Research Article

OXY-PRO AIR PURIFIER

(Acronym: OPAP)

Author:

Nitya Devisetti

Grade 11

July 19, 2019

Research Project for:

EMERGING INNOVATORS PROGRAM

at

CHILDREN'S INNOVATION CENTER

39155 Cedar Blvd, Newark, CA – 94560

Phone: 510-894-1497

Email: info@ChildrensInnovationCenter.org

https://ChildrensInnovationCenter.org

Table of Contents

1. Abstract ---3
2. Introduction ---3
3. Solution Scope --5
4. Inspirations from Nature ---7
5. Solution Design ---14
6. Next Steps: Preparing for the Prototype ---24
7. Discussion --25
8. Acknowledgment --26
9. Industries and Sector --26
10. References ---27

Abstract

This research article aims to address the observed overarching issue of excess carbon dioxide emissions in our atmosphere. My design solution targets indoor air pollutants and carbon dioxide excess indoors which pose significant health problems for people that spend hours indoors.

Attempting to eliminate all of the excess carbon dioxide in our atmosphere is a large-scale problem that may take numerous changes, but starting small and aiming for better air indoors will start the track to tackling the enormous problem of climate change and improve indoor air quality.

Biomimicry was a major inspiration for my solution design because I was able to study various organisms to develop a device that eliminates carbon dioxide and pollutants while producing oxygen for the occupants of the building.

Introduction

With increasing urbanization, infrastructures such as buildings are becoming more and more prevalent in daily lives. More often than not, people spend the majority of their day indoors, whether it is eight hours a day in a software company or ten minutes to grab a cup of coffee. In the day and age where more time is spent performing everyday activities indoors than outdoors, indoor air quality has become a major issue that companies and businesses are focusing on. In order to construct buildings, vegetation in the immediate vicinity must be cleared, and what is often overlooked is that these plants have the marvelous power to decrease the CO_2 levels in the air that raise the concerns of indoor air quality in the first place. Carbon dioxide poses a large problem in our environment as we know it. The popular topics of global warming and air pollution frequently mention CO_2 as a critical source to the rapid increase in global temperatures, as it is a heat-trapping gas and holds the highest positive radiative forcing (RF) number. However, carbon dioxide plays a major role in polluting indoor air quality as well, leading to numerous detrimental health effects. Symptoms can range from minor headaches and fatigue or escalate to nausea, dizziness, and vomiting if CO_2 levels continue to rise. Extremely high concentrations can even lead to unconsciousness.

Unfortunately, carbon dioxide is not the only threat to healthy air indoors. Some widespread indoor air pollutants include asbestos, pollen, carbon monoxide, formaldehyde, nitrogen dioxide, pesticides, house dust, and more which pose significant health threats. Short term effects of repeated exposure include asthma, dizziness, and irritation of the eyes, nose, and throat while long term exposure can lead to severely fatal health concerns such as respiratory disease, heart disease, or cancer. Though the severity of the health impacts varies by individuals, the short term and long-term effects of constant exposure to these pollutants should be emphasized. **How can indoor air quality be improved through efficient filtration of pollutants?**

Solution Scope

<u>Define</u>: The device acts as a two-part air filtration system: one part to convert carbon dioxide to oxygen with more convenience and efficiency than growing plants indoors for improved respiratory conditions and a second part to absorb harmful pollutants indoors to prevent the detrimental effects they cause and improve overall air quality.

<u>Identify</u>: The device will consist of the following functions:

- Convert CO_2 to O_2 and dispense O_2 into the room
- Absorbs hazardous fumes, unpleasant odors, and prevents the growth of mold/bacteria
- Clear out carbon monoxide, tropospheric ozone, chloroform, formaldehyde, benzene, trichloroethylene, radon, pollen, nitrogen dioxide, pesticides, and other harmful VOC's (volatile organic compounds).
- Convert CO_2 to CO using single-atom nickel catalyst converter and then convert byproduct CO to ethanol for a potential energy source
- It will be small, portable, and hang on a wall
- Detect the number of pollutants to oxygen ratio and produce sufficient oxygen for quality air
- Coat the device with dye-sensitized solar cells to use ambient lighting as an energy source
- Have different modes (on, automatic, off)
- Have an alert system if air quality is too toxic, such as when a laboratory leaks

- ❖ Swarm intelligence connects with the fire system and smoke alarms and automatically shuts off oxygen production in the presence of fire
- ❖ Include radon-specific air filtration system to filter radon from the air

<u>Integrate</u>: The following life-principles and strategies will be integrated into the design of this solution.

- ❖ Be resource (material and energy) efficient:
  - ➢ Use low-energy processes
- ❖ Use life-friendly chemistry:
  - ➢ Build selectively with a small subset of elements
  - ➢ Break down products into benign constituents
- ❖ Adapt to changing conditions:
  - ➢ Oxygen production shuts off based on air quality levels
  - ➢ Alert system if the air is too toxic
- ❖ Be locally attuned and responsive:
  - ➢ Use readily available materials and energy
  - ➢ Use swarm intelligence to communicate activity levels

Inspirations from Nature

DISCOVER: I observed various natural models and was inspired by the following models:

1. **Leaves**

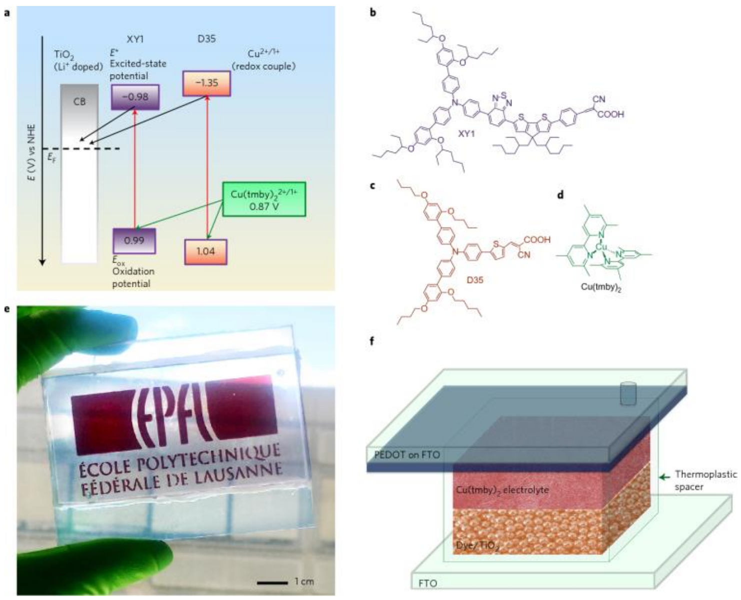
Carbon dioxide enters plants through the stomata, or pores, on the surface of leaves or stems. It then travels to a photosynthetic cell where an enzyme called Rubisco covalently bonds it to a molecule. These molecules are then converted into compounds by ATP and NADPH and serve as an energy source for the plant. As the stomata on the leaves open, they also uptake aerosols from the air in hopes of acquiring precious nutrients.

Source:

https://asknature.org/strategy/photosynthesis-makes-useful-organic-compounds-out-of-co2/

https://asknature.org/strategy/stomata-absorb-nutrients-from-aerosols/

2. Dye-sensitized solar cells



"Solar cells that operate efficiently under indoor lighting are of great practical interest as they can serve as electric power sources for portable electronics and devices for wireless sensor networks or the Internet of Things. Here, we demonstrate a dye-sensitized solar cell (DSC) that achieves very high power-conversion efficiencies (PCEs) under ambient light conditions. Our photosystem combines two judiciously designed sensitizers, coded D35 and XY1, with the copper complex Cu(II/I)(tmby) as a redox shuttle (tmby, 4,4′,6,6′-tetramethyl-2,2′-bipyridine), and features a high open-circuit photovoltage of 1.1 V. The DSC achieves an external quantum efficiency for photocurrent generation that exceeds 90% across the whole visible domain from 400 to 650 nm, and achieves power outputs of 15.6 and 88.5 mW cm at 200 and 1,000 lux, respectively, under illumination from a model Osram 930 warm-white fluorescent light tube. This translates into a PCE of 28.9%."

Source: https://www.semanticscholar.org/paper/Dye-sensitized-solar-cells-for-efficient-power-Freitag-Teuscher/6c50d1f8fae45030fdc75757679f09466ad5ce5c

3. Swarm Intelligence

Communities in nature are able to self-organize and accomplish complex tasks without a central control. Ants are able to leave their nests and release a trail of chemicals called pheromones to communicate with other ants the fastest route to food. Termites have the ability to build enormous mounds that enable gas exchange with their underground nests. "Each insect in a colony seems to have its own agenda, and yet the group as a whole appears to be highly organized. Apparently, the seamless integration of all individual activities does not require any supervision. In fact, scientists who study the behavior of social insects have found that cooperation at the colony level is largely self-organized: in numerous situations the coordination arises from interactions among individuals. Although these interactions might be simple (one ant merely following the trail left by another), together they can solve difficult problems (finding the shortest route among countless possible paths to a food source). This collective behavior that emerges from a group of social insects has been dubbed 'swarm intelligence." (Bonebeau and Theraulaz 2008:73-74).

Source: https://asknature.org/strategy/colonies-self-organize/

4. Maple, Aspen, and Poplar trees

"[D]eciduous tree leaves, such as those from the maple, aspen, and poplar, suck up far more atmospheric pollutants than previously thought. The study concerns the most abundant class of carbon-based particles in the atmosphere, so-called volatile organic compounds (VOCs)… [A] major source [of VOCs] comes from automobile exhaust, coal burning, and other human activities. Some atmospheric VOCs combine with oxygen to form tiny airborne particles called oxygenated VOCs (oVOCs), which insulate the atmosphere and lead to warming…[Scientists] decided to re-examine how deciduous plants interacted with oVOCs…Plants exposed to oVOCs increased their normal uptake of the compounds, absorbing 40% more than expected." (Berkowitz 2010:1)

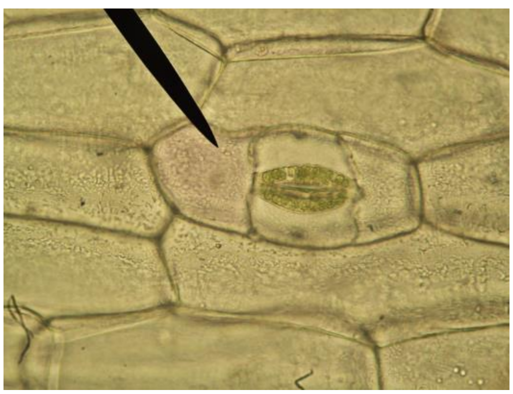
Source: https://asknature.org/strategy/leaves-remove-pollution/

5. Bees: Apidae

Bees have charged electrostatic hairs called scopa that collect pollen. The hairs vary in shape and size; the longer hairs trap pollen while the shorter hairs absorb oils. These hairs occur at various locations on bees' bodies such as their hind legs, the underside of their abdomen, and their head.

Source: https://asknature.org/strategy/charged-electrostatic-hairs-collect-pollen-granules/

6. Apoplasts



Apoplasts contain an antioxidant compound called ascorbate, which oxidizes with tropospheric ozone (O_3) before it oxidizes with the more sensitive parts of the plant. The reaction results in non-toxic products that are handled by the plant. Apoplasts are found in the inner parts of the cell wall in plant cells. "The phytotoxicity of O3 arises primarily as a result of the oxidative damage it causes to the plasmalemma (Heath 1980, 1987, 1988). The pollutant is taken up into the leaf interior, via the stomates (Kerstiens and Lendzian 1989), where it is believed to react with constituents of the aqueous matrix associated with the cell wall (i.e. the apoplast) to yield a suite of reactive oxygen species (ROS) which, in addition to ozone, result in the oxidation of sensitive components of the plasma-lemma, and subsequently the cytosol (Heath 1980; Chameides 1989; Moldau 1998). In this sense, the oxidative stress induced by ozone shares similarities with the initial events associated with other plant pathologies…Since the plasmalemma is the principle site of oxidative attack, the interception of O3, and/or its reactive products, by constituents of the apoplast may play a crucial role in averting cellular damage (Heath 1988). Thus, considerable attention has recently focused on antioxidative systems in the cell wall, and in particular, the role of apoplastic ascorbate (ASC) in the scavenging of O3 (Kelly et al. 1995; Dietz 1997; Cross et al. 1998; Lyons et al. 1999a).” (Plöchl et al. 2000:454)

