Aerem

Team Caeli

https://www.youtube.com/watch?v=fsCK2p9HXZs

Company Introduction

Global warming is one of our world's leading problems. United by our common goal to slow global warming through technological means, we formed team Caeli, a group of seniors interested in environmental innovation. Through combining our knowledge of engineering, chemistry, and entrepreneurship, we developed Aerem.

Our different experiences this past summer provided us with different skill-sets needed to develop Aerem. John interned with researcher Dr. Chen at the NASA Ames Centre, where he learned about engineering and computer-aided modelling. He also studied management at Wharton Leadership in the Business World program. Meanwhile, Grace studied entrepreneurship at MIT Launch, where she learned about marketing strategies, product management, and prototype design. Finally, Max interned at Boston University, where he researched the effects of ion irradiation onto different nanosurfaces. There, he learned about nanostructure processing and the chemistry behind them. After discussing our summer experiences with each other, we realized that all three of us were interested using creative technological innovation to create social impact. Sharing the skills we learned over summer, John focused on the technological aspects, while Grace and Max created a business plan and marketing strategy. Our team's versatility between both the engineering and marketing sides allowed us to help each other create Project Aerem.

Originally, we struggled to find a way to adapt this technology from spacecraft usage into typical household usage. However, after breaking down our technology into different aspects, we realized that we could utilize the aspect that converted carbon dioxide into hydrocarbons as a way to reverse the cycle of hydrocarbons into carbon dioxide. We decided to center the idea of Aerem around slowing global warming through this cycle. Another problem we struggled with was that simply having a green aspect wasn’t enough incentive for consumers to buy our product. After brainstorming different usages for natural gas, our group decided to advertise Aerem as a heat generator for the average consumer in order to break into the market. Once Aerem grows traction, we plan to target the natural gas industry by marketing Aerem as a way to save money on natural gas creation through renewable means.

Business Prospectus

Business Description

The mission of Project Aerem is to develop and distribute a special renewable energy product for the general population. Our product collects energy from sunlight to convert carbon dioxide and water to oxygen and methane, a source of energy.

Aerem is unique because it is much more technically versatile than existing products, making it marketable to a large variety of audiences. Our device does not require special temperature or gas conditions, takes no electrical input, can come in any shape, and does not easily wear.

Renewable energy is a rapidly growing industry, with global investments growing sevenfold in the past decade and more job opportunities created than both the coal and oil industries. Due to its design, our product carves a niche in multiple industries related to energy sustainability:

- **Solar energy:** The solar industry is currently shifting from household-level endeavors to larger-scale markets such as district heating systems and factory settings. This is due to more projected efficiency in targeting these areas. Project Aerem can help revitalize *household* renewable energy products because it is more affordable than solar panels and more marketable due to benefits in combating climate change.

- **Natural fuels:** The energy returns from fossil fuel extraction are diminishing exponentially as humans need to probe deeper into the Earth's crust. Requirements for fuel extraction, transport, and refinement are rapidly rising, outpacing technological developments and making energy collection more difficult. By creating natural gas in each and every household, our product alleviates some of the burden of fuel extraction and has the potential to significantly reduce the costs of fuel transportation.

Project Aerem will be helped by its marketability. Because it may be entirely 3D printed, it can be produced much cheaper than solar panels and be distributed more widely. It will tackle an audience that related industries have largely leftk untapped. Finally, Aerem's side effect of converting carbon dioxide to oxygen brings a humanitarian appeal, leaving it eligible for potential government funding.

Ultimately, Project Aerem has the potential to activate a large platform for energy sustainability: households and industries across the world.

Market Analysis

Our market strategy consists of three major stages: initial, expansion, and regulation. In the initial stage of our plan, our company will be targeting the consumer market, building Aerem for individual household use. We plan to hire a team of contractors to install Aerem in the ventilation systems of private buildings, working to create change at the grassroots level. In particularly polluted areas and green-aware communities, it would also be possible to contact the local governments to seek tax and other benefits for the individual to receive after installation, to add an additional monetary incentive to implementing Aerem. Due to the space-saving nature of Aerem, we seek to begin installation in large city apartments and other areas with low air quality. In this stage, our team will seek government grants for further research and development of the Project, as well as for the initial methods of production.

