Alternative Refrigeration

Duke University
EGR 424/ENVIRON 452
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Duke UNIVERSITY | BASS CONNECTIONS

1. PROJECT DEFINITION

Bass connections aims to bring together interdisciplinary teams to work towards solving some of the world's largest problems. As students in the Energy and the Environment Certificate, we are all interested in making energy more accessible and sustainable. By working on a Energy and Environment: Innovation and Design Team through the Bass Connections Program, we worked to find a solution to an environmental problem by designing, creating, and testing an innovative energy solution.

Problem Definition

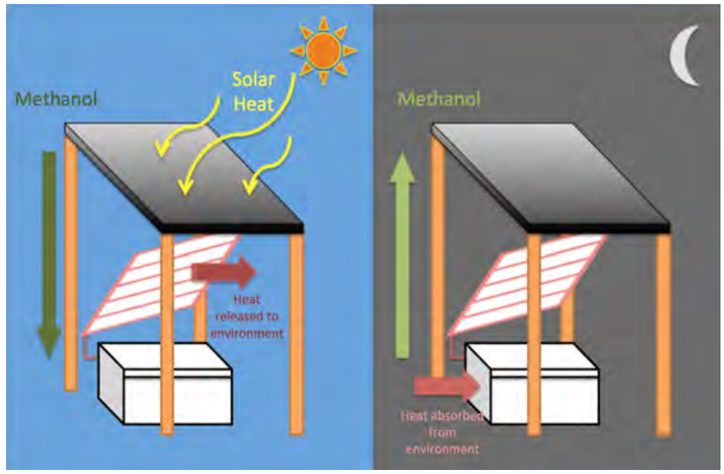
Approximately 50% of vaccines in developing countries are wasted due to improper refrigeration during transportation or long term storage. Hot climates, unreliable electricity grids, and underdeveloped transportation infrastructures limit the ability to distribute vaccines in these areas. Many vaccines are thermosensitive and require constant refrigeration between 2°C to 8°C from manufacturer to patient, therefore the current, unreliable cold chain for vaccine distribution in developing countries results in the generation of large amounts of preventable waste.[1]

Because energy infrastructure is limited in most developing countries, current vaccine transportation methods include the use of ice boxes, which are not temperature regulated. An off-grid and self-sustaining refrigerator would be able to improve the storage of vaccines for longer periods of time and could provide intermediate cooling. Vaccine spoilage and improper vaccine refrigeration also have many social and environmental implications. There are nearly three million vaccine preventable deaths annually, 1.5 of which are children.[2] Furthermore, the World Health Organization estimates that there are 24 million children in the world who are in need of vaccines. [3]

Motivated by these social and environmental issues, we sought to build a refrigerator for the purpose of the last stage of vaccine transport and delivery from the local health clinic to the remote hamlets. Our proposal, the DuiihDac, would be reliable, off-grid, low maintenance, and versatile. In addition, it is designed to have a lower production cost and environmental footprint than current off-grid ice makers.

Project Description

In order to build an off-grid refrigerator for vaccine storage in developing countries, we identified a solar adsorption refrigeration cycle as a possible solution. The cycle uses and adsorbate/adsorbent refrigerant pair and input energy in the form of heat to drive a refrigeration cycle. During the day, the solar thermal energy evaporates methanol adsorbate off of a bed of activated carbon adsorbent. As the methanol expands out of the adsorber box and through the condenser, it releases heat to the environment and condenses to rest as a liquid in the evaporator in the cooler. At night, due to a change in the temperature and vacuum pressure of the system, the liquid methanol evaporates, removing heat from the water surrounding the evaporator, and the methanol re-adsorbs onto the activated carbon. [12]



2. CONCEPT GENERATION

In order to gain a larger perspective of issues at the intersection of energy and the environment, concept generation began by brainstorming “sustainable development” issues around the world. With that idea in mind, lack of electricity in rural areas was a major concern and the biggest associated problem was a lack of refrigeration. Without refrigeration, issues of food and vaccine spoilage cause millions of death each year, therefore the group decided to pursue building a refrigerator to serve areas without access to a reliable electrical grid.

Existing Products

As mentioned before, the most commonly used end component of the vaccine cold chain is an ice box, which is only able to store vaccines until the ice melts. Two common alternative paths to delivering long-term refrigeration are electrical, compression-cycle fridges powered by kerosene generators or by photovoltaic panels. PV refrigerators are currently in use at limited off-grid clinics. Older models require batteries to store solar energy, leading to higher maintenance costs, while newer models are “direct-drive,” using a PV panel’s DC current to directly power a compressor. However, both models are mechanically complex and require specialized skill to maintain. The PV panels require full, direct sunlight limiting their use during times of high cloud coverage such as a rainy season. Kerosene generators are more common in countries that lack a reliable electricity grid, making them more likely to be used over a long period of time. However, they also require the clinic to constantly provide fuel, making it an expensive investment long-term.

In contrast, a refrigerator that is powered by a solar adsorption cycle is mechanically simple and nearly free of operating cost.[7] Past efforts have been made to prototype such a fridge, but they often require daily maintenance to adjust valves. Prototypes have also varied in the type of adsorption cycle used and the overall cost of production.