Source: https://asknature.org/strategy/apoplasts-detoxify-ozone-o3-inside-leaves/

ABSTRACT DESIGN STRATEGIES:

From the above inspirations, I have extracted the following strategies to incorporate into my solution:

1. **Air purification**
    a. **Absorb hazardous fumes, unpleasant odors, and prevents the growth of mold/bacteria:** Use an activated carbon air filter, such as bamboo activated charcoal as a layer in the device to filter unpleasant odors and bacteria
    b. **Clear out**
        i. **Carbon monoxide, carbon dioxide, nitrogen dioxide:** Mimicking the function of stomata on plant leaves and stems will allow for carbon dioxide to enter the device from the air.

ii. **Tropospheric ozone:** Simulating apoplasts containing ascorbate will allow tropospheric ozone to be cleared up.

iii. **Radon:** Including a radon-specific air filtration system will filter radon from the air

iv. **Pollen:** Using electrostatic hairs inspired by bees will trap pollen in the device

v. **Harmful VOC's (volatile organic compounds):** Inspiration from poplar trees to absorb VOCs, ryegrass to store the VOCs, and use plasma catalyst coupling from existing air filters to decompose the VOCs after the storage is full

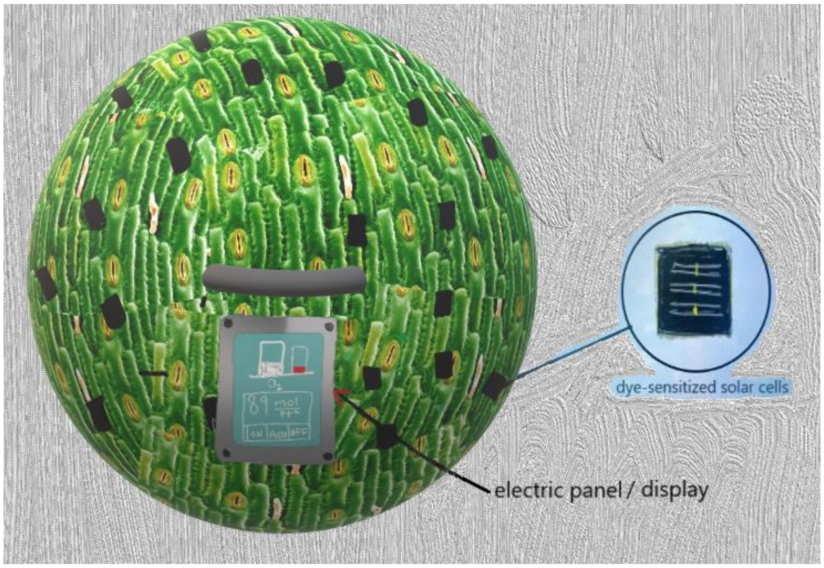
2. **Energy**
   a. **Convert carbon monoxide into a potential energy source:** Convert CO_2 to CO using single-atom nickel catalyst converter and then convert byproduct CO to ethanol which can be used for energy.
   b. **Dye-sensitized solar cells:** Coat the device with dye-sensitized solar cells to use ambient lighting as an energy source
3. **Convenience**
   a. **Portability:** Attach a handle to the top of the device and make it lightweight
   b. **Size:** A hemisphere shape with a radius of 10 inches and it will hang on a wall
4. **Air quality detection**
   a. **Detect the ratio of pollutants to oxygen and produce sufficient oxygen for quality air:** Use existing air-quality technology to detect levels of pollutants and oxygen.

   b. **Have different modes (on, automatic, off) based on the amount of movement and people:** Imitate modern air conditioning systems that have the same modes and control how much oxygen is released into the room.

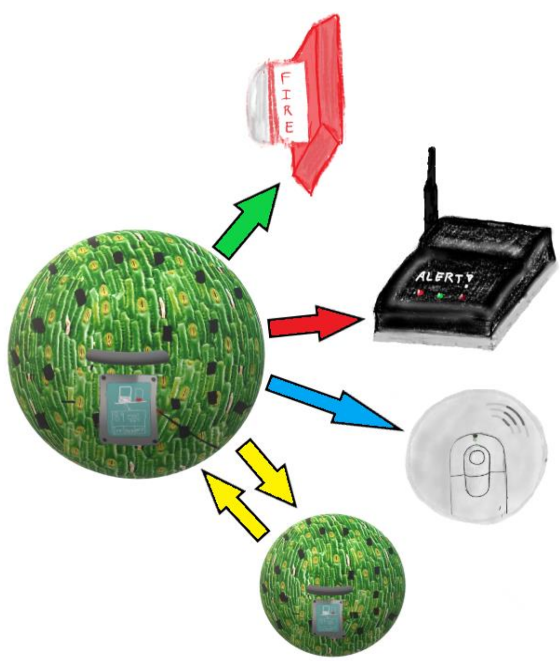
5. **Communication with systems:** Imitate communication between communities in nature such as bees and ants to incorporate swarm intelligence into the following functions:
   a. **Connects with the fire system and smoke alarms and automatically shuts off oxygen production in the presence of fire.**
   b. **Devices in various rooms communicate to turn on and off based on detected movement from sensors which will save energy:** Use existing motion sensors to implement feature.
   c. **Have an alert system if air quality is too toxic, such as when a laboratory leaks.**