The expansion stage of our company will consist of large investment towards creating more production and increasing the scope of our market. With a steady source of revenue from the consumer market, we will look to invest a large percentage into factories, transportation, and contractors. Targeting not only individual household use, we will start to seek licensing deals with energy companies. After foresting and farming, energy companies have been shown to release the greatest amount of carbon into our atmosphere. Large corporations like Exxon and BP have significant investments in carbon capture technology; by licensing Project Aerem, they look to significantly reduce their carbon emissions at a low cost.

As our company gains more traction in both the consumer and industrial markets, the last stage of our plan would constitute government contracting. We look to have Aerem become an integral part of pollution regulation both at home and abroad. At this stage, with our effectiveness shown in both industry and commercial markets, it would be crucial to pursue government contracts for a final, large expansion.

Our choice of market is due to the nature of our product. While special conditions (waste heat, excess materials) could make other energy sustainability methods more suitable than Aerem in many industrial cases, Aerem can be widely distributable as a home product. Because Aerem is relatively cheap and does not require advanced infrastructure to install, our consumer body can be incredibly diverse and large.

Competitive Analysis

Home Sustainable Energy Systems

Although various micro-hydropower, wind, and solar systems exist for household use, the most common energy system currently involves solar panels. Aerem is better than solar panels in these ways:

- **Cheaper production:** Solar panels cost over $10,000 for the average household to install. The 3D-printed nature of Aerem makes it significantly cheaper and affordable for a wider range of consumers. We estimate it to cost $4,000 per unit.

- **Environmental benefits:** Aerem, in addition to harnessing sunlight to create fuels, converts carbon dioxide to oxygen. This has positive implications on environmental sustainability and can be stressed to encourage the public to use this product.

Competing Technologies

Although no products similar in nature to Aerem exist in the market, there are various competing technologies in development that involve converting CO_2 to hydrocarbons. These include pyrolysis, electrolysis, conventional PEC, and the Sabatier process. Aerem uses a High Tortuosity PhotoElectroChemical (HPTEC)system, which has distinct benefits over competing methods:

- **Low input requirements:** it requires no special heat or electrical input. Reactants include CO_2 and H_2O, both of which are found naturally in the atmosphere.

- **Versatile:** HPTEC is a relatively simple process and doesn't require special storage tanks or air compressors. This allows for Aerem products of all shapes and sizes, fitting the dynamic needs of the various houses across the globe.

Cost

R&D:

The cost of completing Aerem to be reliable and efficient enough to market on a mass scale depends on two factors: the quality of researchers and the funds set aside for them. Because Project Aerem was originally a NASA-sponsored project, and is in the second stage of funding for NIAC, it shows great promise. Because the timetable is unclear as to when it is projected to be perfected, as well as the fact that there is already a working prototype, we will estimate the costs as if the product design is already completed. Of course, further research will be done to improve the current working model but the main focus in the initial stages would mainly be production.

Production

Project Aerem's main cost of production will come from the 3D printers. We have decided on the Fortus 250 MC model, costing $45,000 apiece, due to its large printing capabilities and its relatively high resolution in printing. In the first year, we estimate two printers would be enough; each unit would take roughly one week to print and complete. The staffing would consist of one technician, paid full time to run the two printing machines. An average salary would be $37,386 according to GlassDoor. Contractors would be hired at a fixed rate, averaging $90,162 in one year for all the installations. Finally, it gets down to the material costs of both the structural material as well as the catalyst material. The specific type of acrylic we use costs roughly $3 per cubic meter, which is the amount we use in one full unit. The copper and titanium dioxide average costs are $6.50 and $7.50 per unit respectively, depending on the shape and density of the required structure. The processing to create the catalyst is roughly $10 a unit, calculated by the cost of renting the laboratory we used to develop the technology. It will be created by our team independently to reduce costs and preserve patented information.

In total, the costs of production for the first year come out to be approximately $220,748--a large portion of which consists of the printers.

Innovation Summit

The Summit will cost about $1000 per person (three nights at $200/person, $200 round trip flight tickets, and $200 allowance for food and accomodation).

In total, the project will cost roughly $221,748.

Funding Sources

Caeli plans to raise money to build and distribute Aerem through three main methods.