Evaluation of Refrigeration Technologies

When analyzing existing off-grid refrigeration models, we found four potential ideas: (1) a compression model with a kerosene generator, (2) a compression model with a solar generator and batteries, (3) a phase change material with direct-drive solar generator, and (4) an adsorption cycle model powered by heat energy. These ideas were put into a Pugh matrix to evaluate their strengths and weaknesses.

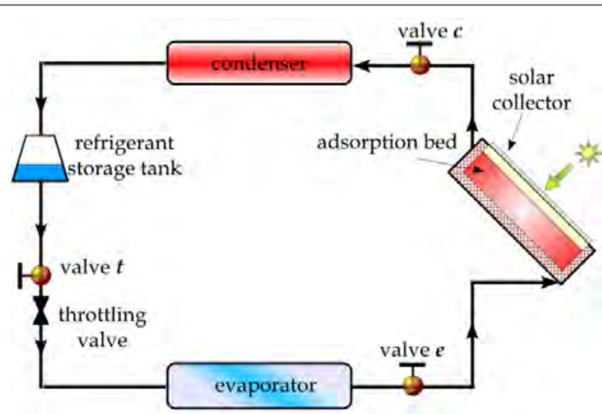
	Weight	Solar Adsorption	PV Direct Drive	PV Electric Battery	Kerosene
Type of Cycle		Adsorption	Compression	Compression	Compression
Cost	0.9	6	5	3	2
Domestic Sourcing of Materials	0.6	8	3	3	2
Performance	0.9	6	8	8	8
Off-Grid Capability	1	9	8	8	5
Lifetime	0.5	7	4	4	4
Operating Costs	0.8	8	5	5	2
Reliability	0.8	7	4	4	6
Total		40.1	30.7	28.9	23.6

Based on the CTQ values, the adsorption cycle was the cheapest and easiest to operate of the refrigeration technologies. Our next decision was to choose a refrigerant pair for the adsorption cycle. A second Pugh matrix examined traits such as corrosiveness, cost, availability of materials, etc., and we determined that an ammonia-calcium chloride or a methanol-activated carbon pair were best suited for our needs. Ultimately, we opted for a methanol-activated carbon pair because of safety risks associated with ammonia including toxicity and operating a high pressure.[9]

	Weight	Ethanol - Act. Carbon	Methanol-Act Carbon	NH3-CaCl	NH3 - Water	Silica Gel-Water	Zeolite-Water	LiBr-Water
Cost	0.9	6	6	4	4	2	2	1
Corrosion	0.7	4	4	2	2	10	10	10
Domestic Sourcing Of Materials	0.8	10	9	4	6	2	2	2
Performance	1	4	4	6	5	2	5	6
Reliability	1	7	7	4	3	6	6	4
Maintainence	0.9	7	7	7	6	8	8	7
Operating Costs	0.9	9	9	7	8	6	6	6
Repairability	0.8	5	5	3	3	5	5	5
Environmentally Friendliness	0.5	8	8	8	8	6	7	7
Size & Weight	0.3	5	4	5	4	4	5	4
Lifetime	0.5	6	6	4	5	5	5	5
Toxicity	0.4	5	4	2	2	8	7	5
Prior Usage?	0.7	10	10	10	10	8	8	4
Total		63.1	61.6	48.5	48.3	50.5	53.9	47.2

Preliminary Design

Our group had several options for the most intensive design component, the solar collector. After conducting a literature review, we found that the two most common types of solar collector utilized were a parabolic reflector and an insulated flat-box collector.[7,9] While many high-temperature cycles require a parabolic reflector, our methanol-carbon cycle does not require temperatures above 100°C.[9] We decided that the parabolic reflector, while able to reach higher temperatures, was unnecessary for this degree of heating. The simpler flat-plate collector should be adequate, when paired with insulation, to provide necessary operating temperatures.[11]



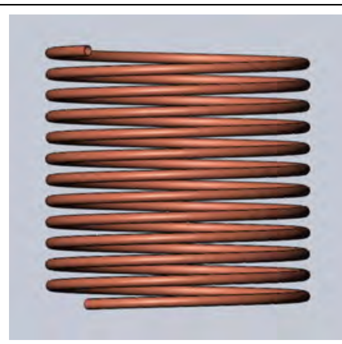
3. DESIGN ANALYSIS

Evaporator

In order to maintain the necessary temperatures for vaccine stability, MATLAB was utilized to determine that 274.04 kJ of energy was necessary to be removed from the cooler. Using the chemical properties of methanol, vaporization of 0.320 L of methanol would provide adequate cooling energy. The evaporator design has a surface area of 230.5 in^2 in order to provide more than enough surface area for heat transfer to occur. The evaporator was designed to be made from soldered copper, which has both good heat transfer properties as well as resistance to corrosion from methanol. (See diagram below).

Condenser

The condenser would be designed as a standard cylindrical condensing coil, using half-inch copper tubing to reject heat. Using the correct copper tubing, fabrication of the twelve inch in diameter helical structure should not be exceedingly difficult. Also made of copper, the condenser has a surface area of 704.4 inches squared to ensure proper heat rejection to condense methanol from gas to liquid. The condenser will be attached above the evaporator utilizing a removable valve to ensure isolation capabilities for the system. (See diagram below).



