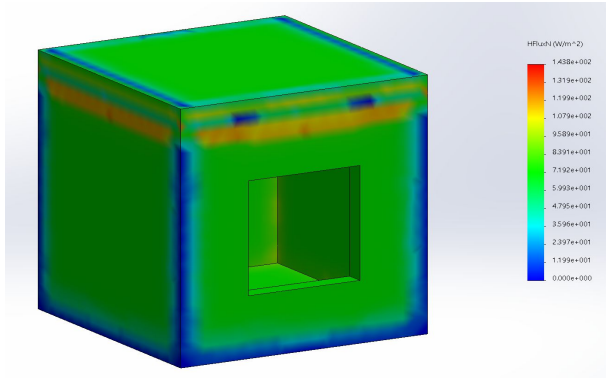
# Small-Scale Prototype

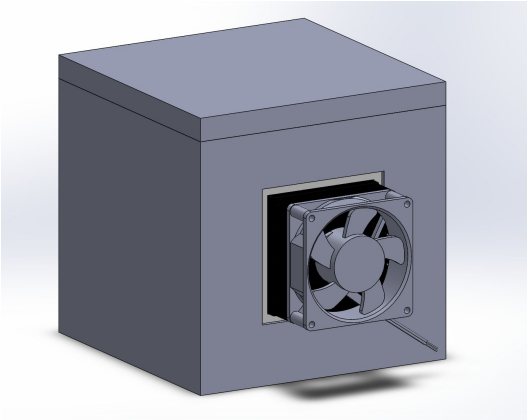
Why?

- to test heat removal capabilities of TEM assembly

Design Goals

- similar heat removal requirements
  - 11 W
- similar geometry
  - 0.125 $ft^3$ = 3.5L
  - 15% of full-scale volume



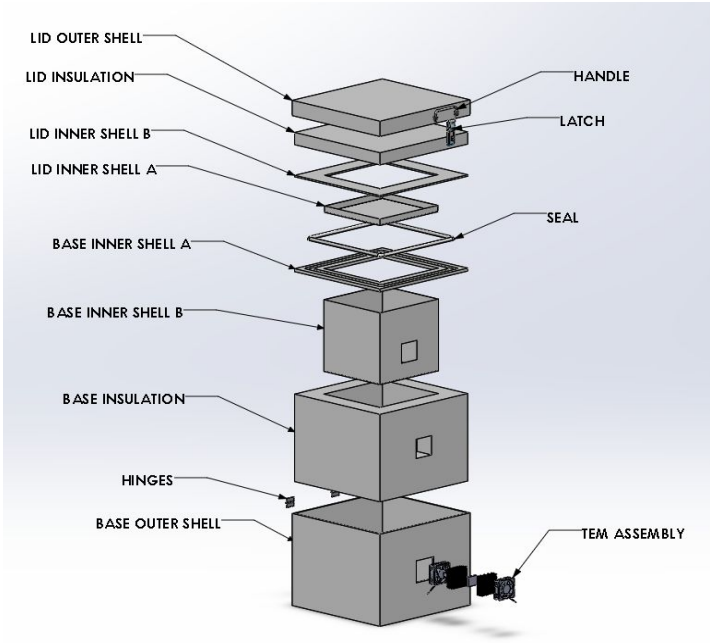
# Prototype Design

Materials:

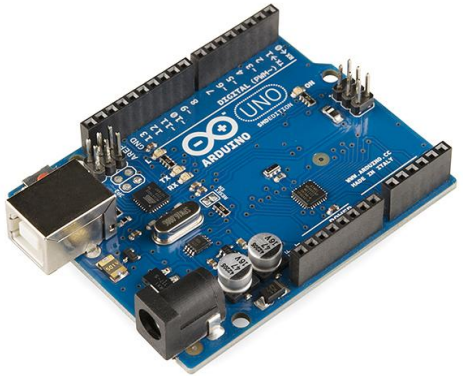
- Outer Shell: UV-Resistant HDPE
- Insulation: Rigid Polyisocyanurate Foam Insulation
- Inner Shell: Polypropylene