Our main method of raising money will be through crowdfunding on fundraising sites. Because the people who donate money to our cause are part of our target market of consumers, we will be able to spread word about our product to potential customers as well as gauge their interest levels. Online platforms such as GoFundMe, YouCaring, and CustomInk will help us gain the traction we need to jumpstart Aerem. We hope to raise $60,000 from these platforms, which will help us cover 27% of our cost.

We also plan to apply for funds that emphasize social innovation. For example, the Humanitarian Innovation Fund supports groups that offer innovative and scalable solutions to global challenges on humanitarian issues. By emphasizing Aerem's mission to slow global warming and revolutionize the natural gas industry, we hope to gain support and seed funds from at least one incubator or outside organization. Other social entrepreneurship funds we plan to apply to include the Global Innovation Fund, Verizon's Powerful Answers Award, OCHA Humanitarian Research and Innovation Grant, Google Org: Impact and Community Grants, Deloitte Humanitarian Innovation Program, WFP Cooperating Partners Innovation Fund, and the UNICEF Innovation Fund. We also plan to apply for young entrepreneurship funds, such as UnLtd, which funds social entrepreneurs under 21, and TOMS Social Entrepreneurship Fund, which funds entrepreneurs focused on global impact. Through emphasizing the marketability of our product, we hope to to raise anywhere from $20,000 to $30,000 through these incubators.

In addition to seed-funding, we plan to participate in entrepreneurship pitches that award prize money to winning teams. Because we will be college students by the time we kickstart Aerem, we plan to participate in college competitions that offer cash awards to the winners such as MIT Clean Energy, the Harvard Business Plan Competition, and the Wharton Business Plan Competition. However, because of the competitiveness of these competitions, we are not relying on funding Aerem through contests.

We also plan to partner with environmental nonprofits, such as Greenpeace and Echoing Green, to raise money for Aerem. Green nonprofits focus on environmental sustainability, which aligns with Aerem's renewability of the carbon dioxide into natural gas cycle. In addition to this, Aerem can slow global warming and even prevent it if produced enough in large scale, which is highly appealing to green nonprofits. Implementing 100 units of Aerem, targeting the most carbon-rich air in our atmosphere, costing roughly $40,000 in materials and installation, is multitudes more beneficial for our planet than planting 100 trees, costing roughly $13,800.

As a last resort, we would rely on private investments from members in our community to raise the necessary funds to build Aerem.

Because Aerem is working towards a humanitarian cause, we will not raise money through selling equity. We hope to retain total control of our company to ensure that our commitment to slowing global warming will not be overturned by purely financial motivations.

Our planned efforts total to a starting fund of around $90,000, which is enough to build and sell 30 units. Because we profit $1700 from each unit we sell, we would be able to grow our product at a rate of 25% per quarter. Building a unit will take us around 1 week, and so if we continue to grow Aerem at the same rate, then we will be able to make $170,000 annually. Additionally, once we finish our product development and break into the market, we plan to expand our methods of funding by applying for government grants from both the United States and other first-world countries, such as China. By selling units of Aerem, partnering with green nonprofits, and applying for incubator funds and government grants, we plan to expand Aerem.

Technical Concept Report

Technical Summary

Our concept is a transformative photoelectrochemical system that relies on one main technological innovation, our catalyst, and the scientific principles of gas flow and light permittivity.

Catalyst

On the surface of the structure is a deposited, breakthrough co-catalyst composed of Cu and TiO_2. Using gas chromatography, it has been shown that the catalyst has a quantum efficiency of 10% , activated solely by light. The chemical equation for this transformation is:

$$CO_2 + 2H_2O + h\nu \text{ (light)} \rightarrow CH_4 + 2O_2$$

This is essentially the reverse of the combustion process, where under the law of conservation of energy, light makes up for the difference.