Adsorber - Activated Charcoal

In order to find the amount of activated charcoal necessary for complete adsorption of the methanol vapor, the Dubinin-Radushkevich equation was utilized. For the system's minimum operating capabilities, at least 22.87 lbs of activated charcoal was deemed necessary. [10]

$$X = X_0 \exp\left\{ -D\left[T \ln\left(\frac{P_S}{P} \right) \right]^n \right\}$$

Activated charcoal made with coconut shells was selected due to its high micropore density, which should aid in methanol adsorption performance. [10] A graded-mesh size of 12x30 was selected to facilitate easier handling and packaging.

Solar Collector & Greenhouse Box

Enough solar energy must be collected by the rectangular solar collector to power one iteration of the entire cycle. From earlier calculations, this is 77.5 W*h. Based on local climate characteristics and heat losses of the solar collector, a solar collector with a minimum area of 9.21 ft^2 was deemed necessary for providing the required input energy.

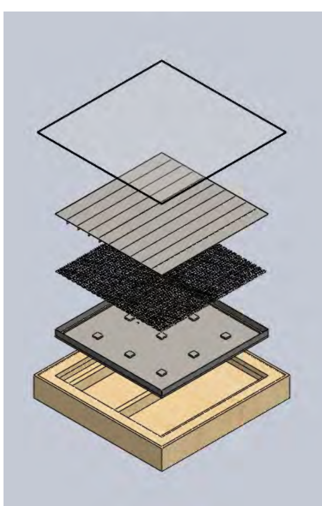
The Solar Collector design was centered on the dual concepts of providing adequate heat transfer to the activated charcoal and gas flow. The box was designed to be manufactured in two part. The top portion of the box, designed to receive incoming solar radiation, consisted of a flat steel plate, to which twelve steel fins were welded to facilitate heat transfer. The fins were designed to allow heat transfer from the top of the box to the layer of activated charcoal sitting below this.

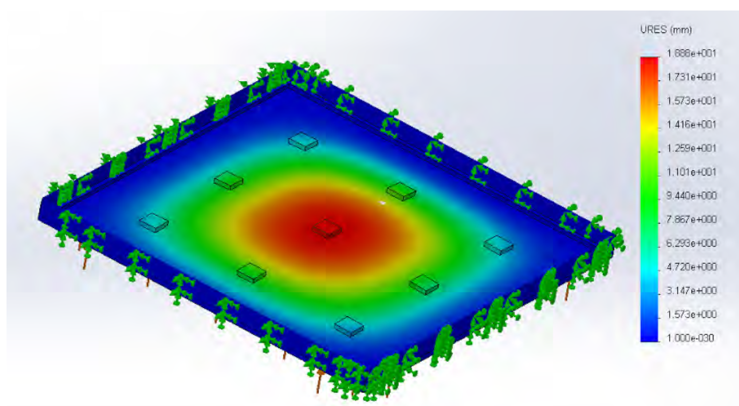
The activated charcoal was designed to fill the top portion of the box, from the top flat plate to a support structure near the bottom. The support structure was designed to be an expanded metal layer to provide structural support, wrapped in fine aluminum mesh to stop the small particles of activated charcoal from falling through. This layer of activated charcoal and its corresponding support structure rests upon nine half-inch spacers welded to the bottom of the box, allowing a layer through which the methanol gas can adsorb/desorb from the activated charcoal.

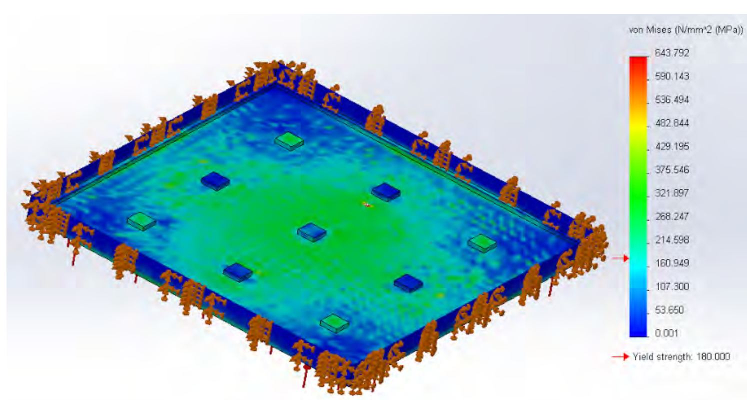
Appropriate connections were also made for measurement instrumentation and the allowance of gas flow into the solar collector. This consisted of welded couplings to which pipes/thermocouples could be attached. Upon assembly, the box should be welded closed in an airtight manner, so as to maintain the ability to draw a vacuum in the system. The entire steel box structure was also enclosed in a greenhouse structure. This greenhouse structure was to made using cut plywood and standard house insulation. A polycarbonate solar glazing would be affixed to the top of the box. The polycarbonate panel would allow incoming short-wavelength radiation through to warm up the box, but should block most longer-wavelength radiation outward from the warm solar collector. [8] Overall, the greenhouse should be quite effective in raising the temperature of the solar collector.

Steel was selected for the box and internal fins due to the need for strength and methanol's corrosive properties. Aluminum fins would have provided superior heat transfer, but tend to corrode over long periods of exposure to hot methanol vapor. Steel also provided the structural stability to ensure that the system would be durable enough to hold a vacuum.