Assembly:

- Base & Lid
  - constructed separately
  - hinge + latch connection
  - rubber seal for airtight seal
- TEM & Heat Sinks
  - connected via thermal paste
  - press fit into insulation



# Controls Design




## Goal

- Maintain temperature between 2°C - 8°C
- Easy to use and replace
- Robust
- Low Power consumption

## Ideas

- PWM, PID, Regulators, TEC Controllers, Potentiometer, and Thermostatic control

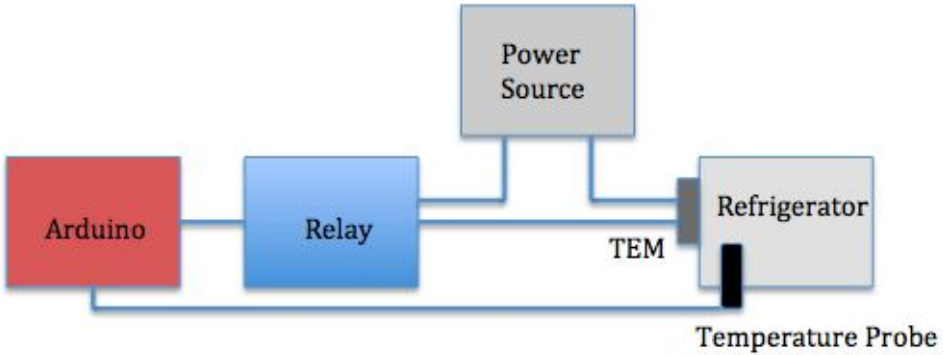
  **Feedback Loop: Temperature Probe ⟷ Controller ⟷ TEM Power**

# Controls Design

- Thermostatic Control most apt

- Below 2°C off. Only turn on at 6°C

- Temperature changes very gradually

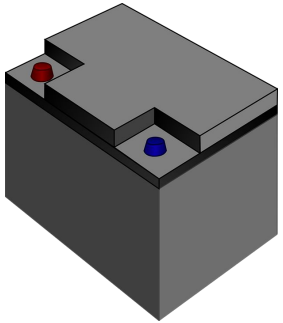


# Solar Panel and Battery Sizing

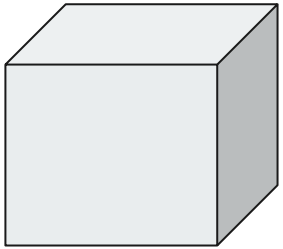
## Design Considerations

- Off-grid capability with 24-hour backup
- Flexible in power source
- Easy to maintain and repair
- 1.1 kWh per day energy required for refrigerator
- Lowest insolation in Maiduguri: 0.925kWh/m$^2$/day in August[1]