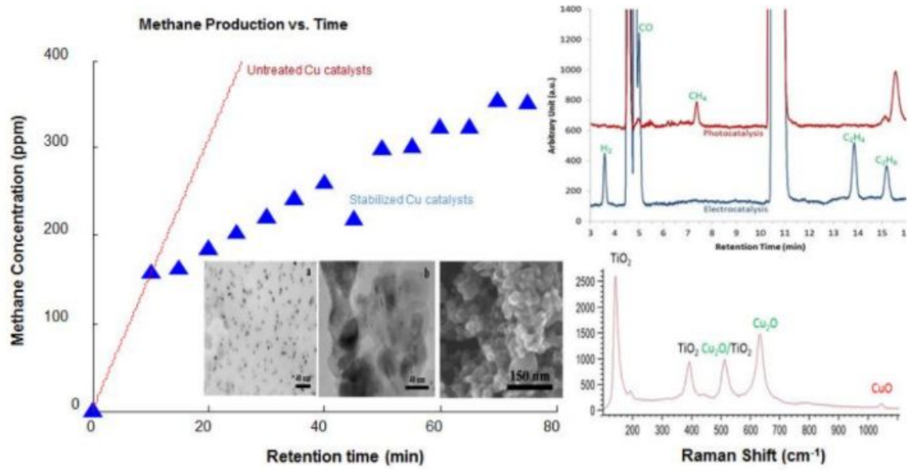


Fig 1 *Left:* CO_2 conversion rate measured by careful gas chromatograph GC analysis of methane using passivated Cu NPs (See inset TEM and SEM images) supported on TiO_2 nanoparticle films. *Right:* GC identification of carbon species, and Raman monitoring of the degree of oxidation of Cu NPs.

In the leftmost graph shown above, we can observe the steady increase of methane concentration from carbon dioxide, using a small sliver of the catalyst. The top right graph shows the identification of other hydrocarbon products such as C_2H_4. The bottom right graph monitors the oxidation of the copper.

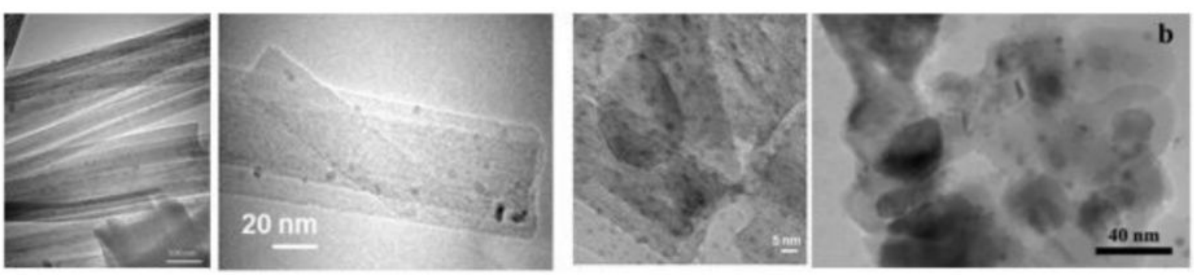
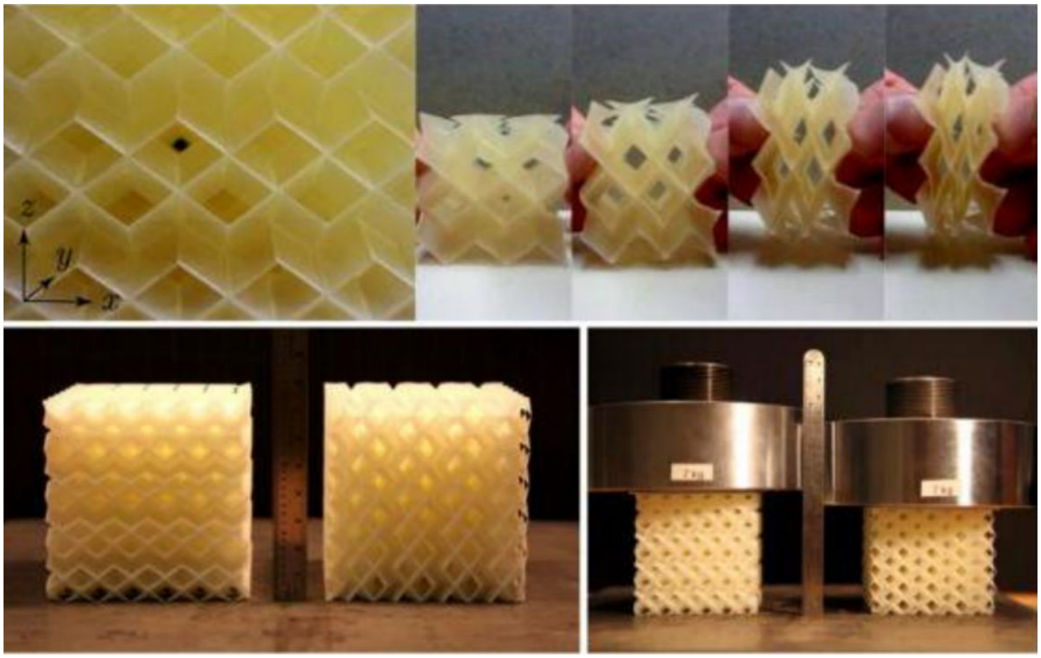