After being designed in Solidworks (see diagram below), the steel box was subjected to the vacuum pressures and weight of the activated charcoal that it would be forced to hold. Stresses were an order of magnitude below the yielding points of the steel, and expected deflection would be approximately 1 mm (see diagram below). Satisfied with our modeling results, we decided to move forward in the design process.



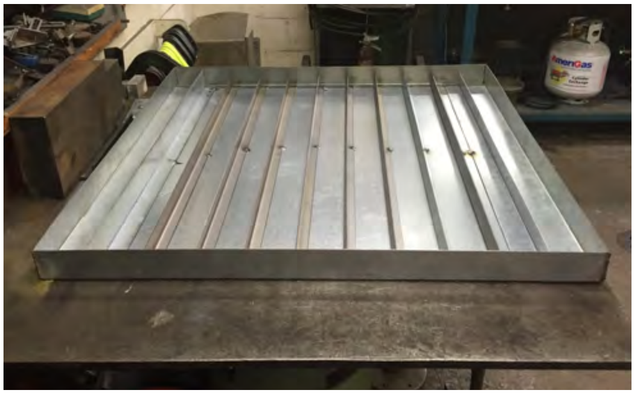




4. FINAL PROTOTYPE DESIGN/ARCHITECTURE

Solar Collector

Fabrication for the solar collector was similar to the original design. The welded box is 40 inches square, and weighs approximately 80 lbs. The sides were welded shut, with only two entrances for a thermocouple port on the right side and the welded adapter to which pipe could be attached.



Condenser

Unlike the solar collector, the condenser went through major design changes of the course of the project. From its original helical structure, the condenser become a ladder-shaped copper structure consisting of rungs with aluminum fins attached. This configuration offered superior heat transfer performance as well as a more straight-forward manufacturing process. The aluminum fins had holes punched into them and slid onto the copper tubing, after which they were affixed in position by a thermally conductive epoxy to both keep them in place and ensure excellent heat transfer properties. The condenser was designed to be angled at 45° in order to both save vertical height as well as allow liquid to properly flow downward once condensed.

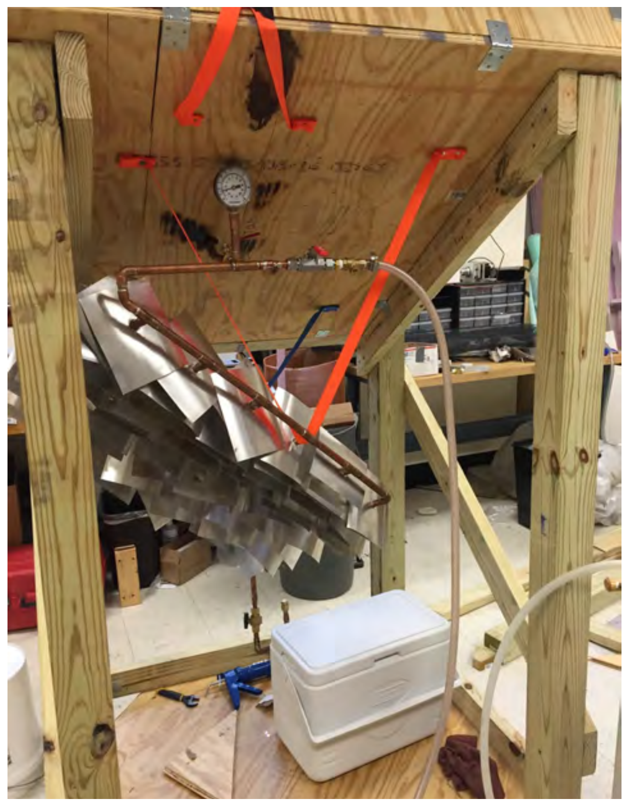
Evaporator

Fabrication for the evaporator was nearly identical to the initially planned design. Copper joints soldered together fit into the cooler used. The evaporator contained enough internal volume to hold the necessary amount of methanol. It was attached inside the cooler, below the condenser, and connected via a valve. It also possessed another capped entry point, into which liquid methanol could be added.

Supporting Structure and Constructed Prototype

The supporting structure, measuring 44 inches square, is made out of wood and holds all the working components of the prototype. The structure angles the solar absorber & greenhouse box at 30°, in order to be tested in Durham. In addition, it is mounted on wheels so it can easily be positioned towards solar south. The vertical nature of the system gives the prototype a smaller footprint and keeps heat sensitive components, such as the condenser and cooler in the shade.