Solution Design

The device will be a hemisphere hung up against a wall. A handle will be on the top for convenient portability. The surface consists of the dye-sensitized solar cells, the electric panel, the display, and the “stomata.” The dye-sensitized solar cells serve as an energy source by using ambient light. The electric panel and the motor use the energy generated from the dye-sensitized solar cells to perform their respective jobs. The electric panel communicates with other systems and devices, while the motor pushes air in and out of the device. The display on the device allows users to see the ratio of oxygen to pollutants in the air and change the modes for oxygen production. The three modes are “ON,” “Auto,” and “OFF,” similar to existing air conditioning systems. When "ON" is the selected mode, oxygen will constantly be produced, regardless of surrounding conditions. If hazardous situations arise, an alert will be sent to the fire and smoke

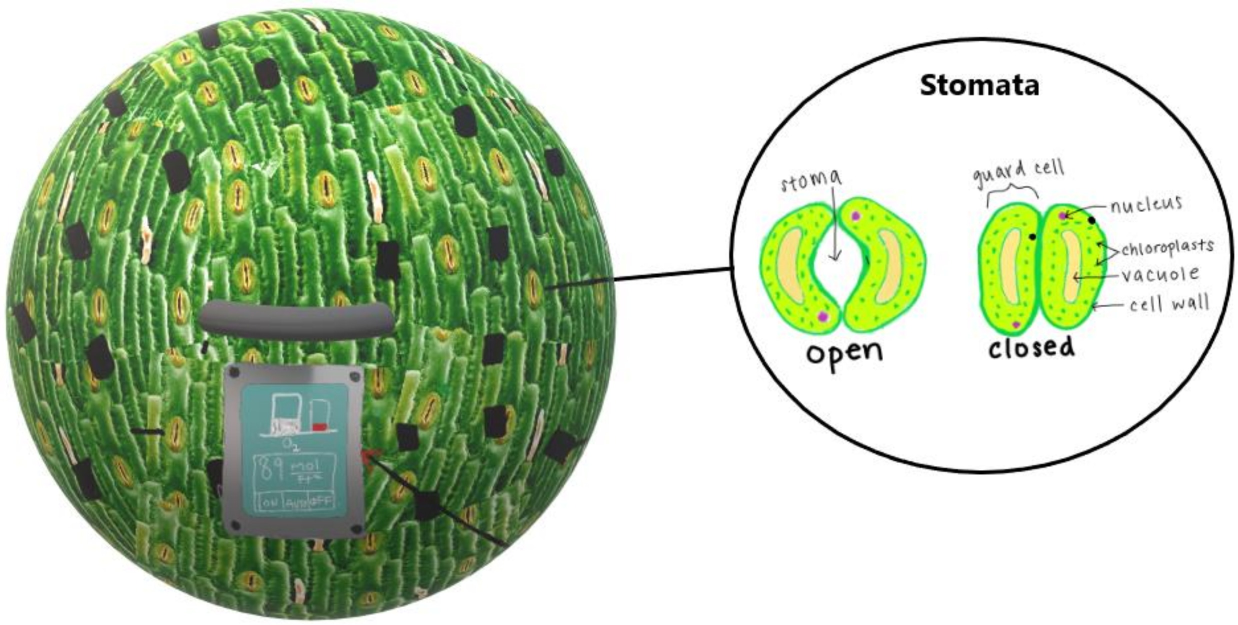


alarm systems, HVAC and central servers in buildings, along with other OPAP devices. Oxygen gas is largely known to feed fires so, in the occasion of a fire which is a severe condition, the device would have to manually be turned off whereas in "Auto," the device would turn off oxygen production automatically and simultaneously send alerts to the



other systems. Under "Auto," the flag will be set as moderate under the circumstance of a laboratory leak or high pollutant ratio, and the device would only communicate with other systems. The flag will be set as severe under the scenario of a fire in which the device would stop oxygen production and then send an alert to systems. The "OFF" mode stops oxygen production completely, and to produce oxygen, the device would manually need to be turned to "ON" or "Auto."

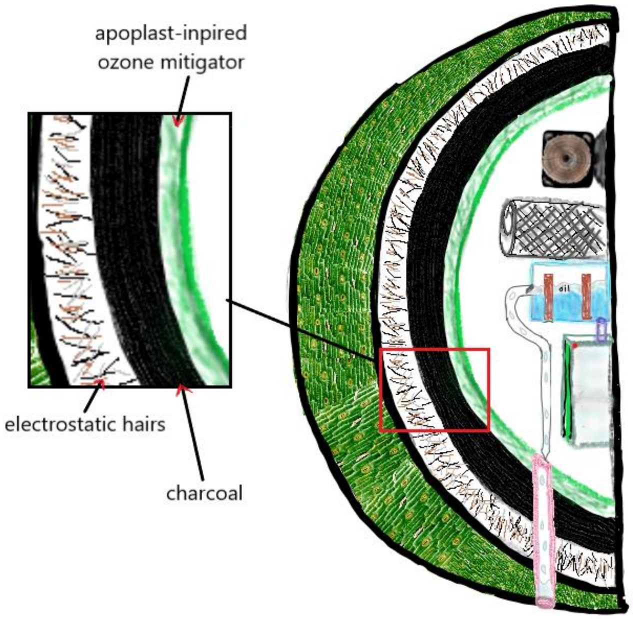
The "stomata" inspired by plant leaves and stems allow the absorption of air. Plants are known for their ability to absorb harmful pollutants from their surroundings through the stomata,



thus the implementation of mimicking them. Additionally, stomata have the ability to exchange gases controllably, so the absorption of carbon dioxide and release of oxygen is balanced with the functions of the plant. Stomata in plants also uptake aerosols from the air, so the stomata on the OPAP device can absorb harmful aerosols that contaminate the air.