Fig. 2 TEM image shows the Cu NP (3-5 nm) catalyst stabilized onto TiO_2 nanostructures in tunable concentrations for gas absorption and conversion

It has been shown that the titanium dioxide absorbs photons to generate electrons and hole pairs(excitons); in other words, absorbing the energy from light to excite its electrons. This is due to the tendency of electrons in transition metals to jump energy levels when absorbing photons. The copper nanoparticles present in the catalyst trap the excited electrons, harnessing their energy and using it to break the double bonds between carbon and oxygen in CO_2. Meanwhile, the water vapor nearby the copper nanoparticles are electrolyzed as the hydrogen protons bond to the highly electronegative carbon ions, creating methane. The remaining oxygen ions from the CO_2 and H_2O neutralize each other, bonding to create neutral, diatomic oxygen gas.

Structure

As far as the structure goes, the design has to have both sufficient gas and light permittivity. Fluid dynamics is taken into consideration. The current design has a high-tortuosity (lots of bends and curves) maze-like structure, designed to be both space-efficient and allow for sufficient exposure of the air to the active sites of the catalysts. However, the tortuous airways must be smooth enough in order to avoid trapping sediment and other contamination during the reaction process over time.



Need Statement

Aerem is geared towards the many different sectors of industry by providing a renewable, eco-friendly, and cost-efficient means to produce natural gas. Some industries that are highly reliant on the production or usage of natural gas include the water heating industry, the energy industry, and the home appliance industry.

In our world today, efforts to curb global warming have involved reducing carbon emissions by imposing fines and restrictions upon foresting, energy, and gas companies. While this method is effective somewhat, often times it curbs production and incurs job losses. This method, as well as other carbon sequestration methods, are either passive methods that are unrealistic or kicking the can down the road (burying the carbon dioxide in storage vats). Project Aerem seeks to target the issue at its roots, closing the link between natural gas harvesting and combustion. In time, we envision Aerem fully creating a sustainable energy source with zero net gas emissions into our atmosphere.

In the Energy industry today, oil and gas companies scramble to meet government regulations and improving public image. According to Bloomberg, Exxon, the world's most valuable oil company, invests roughly $1 billion a year on green energy research. Efforts by foresting and farming companies are similarly tremendous to improve the condition of our atmosphere. However, their efforts prove to be too slow, as carbon levels in our atmosphere have risen to a levels unprecedented in Earth's history (400 ppm).

Project Aerem aims to take a long term approach to this problem, removing carbon dioxide from our atmosphere at an increasing, geometric rate. As more and more units are installed, we envision a snowball effect that would one day fully meet our carbon emissions.

Background Technology

The concept of converting carbon dioxide in the air has been continuously improved and tested upon, especially in spacecraft use and on the International Space Station. Mostly centered around the space industry, the current technology that has been developed has mainly been focused on time and space efficiency. Aerem takes a different approach, focusing mainly on sustainability. It is designed to be self-sufficient and long-lasting, leaving a slow-moving but steadily increasing positive impact depending on its scale.

Competing Technologies:

Table 1 Mass, volume and power budget of conversion reactions

	Mass payload	Volume footprint	Electric Power	Quantum efficiency	Typical catalysts
This approach	< gram	< meter ^{3}	negligible	10%	TiO_2/Cu, Co, Ni
Photocatalysis	> gram	< meter ^{3}	negligible	< 1%	TiO_2
Conventional PE	> kilogram	< meter ^{3}	< 100 W	< 1%	TiO_2, Cu, Ni, Co
Electrolysis	> kilogram	< meter ^{3}	> 100 W	> 50%	Au, Pt
Pyrolysis	> kilogram	> meter ^{3}	> 1000 W	> 50%	Pt, Pd
Sabatier	> kilogram	> meter ^{3}	> 1000 W	> 50%	Ru

3 orders of magnitude payload saving

high efficiency, low cost

Key Differences

- No electricity--Project Aerem relies solely on UV rays for energy, as opposed to a costly supply of electricity. Besides the initial cost and relatively minimal upkeep, companies and individuals who invest in us will not suffer the tremendous electricity costs of the existing technologies.