1.2 m$^2$ 150-200 Watt solar PV panel

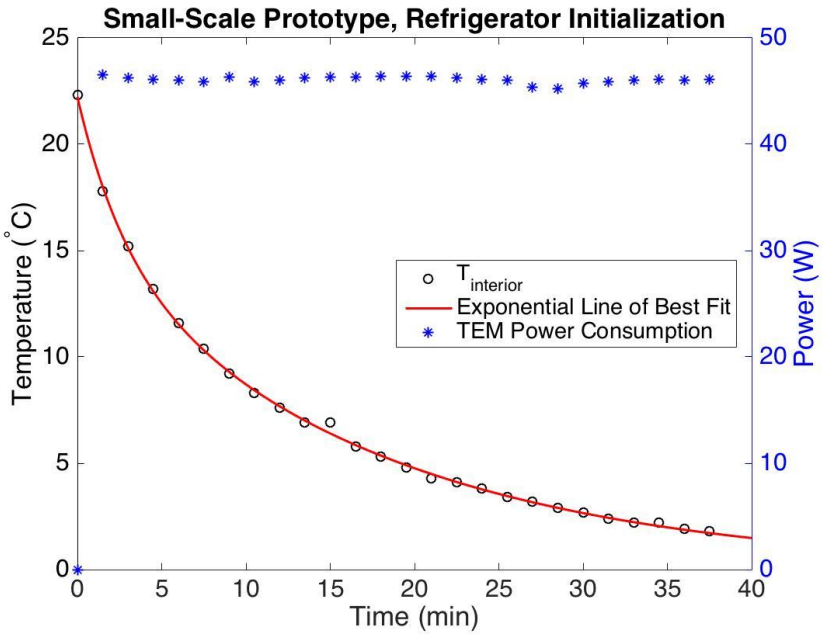


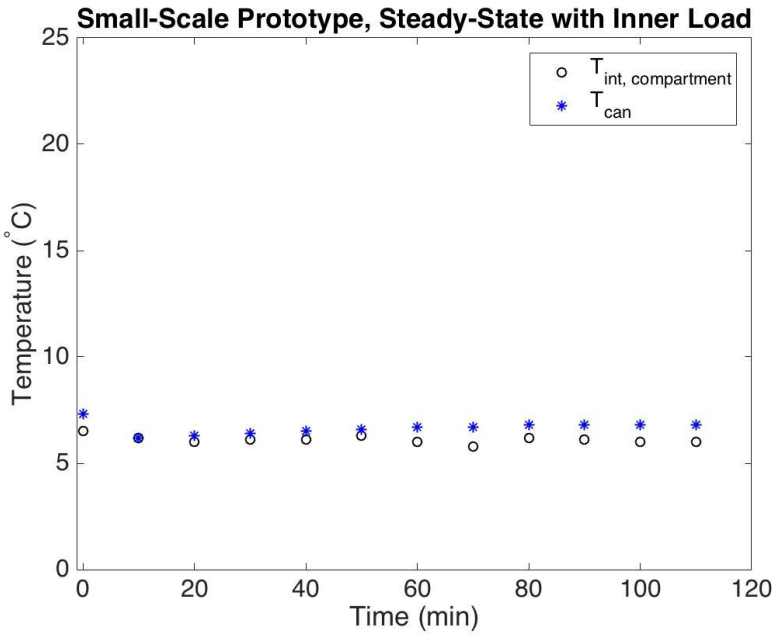
12V 1.5 kWh Lead Acid battery



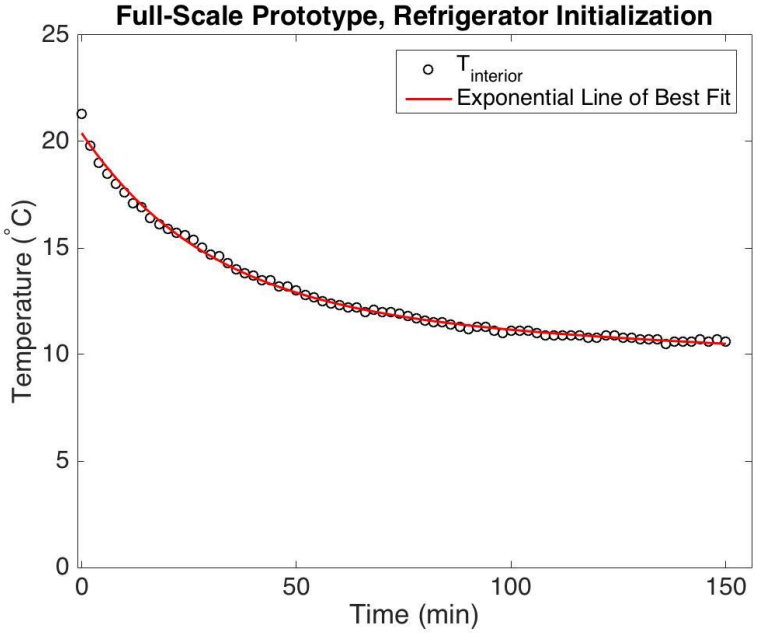
TEM Refrigerator

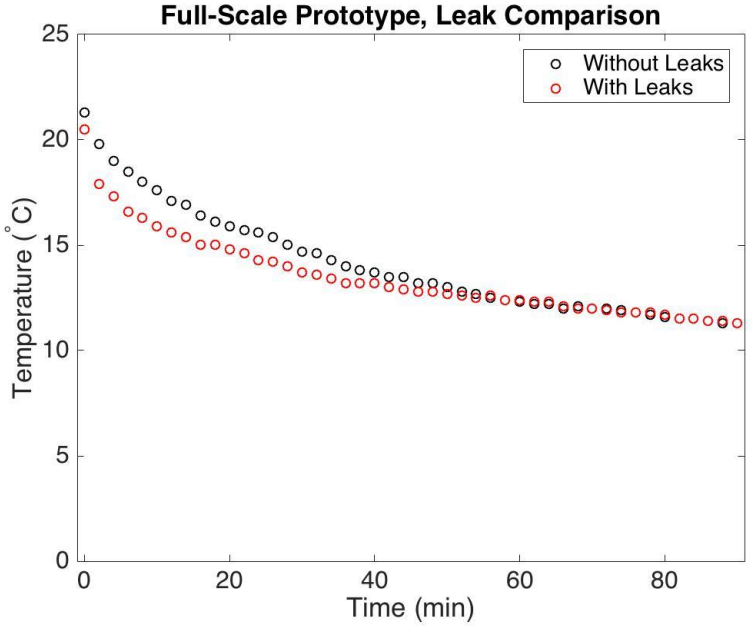
# Results: Small-Scale Prototype



# Results: Full-Scale Prototype



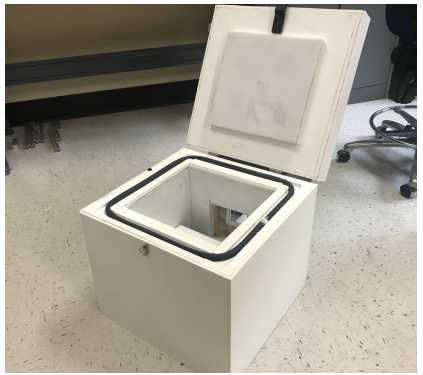
# Prototype Conclusions

## Small-Scale Prototype

- achieves cold chain temperatures ✓
  - 22.3˚C → 7.6˚C in 13.5 minutes
- maintains cold chain temperatures with load ✓