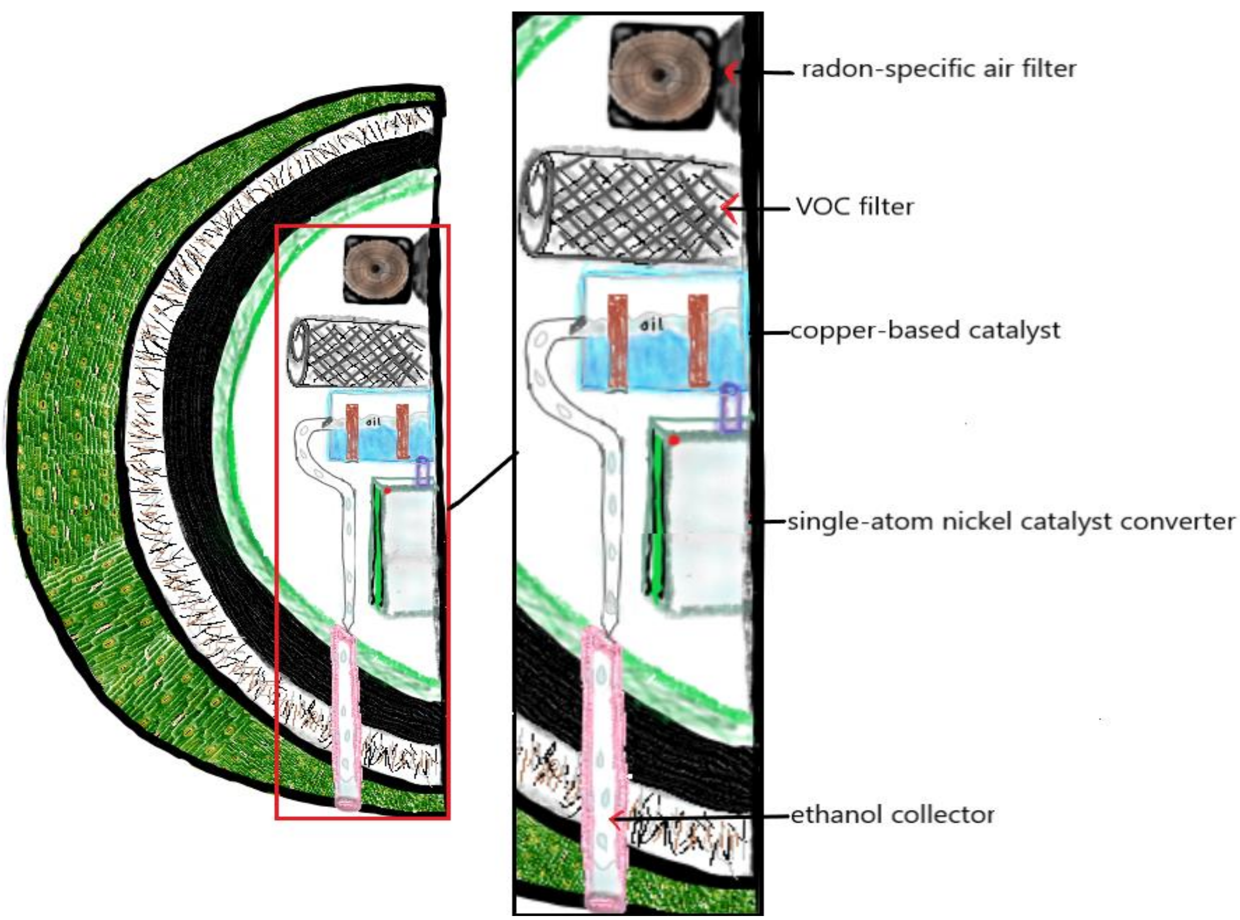
The air enters the device through the "stomata" and passes through three layers, each with their distinct functions. The first layer the air passes through is filled with electrostatic hairs inspired by bees. These hairs trap pollen, house mites, dust, and other large particles that may cause irritation or allergies. After being cleared of large particles, the air proceeds to the bamboo-activated charcoal layer. Charcoal has air-purifying properties that allow it to absorb hazardous fumes, unpleasant odors, and prevent the growth of mold/bacteria. The air then arrives at the apoplast-inspired ozone mitigator. Apoplasts contain a compound called ascorbate, which oxidizes with ozone to create non-toxic products, thus mitigating it from the air. Ozone is particularly harmful because it oxidizes with sensitive organs inside the body, so ascorbate serves to oxidize with ozone instead of it oxidizing with another substance.

After progressing through the three layers, the air reaches the inner chamber which