- Space allowances--with its high tortuosity structural design, our product is is several times more space efficient than existing technologies. Aerem will be able to fit in the tightest corners, allowing for the targeting of the most carbon dioxide-rich air.

- Installation simplicity--all of the other processes that remove carbon dioxide from the atmosphere rely on complex and fragile chemical processes that have additional requirements such as pure hydrogen gas or aire devoid of any water vapor. These requirements make any existing technologies impractical to be implemented on a terrestrial level. Aerem can be fitted onto any HVAC (Heating, Ventilation, and Air Conditioning) system for immediate use. It's foldable and sculptable nature also allows for even more flexibility in installation.

- Cheap Production--The majority of the cost of production lies in the production of the structure, which is reliant on 3D printing of acrylic and resin. The catalyst is cheap to produce in bulk; with the absence of the need to install any additional supporting structure, the cost is kept at a very low level, reducing even more as we scale up.

Concept Details

Aerem is a High Tortuosity PhotoElectroChemical (HPTEC) system adapted for household use. It runs carbon dioxide and water through a system of tortuous, light-exposed pathways lined with a special catalyst in order to carry out this chemical reaction:

$$CO_2 + 2H_2O + h\nu \text{ (light)} \rightarrow CH_4 + 2O_2$$

TiO_2 harvests light energy to generate electron and hole pairs (excitons). Since they are separated within a few hundred nanometers, Cu nanoparticles (NPs) trap the photoelectrons and activate the C=O bonds in CO_2. As both electrocatalysts (Cu NPs) center for C=O from CO_2 and photocatalyst center for protons from water are designed within nanometer reaction distance, internal charge transfer is sufficient with no need for an external electricity circuit.

<u>Potential Research</u>

There are two main considerations for the device that will require research:

(1) Facilitating an efficient reaction
(2) Creating a space-efficient structure

<u>Chemical Reaction</u>

The HPTEC system relies on a key innovative component: a co-catalyst design. This means that the device will rely on tubing lined with a hybrid catalyst: TiO_2, a typical photocatalyst to collect light, and a metal in order to trap photoelectrons for the CO_2 reduction reaction. The current co-catalyst used is Cu-TiO_2, but more experiments are needed to further develop the device's efficiency and investigate alternative methods. Research needed includes:

- **Catalyst Refinement:** Constructing a test device in order to evaluate the performance of the Cu-TiO_2 co-catalyst. Raman spectroscopy and gas chromatography can be used to analyze Cu-TiO_2 selectivity of hydrocarbon compositions, with the ultimate goal of refining its selectivity and longevity.

- **Reactant Conditions:** Investigation of the optimal CO_2 and H_2O ratios for the reaction, as well as the ideal temperature and humidity conditions for the reaction would help optimize the installment of the device.

- **Possible Alternatives:** Studying the conversion efficiencies of not only Cu-TiO_2 but also Ni-TiO_2, as well as other potential metals for the co-catalyst. This will provide alleyways to not only optimize the current HPTEC system but also explore the generation of other hydrocarbons for potential alternative methods.

The current HPTEC method has been shown through experimentation to have a 10% quantum efficiency, similar to the rate of commercially distributed solar panels (14%), but at a much cheaper cost. Further research for its efficiency could help make it even more appealing.

System Structure

Aerem's structure must facilitate an efficient reaction but also be space-efficient and versatile. In order to do this, it must hold the co-catalyst well, but also be lightweight and flexible. It needs to contain airways full of twists and turns, but these tortuous pathways must be designed to avoid trapping sediment. Experiments to develop this technology include:

- **Catalyst Deposition:** Research will be needed to figure out the best method for depositing co-catalyst on acrylic substrates (Aerem's framework will be made out of acrylic). Research will reveal the optimal flow and pressure conditions in order to coat the acrylic with the catalyst at an optimal configuration.

- **Optical Configuration:** The optimal device would be configured to capture as much light energy as possible to facilitate the reaction. Studies to determine the optimal angles of the pathways and their effect on the power distribution and transmission of light throughout the device would be needed to refine Aerem.