## Full-Scale Prototype

- provides some cooling ✓
  - ΔT ≈ 10˚C



**Thermoelectric Cooling at Cold Chain Temperatures is Possible!**

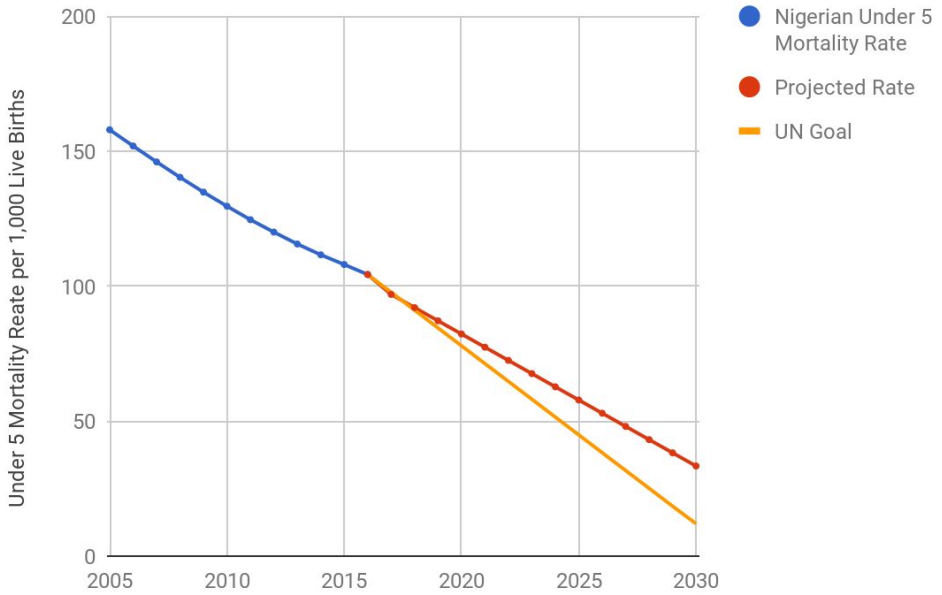
# Environmental Benefit Analysis

| Environmental Metric | Benefit/drawback vs. conventional refrigerator |
|---|---|
| $CO_2$ Emissions Abated | 40 x  = 1 x  of $CO_2$ abated in a year* |
| Life Cycle Emissions of Lead | ~50g of toxic Lead emissions[2] from battery |
| Other factors | - Waste reduction due to fewer components<br>- No risk of indoor air quality issues through leakages since there is no refrigerant |

*Assumption: compared to a 30W small vaccine refrigerator, and 420g$CO_2$/kWh Nigeria grid carbon intensity

# Social Benefit Analysis

- Decreased strain on public health facilities
- Increased economic productivity
- Decreased  spending on treatment
- Improved quality of life
- SDG 3




**Hep B in Kano: $3,771/unit/year**

# Business Plan: Market Optimization

- Minimize maintenance costs
- Utilize community partner to connect with clinics
- Compatible with Particle Mesh to improve cold chain data
- Competitors: Haier, Vestfrost, Dometic, Sure Chill* and SunDanzer*($2500-$3500)

# Business Plan: Pricing

**Production Costs**

- For one unit…
  - Materials: $800, Labor/Operations: $120, Shipping: $200
  - **Total: $1135**

**Overhead Costs**

- For one year…
  - Tools: $6500, Salary: $60,000, Leasing: $40,000
  - **Total: $106500**

**Unit price: $2199 if 100 refrigerators are sold**

# Business Plan: Manufacturing

## Prototype Manufacturing

- Imprecise plastic assembly
- Non-standardized production method

## Upscaled Manufacturing

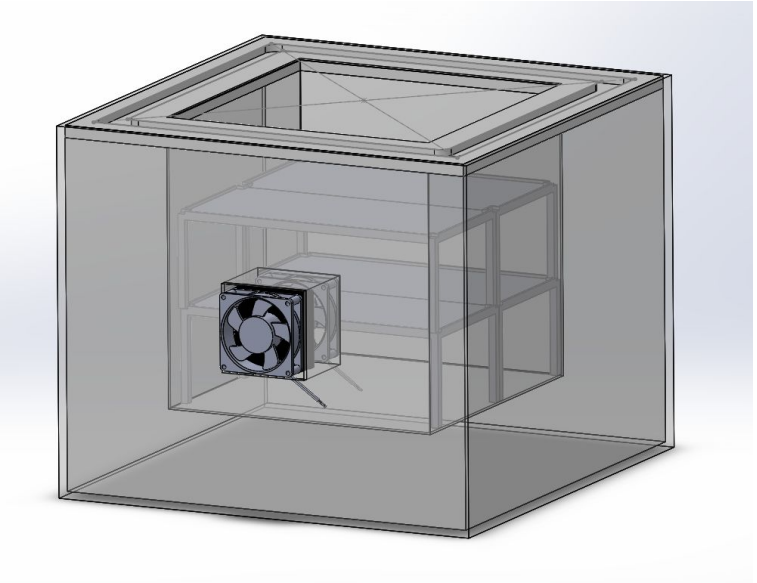
- Plastic thermoforming
- Economies of scale

# Next Steps

Optimize Full-Scale Prototype:
- reduce volume
- integrate multiple TEMs

Fully Develop Business Plan
- local networks
- distribution

Refine Prototype
- User friendly and ergonomic functionalities



# Questions?

# References


1. Osueke, C. et al. June 2013. *Study and Evaluation of Solar Energy Variation in Nigeria*. Sourced from: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.413.8387&rep=rep1&type=pdf
2. Liu, W. et al. December 2015. *Life cycle assessment of lead-acid batteries used in electric bicycles in China*. Sourced from: https://www.sciencedirect.com/science/article/pii/S0959652615009063