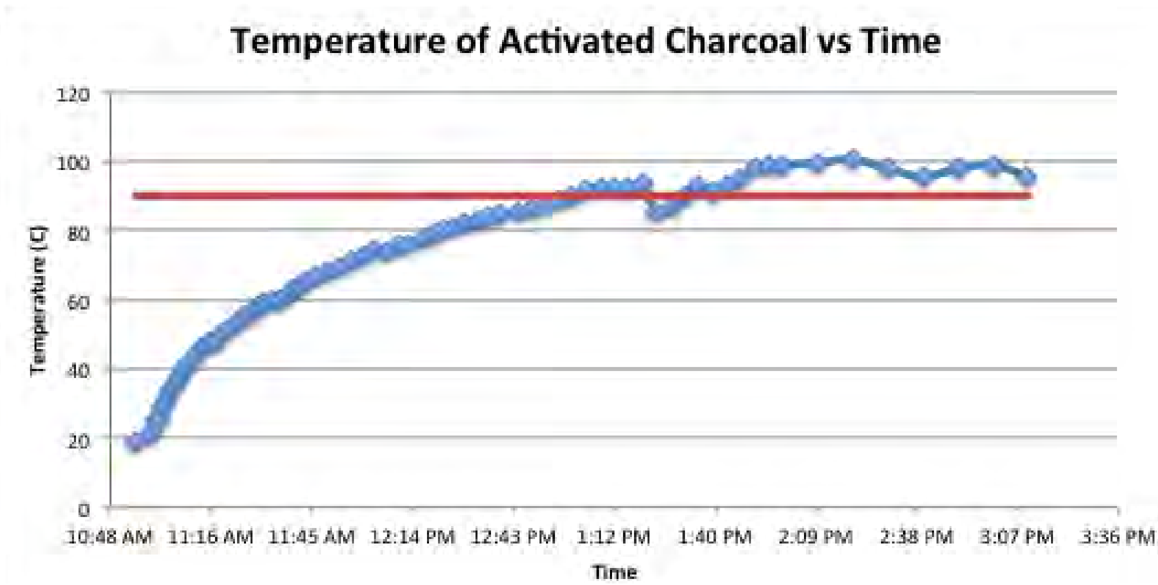
Three valves were used in the piping system, one on either end of the condenser, and another allowing the attachment of a vacuum pump. A pressure gauge was also added in between the solar collector and condenser in order to properly monitor the system.



5. EXPERIMENTATION AND RESULTS

Due to long stretches of inclement weather, uncommon to the regions in which DuiihDac would be sold and operated, we were only able to get test the prototype once. Moreover, due to several incomplete welds, the prototype could not yet hold vacuum pressure. This prevented full testing of the prototype's refrigeration cycle. However, we were able to test the heat absorbing and retention properties of the flat-bed solar absorber. Given the properties of our refrigerant and adsorption material, the solar absorber needs to attain temperatures of at least 90℃ for the methanol to desorb off of the activated carbon bed.

For testing, the solar absorber was aimed at magnetic south and temperature data was collected both before and after solar noon (1:16 pm EDST). The solar absorber surpassed the minimum temperature threshold of 90℃ for desorption shortly before solar noon and retained that temperature for several hours, reaching a peak internal temperature of 102℃. Importantly, data indicated that ambient temperature plays an important role in sustaining internal temperatures within the absorber, with peak ambient temperature occurring at 3:16pm EDST.



Testing of the solar absorber also revealed several prototype design flaws. Specifically, internal temperatures dropped quickly and significantly when stretches of clouds shielded direct sunlight. Given the insulation and greenhouse effect designed into the solar absorber, such dramatic temperature changes should not have occurred. However, inspection revealed that the polycarbonate sheet had warped over the testing period, breaking its seal with the insulation box and allowing large amounts of hot air to escape, especially during periods of shade. This flaw can be fixed by securing the polycarbonate sheet with more fasteners and caulking at the seams. However, even for this initial prototype, solar collector temperatures were able to easily exceed the desired temperature.

6. BUSINESS PLAN

Market Size of End-Users

Original Market: The DuiihDac refrigerator functions as both an offgrid vaccine refrigerator, addressing the refrigeration end-user market for all populations lacking reliable power. Currently, 23% of the world's population lacks access to reliable electricity, located in regions that are the most underserved in medical care and lack adequate nutrition. As an off-grid vaccine refrigerator, DuiihDac is well suited and affordable solution for the over 300,000 rural medical clinics worldwide that currently lack reliable power sources.

Supplemental Markets: Importantly, DuiihDac, as a general purpose ice maker, also serves additional end-users that extended beyond the scope of our original target market. Capable of preserving perishable foods, DuiihDac provides an affordable, off-grid solution for the 790 million people in developing countries who are undernourished and currently lose nearly 25% of food supply to spoilage.

While the dual use of the DuiihDac targets two different end-users, both medical clinics and off-grid populations share the same geographic areas, namely Africa's Meningitis Belt and rural South and Central America.

Target Customers

While the DuiihDac refrigerator end users are remote populations and clinics, target customers are confined to Global Health Organizations. These organizations not only have adequate funding to purchase our product, but also have existing distribution networks, local contacts, and expertise in target regions. Our biggest potential customers include the WHO, UNICEF, PATH and the Global Alliance for Vaccines & Immunization. All four of these Global Health Organizations have already publicly called for innovative, cheap, and flexible refrigerating solutions for the vaccine chain. Notably, the WHO and PATH co-founded "Project Optimize," tasked with using the latest technology to create better vaccine supply chains.

Pricing

The DuiihDac will be priced significantly under competitor products. While prototype costs amounted to $1,400, the DuiihDac can be produced for $400 when produced at a minimum scale of 30 units. As with any manufactured product, pricing will further decrease with any further increases in scale. This $400 price point puts it below the market price of existing PV and Kerosene compression-cycle refrigerators and even undercuts the cost of a WHO certified Coldbox, the non-sustainable cooler normally utilized for the last leg of the cold chain. Importantly, as the DuiihDac is fuel-free, there are no recurring or hidden fees.