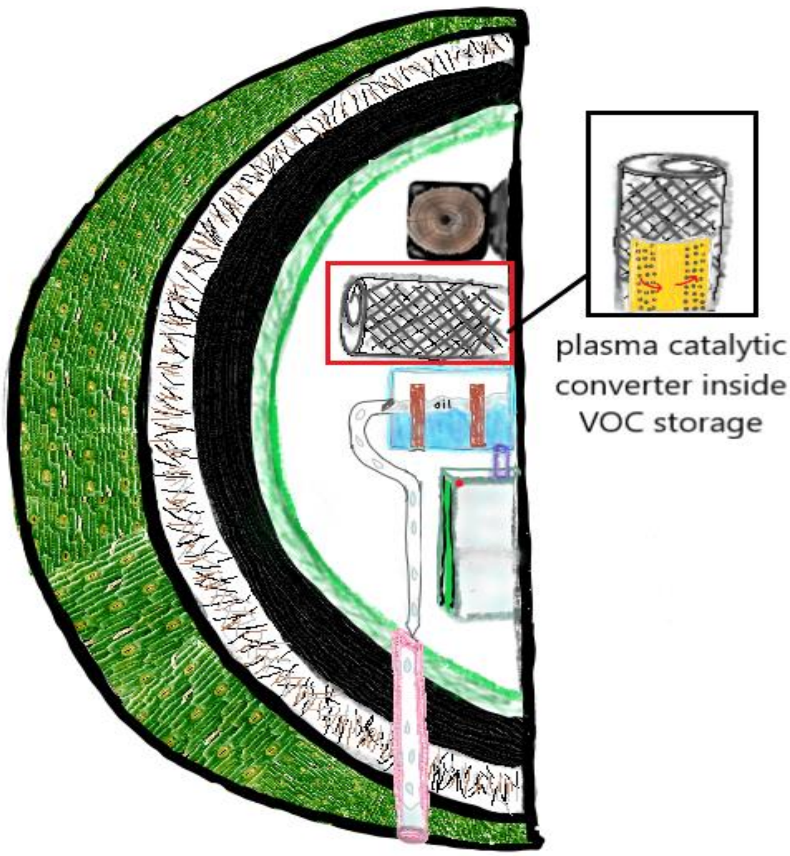


contains the radon-specific air filter, the VOC filter, and the "oxy-pro chamber." The radon-specific air filter targets radon, a very harmful pollutant, and clears it from the air. The VOC filter, inspired by poplar trees, has a series of actions. First, the VOC filter mimicks the poplar trees in absorbing a substantial amount of VOCs. The VOCs then reach a plasma catalytic converter that is located inside the filter where they are broken down. There are current air filters that have a plasma catalytic converter to break down VOCs, and that is essentially what is being implemented in the OPAP device.

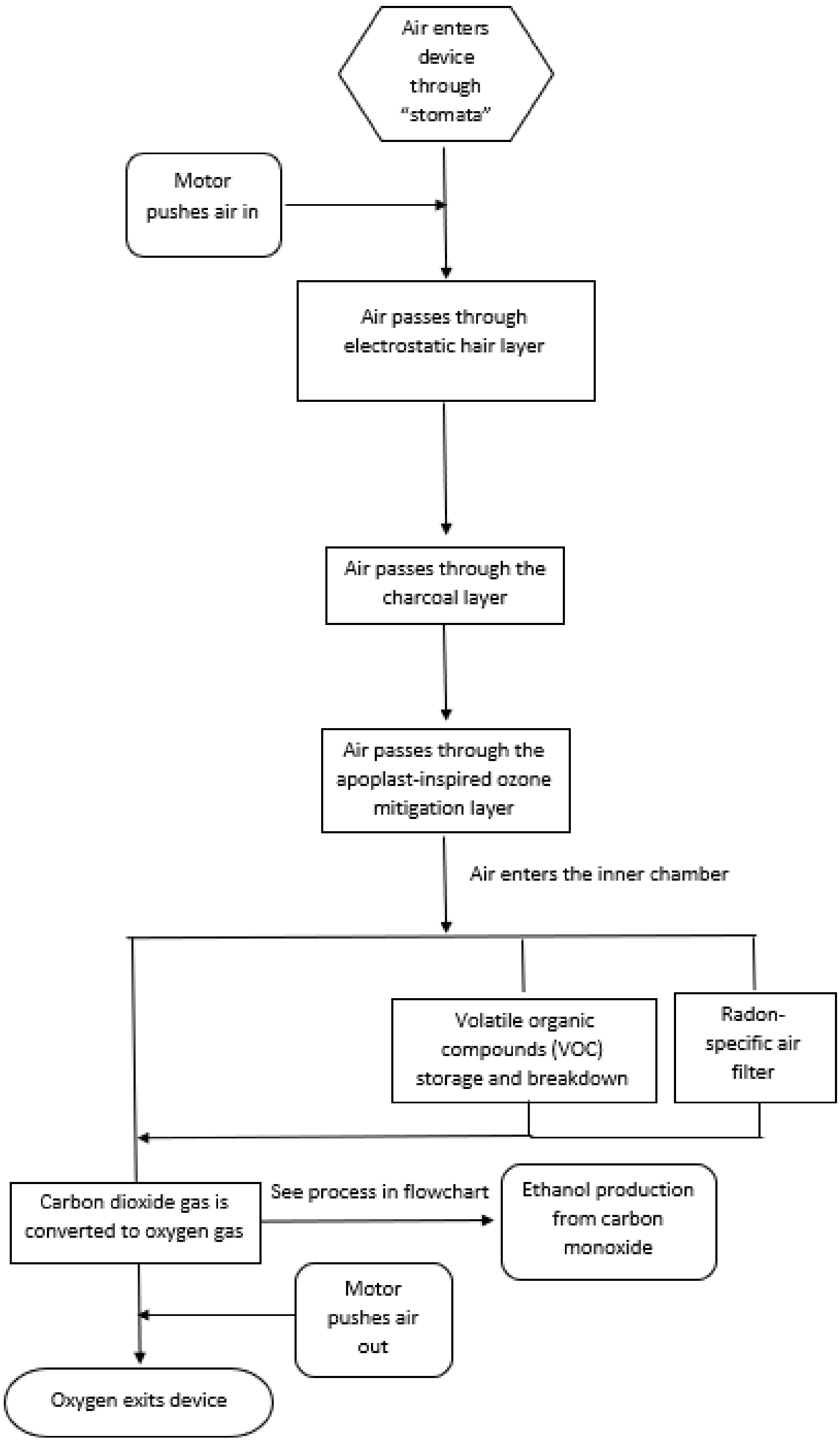
The air also reaches the "oxy-pro chamber" which is the chamber where oxygen is being produced from carbon dioxide. The chamber consists of three major parts: the single-atom nickel catalyst converter, the copper-based catalyst, and the ethanol collector. First, the CO_2 is converted into carbon monoxide (CO) and a single oxygen atom (O) by the single-atom nickel catalyst converter. Scientists at Brookhaven National Laboratory emphasized that the converter is cost-effective compared to using gold or platinum and the single-atom nickel produces CO instead of the alternate reaction of hydrogen evolution reaction (HER) which is what usually occurs with noble metal nanoparticles. Fundamentally, the reaction is an interaction between isolated nickel atoms and the graphene nanosheets surrounding them. After the CO_2 is reduced to CO and O, the O atoms will naturally bond with each other, as oxygen occurs in nature as diatomic molecules. By density, the CO molecules will float above O_2 molecules because CO's density (1.14 g/L), is less than O_2's density (1.429 g/L). The O_2 exits the OPAP device through the stomata and is dispensed into the room, while the CO is left as a byproduct. This CO drifts above to the second part of the oxy-pro chamber: the copper-based catalyst. This catalyst was created by Stanford scientists in order to produce ethanol in a more eco-friendly manner from carbon monoxide. At room temperature and pressure, oxide-derived copper electrodes and water saturated with CO form an electrochemical cell that can produce ethanol. Because water is an electrolyte in this cell, it maintains the same volume throughout the production of ethanol. When