- **Scaling Up:** How will our proof-of-concept design be scaled up to a household product? One appeal of the HPTEC is its ability to easily be implemented into HVAC systems. However, research will be needed to detail steps of implementation.

Graphic Concept Representation

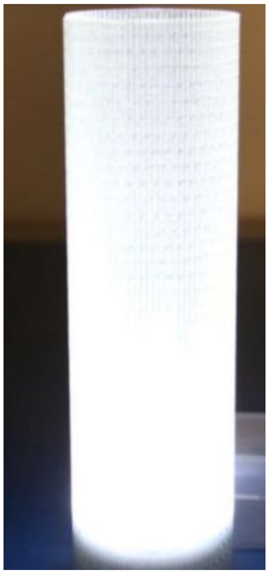


Figure 1: A concept design showing optics capabilities, carrying light using a transparent resin structure

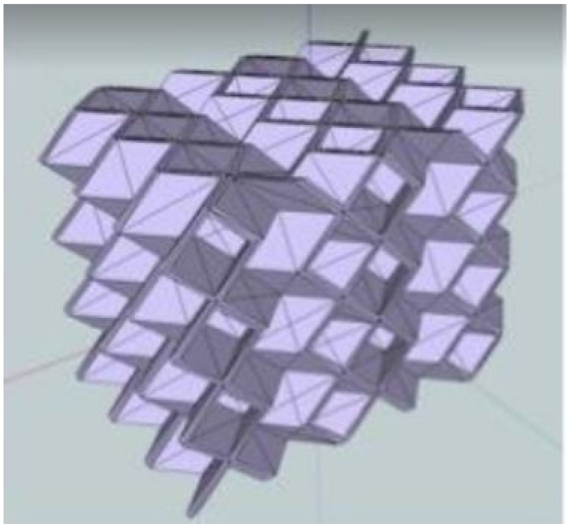


Figure 2: A computer modelling of the crystalline structure

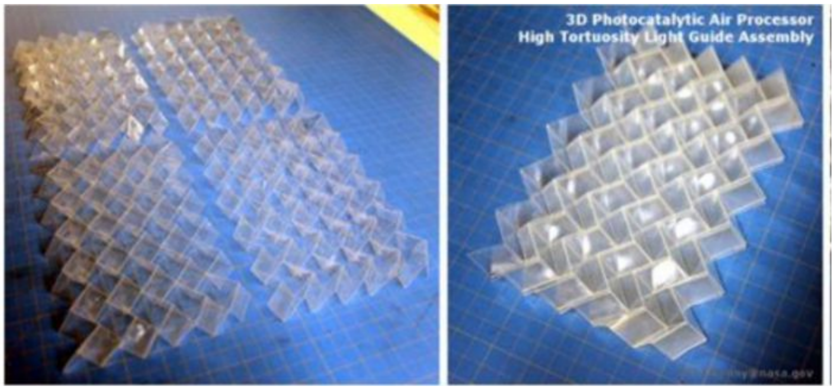


Figure 3: Printed structures

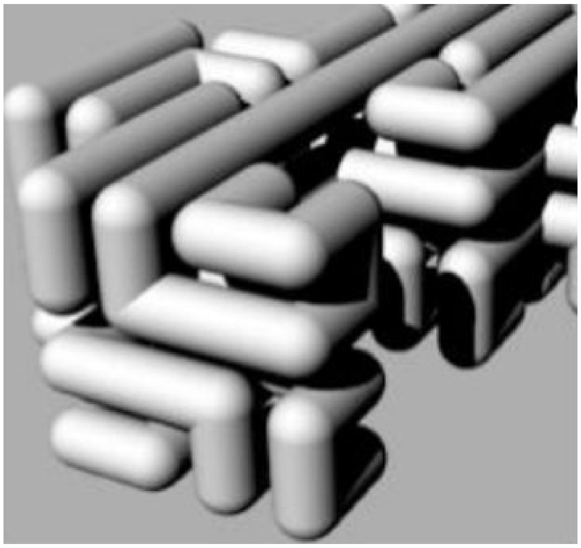


Figure 4: Sample algorithmically generated passages for gas mixture

Figure 5: Possible printed shapes and structures