	Prototype costs	Scaled costs
Activated Carbon	$3.08/lb	$0.70/lb
Plywood	$18.35/m3	$13.04/m3
Insulation	$10.24/m2	$1.50/m2
Steel	$0.84/lb	$0.25/lb
Methanol	$21.20/gal	$1.05/gal
Mesh	$3.12/ft2	$0.05/ft2
Total Cost (estimated)	~$1400	~$400

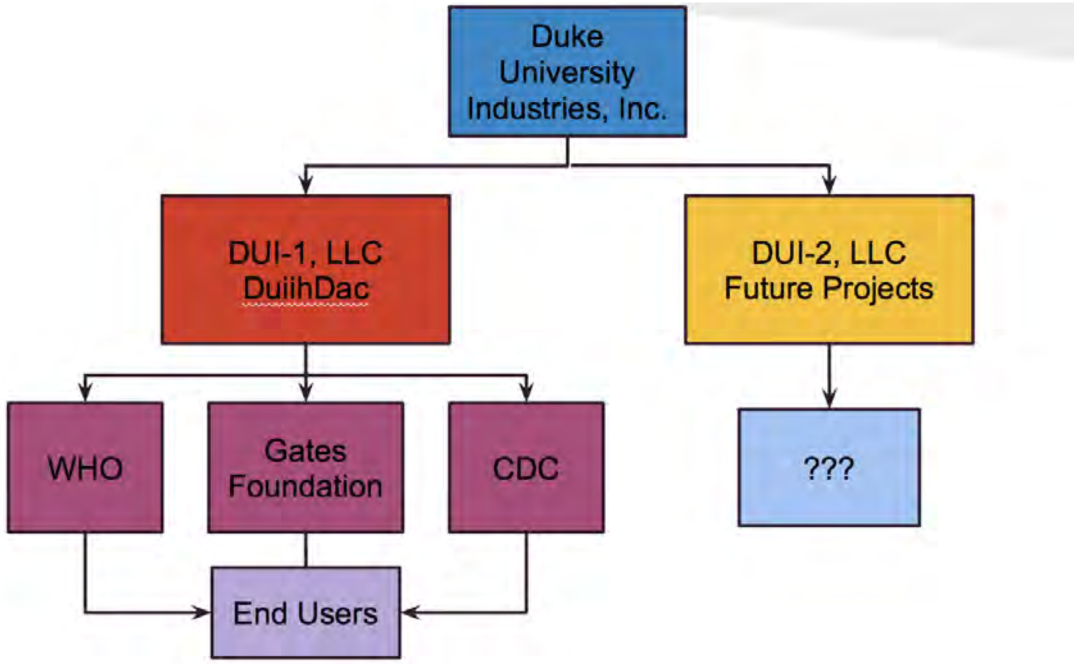
	Kerosene Fridge [1]	PV Electric Battery [2]	PV Direct Drive [3]	WHO Coldbox	DuiihDac
Initial Investment	~$1,500	$2,095	~$1,490	$798	$400
Fuel Costs / year	~$270 *	--	--	--	--
Total Costs	$1,770 + fuel	$2,095	$1,490	$798	$400

1 Reference model: Sibir V110
2 Reference model: Sun Frost RFVB 134a
3 Reference model: Vestfrost MKS044

* Low end average based on average kerosene fuel costs in Ghana, 2014

Corporate structure

Duke University Industries (DUI) will have a multi-tiered structure consisting of a main holding company (Duke University Industries, Inc.) and smaller limited liability companies that will hold the assets for current and future projects (Duke University Industries-1, Duke University Industries-2, etc.) The main holding company will retain ownership of all assets that span across the entire company, such as facilities and employees. The LLCs will hold all project specific assets. DUI-1 will hold all intellectual property, inventory, and research associated with the DuiihDac refrigerator. Through DUI-1, individual units could be sold to potential distributors such as the WHO, product rights could be licensed to interested third parties so that they could handle manufacturing and distribution, or the entire LLC with its assets could be sold to an interested buyer without the potential consequences of employees and other major company assets being absorbed by another company. Along with protecting the major assets of the holding company, the multi-tiered model allows for multiple avenues that potential investors can take that are tailored more closely to their specific goals.



Funding Strategy

DUI will aim to avoid potentially dilutive Venture Capital funding that would both disincentivize private investors and also limit the company's decision making capabilities. Although somewhat more difficult to attain, DUI will seek private investment from family firms, government grants, and interested organizations such as the Bill and Melinda Gates foundation will allow the company to retain its original purpose and goals. DUI will additionally seek out strategic partnerships with various Global Health Organizations, many of whom are target customers, in order to leverage their pre-existing supply chains and soft networks in target markets.

Investors and partners should be attracted to DUI due to its corporate structure and active dividend program. They will have the opportunity to invest directly into individual project LLCs, giving them more agency over where their dollars go and shielding them from risks associated with other DUI products and projects. Additionally, investors will receive regular dividends and will get preferred payout based on differential stock options based on multiple offerings throughout the development process.

Timeline and Uses of Capital

3-6 Months: For the first 3-6 months of development, the company will be looking mainly for investment partners who are looking to invest in the entire holding company itself along with loans to create an initial base of capital for facilities and employees. Initial funding would capitalize the holding company and facilitate the creation of each LLC. Initial investors will find this attractive, obtaining attractive yield from dividends issued at the parent company and project subsidiaries. In this period, initial optimization and supply chain development for the DuiihDac refrigerators will take place, moving from its current prototype state to a more practical model better suited for transport to the remote areas the product is intended for.