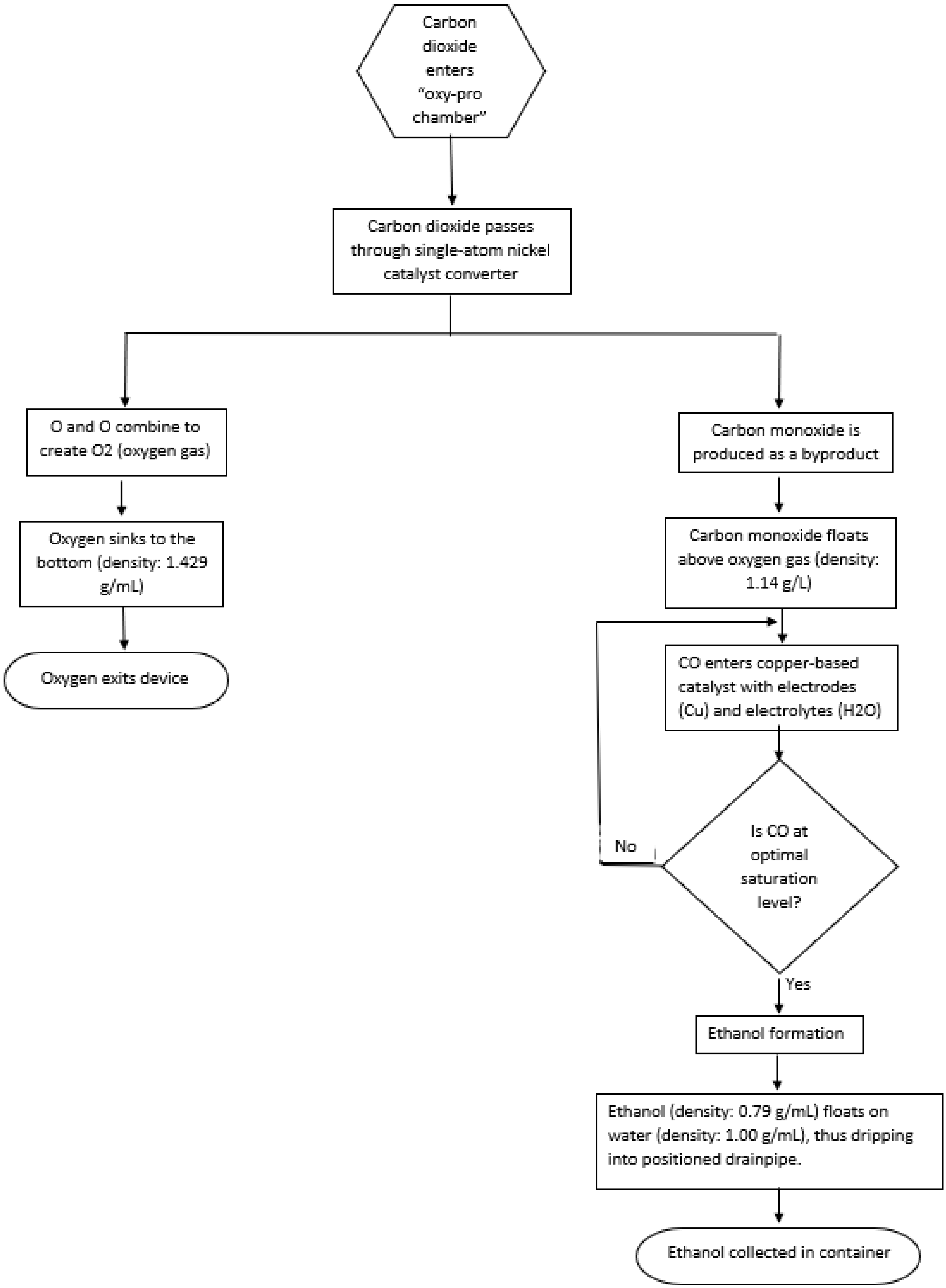
the ethanol is produced, it will float above the water because the density of ethanol (0.79 g/mL) is less than the density of water (1.00 g/mL). Therefore, the drainpipe that is positioned right above the water will collect the floating ethanol. The pipe has a flap that will open as the ethanol pushes against it. From here, the ethanol will travel down to a bottle where it is collected. Users can remove the bottle, collect the ethanol in a different container for energy use, and insert the bottle back into the device.