6-12 Months: After this first period of investment the 6-12 month range of the business will have a second round of investment where investors can begin investing in DUI-1. During this period DUI will begin initial sales and distribution of DuiihDac systems and revenues will be used for initial payouts to original investors.

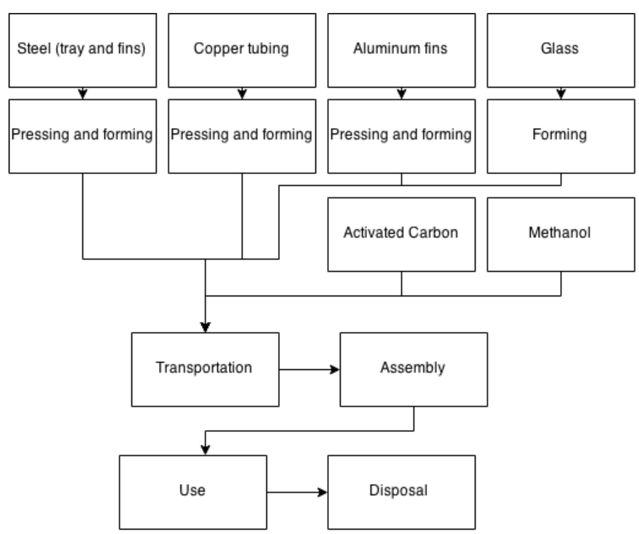
Year 2: For the future after that the company will continue to seek investors in DUI-1, but will also begin looking for potential buyers of the project or anyone interested in a licensing agreement. Once sold or licensed, the money from the transaction will be paid out to investors and then extra profits will either be put towards expansion of the parent company, or into one of the other DUI LLCs that will be in the early development stages of a project. Regardless of whether DUI-1 is bought at this point, development into other projects will begin to diversify the company's assets and to allow it to grow.

7. ENVIRONMENTAL ANALYSIS AND SOCIAL IMPACT

Before scaling up the production of the DuiihDac for worldwide use, it is important to get a sense of the environmental and social impacts that will result from the production and use of the product. Our analysis of the potential environmental impact consists of two parts: a Life Cycle Analysis of the ice maker and an estimate of the avoided carbon emissions resulting from the use of the ice maker. Our analysis for potential social impacts incorporates immunization, nutrition, and other health considerations.

Life Cycle Analysis - Ecopoint 99 LCA

A Life Cycle Analysis (LCA) is a common method used to quantify the total impact a product has on the environment throughout its entire lifetime. There are many ways one can conduct an LCA, each one highlighting different types of environmental harm, the most common being lb CO_2e. Some LCA systems consider multiple types of harm at once, weighing each type to arrive at an approximation of the total harm caused by a product. The Ecopoint 99 LCA system utilizes this strategy, recognizing three different types of harm: human health, ecosystem quality, and depletion of resources. Developed specifically to inform the product design process, the Ecopoint system quantifies harm into a point system, allowing designers to understand what materials and processes of the product have the biggest impact on the environment (Eco-indicator 99 Manual for Designers, 2000).



The Ecopoint 99 LCA process starts with a catalog of the materials used, the way the materials are processed, the distance and method they are transported, the amount and type of energy used to construct the product, the amount of energy used during the "use" of the product throughout its lifetime, and the energy used to dispose of the product. (See figure above.)

Then, each material that is included in the map is assigned a point value for the harm resulting from the production and processing of that material. One point is equivalent to 0.10% the impact that the average European has on the environment annually. The results of this step is represented in a table below.

	Volume	Density	Mass (lbs)	MPoints/kg	Milli points	% of total
Steel	211.97 cu in	4.65 oz/cu in	61.60	86	2408.12	18.23%
Pine	7680 cu in	2.17 lb/ft	173.32	39	3072.64	23.25%
Activated carbon	-	-	50	180	4090.90	30.96%
Insulation (PUR Hardfoam)	1728 cu in	0.14 lb/sq ft	2.24	420	427.64	3.24%
Copper pipe	15 ft pipe, 1/2" diameter	2.85 lb per 10 ft	4.28	1400	2720.46	20.59%
Casters (PS (HIPS))	-		2	370	336.36	2.55%
Methanol	2 L (0.002 m3)	791.80 kg/m^3	1.58	99	156.78	1.19%

The total ecopoint score resulting from the material used is 13212.898 millipoints. Considering the obscurity of the unit, "millipoint", the total score is not very useful in evaluating the design choices made. Instead, it is more useful to evaluate each material individually. From this, it is clear that the activated charcoal is the most environmentally harmful material used in the ice-maker. The second most harmful material used is the wood used in the frame, followed by the steel used. While it is unlikely that the charcoal could be substituted for a less harmful material, an energy efficient alloy could be used instead of pine wood.

We were unable to quantify the harm resulting from the disposal of the ice-maker because the publically available Ecopoints 99 Manual does not assign points to the disposal of the materials we used. However, in the United States, both methanol and activated charcoal are treated as hazardous substances. There are no available estimates of the energy used in the treatment of the two materials nor of the harm imposed by the improper disposal of the materials.

The results of this environmental analysis are limited in many regards. First, we were limited to the point values enumerated in the Ecopoints 99 Manual from 2000. This manual did not specify point values for the exact materials used in in the ice-maker. For example, we used the point value assigned to "General organic chemicals" to represent the environmental harm caused by methanol. In addition, we did not take exact measurements of the mass of each material used, so we used approximate volumes and general density conversions in order to estimate each mass.

For example, we do not know exactly how much steel we used for the solar collector, so we multiplied the volume used by the typical density of crude steel.

Avoided Emissions

Another useful metric of the environmental impact of the product is the emissions that are avoided by using the product. It is important to note that the current practice of refrigerating vaccines with ice boxes has minimal associated emissions.[12] However, the service delivered is low quality in that the vaccines cannot be refrigerated after one week, at most. As a result, we will be comparing the emissions of our product to the emissions that result from pathways that deliver the same quality of service. Other than a solar adsorption ice maker, the two most common ways of refrigerating vaccines are refrigerators are refrigerators powered by an electrical grid and refrigerators powered by a kerosene generator. A 1.7 cubic ft refrigerator, which is approximately the same size as the cooler box used in our design, requires 360 kWh a year to operate. If that electricity is provided by a grid that is powered by the combustion of bituminous coal, the operation of the refrigerator would result in 745.3 lb CO_2 released. If the same refrigerator were powered by a kerosene generator, its operation would result in 206.4 lb CO_2 released per year. Because the operation of the DuiihDac does not consume any electricity, it is assumed to release 0 lb CO_2 per year.

Potential Social Impact

In its capacity as a vaccine refrigerator, the DuiihDac can help reduce the 50% of vaccines that currently go to waste in developing countries due to breaks in the Cold Chain. With a reliable, portable, off-grid refrigeration mechanism for the last steps of the vaccine cold chain transport, over 3 million vaccine-preventable deaths can be avoided while also facilitating the widespread use of vaccines (Immunization). By having an easily transported refrigerator, vaccines will become more accessible, and consequently, we can reduce resource consumption, saving over 2.5 billion vaccine does a year (Vaccination). [6]

In its capacity as a food refrigerator, the DuiihDac provides the potential to increase food availability and storage in the developing world, which loses 23% of its food from poor refrigeration. With a larger availability of food, DuiihDac can aid in feeding the 790 million undernourished people in the developing world. [1]

One possible negative consequence of this alternative refrigeration cycle is the use of methanol. If methanol leaks, it could contaminate the vaccines or food sources. Since methanol is toxic to human health, we have taken many precautions to prevent leakage in the DuiihDac; however, it remains as a rare, potential, negative social impact.

8. CONCLUSIONS & NEXT STEPS

The DuiihDac refrigerator design has the capability to increase the efficiency and efficacy of the Vaccine Cold Chain and food storage capabilities of developing countries with its off-grid, no maintenance, and affordable design. Future efforts should look to complete the working prototype and to condense the physical scale of each unit.

Next steps: Several next steps are needed to make the prototype work. Before the system can be fully tested, the following adjustments will have to be made: to be made to the prototype.

1. Identifying all leaks and sealing them to ensure a vacuum
2. Retesting the heating of the system under vacuum pressure
3. Adding methanol
4. Running a full cycle

Future progress: After the prototype has demonstrated the feasibility of the refrigeration cycle, substrate and absorbent pair, and basic design, future iterations should seek to downsize the scale of the entire unit. At smaller sizes, the refrigerator could possibly be housed in one, fully portable unit that could be more easily transported. Future iterations should also attempt to scale down the cost of the design in order to actually allow the system to be implemented in the developing world.

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APPENDIX A: User Manual

The DuiihDac system's valve-less cycle is designed for minimal operational maintenance when running properly. Once fully functional, operating the system should consist of only moving the adsorber box in the direction of solar south. Intermediate functionality could require a rechecking of the vacuum and opening of the valves for operation.

Initial Setup

The DuiihDac prototype is preconstructed and mounted onto the frame. Setup includes two steps.

Step 1: To activate the refrigeration cycle, liquid methanol must be added to the system. 0.320 L of liquid methanol should be added through the Endcap located next to Valve 2 (see photo below). After filling, resecure the endcap.

Step 2: Attach a vacuum pump to any of the three valves and draw down the pressure to less than 5 PSIA. Verify the system pressure on the gauge attached at the top of the condenser. While drawing a vacuum it may be advisable to open the system section by section.

Orienting the DuiihDac

Step 1: Locate true solar south in your location to optimize the solar absorption of the system. To do this, find the solar declination in your area based on longitude, latitude, and time of year. NOAA offers a handy online calculator that can assist in finding solar declination in your area. If, for example, your area has 9°W, that means that magnetic north is 9° to the west of true north. Thus, to find true north, correct 9° towards the east of the where the needle is pointing. Then, to get solar south, add 180°. http://www.ngdc.noaa.gov/geomag-web/

Step 2: Locate the DuiihDac in an area that is clear of trees and structures that might project shade on the solar absorber throughout the day.

Checking the System

Periodically the system will have to be checked. Check thermometers within the cooler to ensure adequate refrigeration has been obtained. Check the pressure gauge above the condenser unit to ensure vacuum pressure has been retained in the system. Finally, check the caulking and fastenings around the greenhouse box to avoid unnecessary efficiency losses.