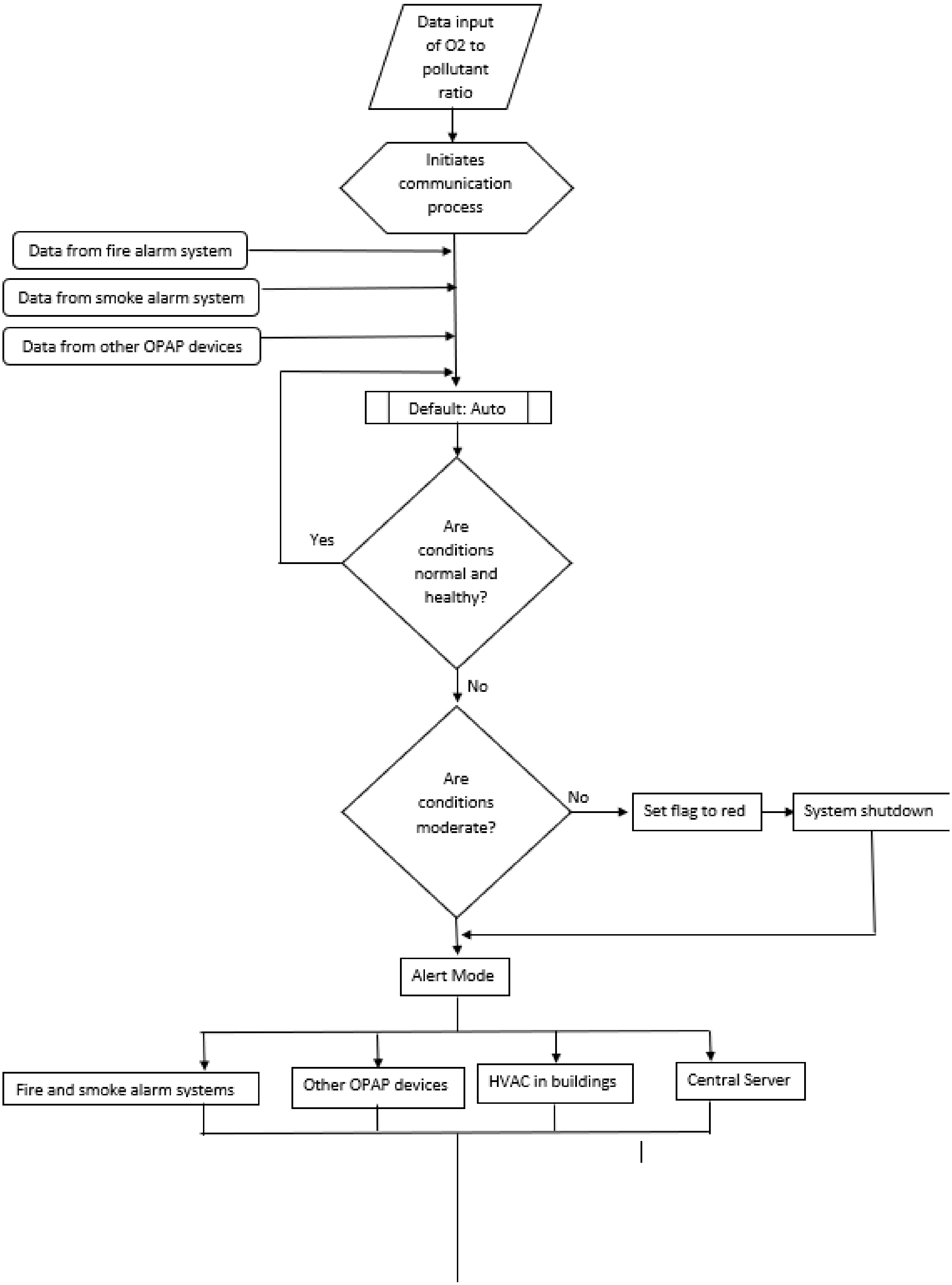
The following flowcharts demonstrate the functions and pathways of the OPAP device:

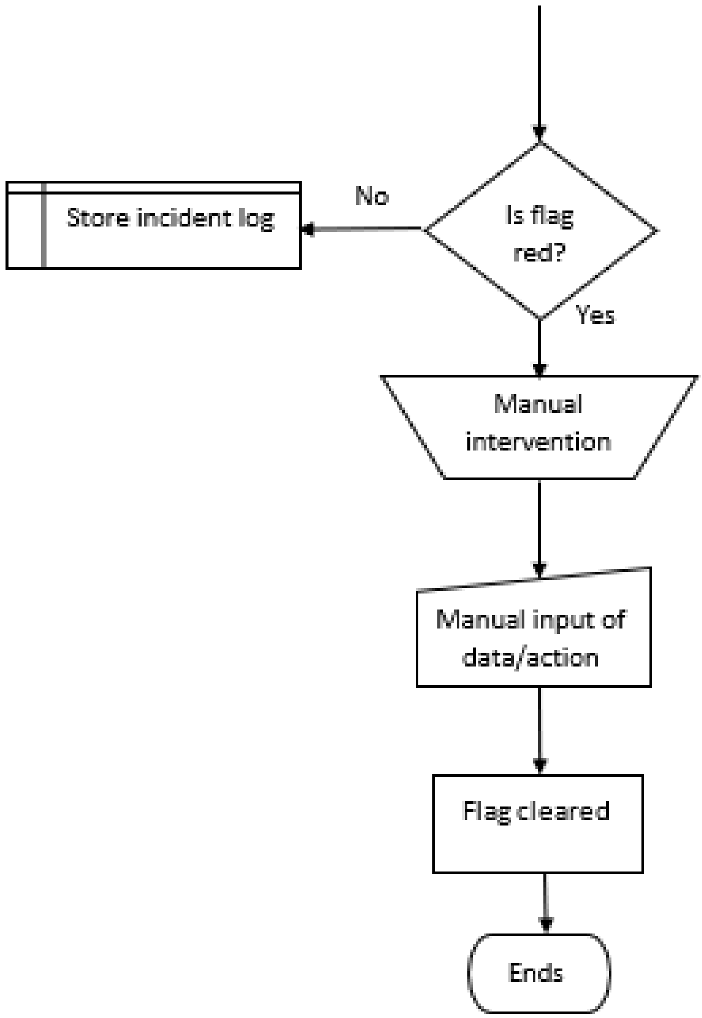


Oxy-Pro Air Purifier-OPAP
By, Nitya Devisetti



Oxy-Pro Air Purifier-OPAP
By, Nitya Devisetti




Is flag red?
No
Store incident log
Yes
Manual intervention
Manual input of data/action
Flag cleared
Ends

Next Steps: Preparing for Prototype

The following is information on further steps required to prepare a prototype.

1. **Oxy-pro chamber:** Further research and communication with the scientists of the single-atom nickel catalyst converter and copper-based catalyst is needed in order to implement it inside the device.
2. **Swarm Intelligence:** Collaboration with experts in Artificial Intelligence and Swarm Intelligence to develop a code that can allow OPAP devices to effectively communicate with fire and smoke alarm systems, as well as alert HVAC and a central system in buildings.
3. **Green Chemistry:** Additional communication and research with scientists is required in order to produce materials such as the “stomata” and “apoplast” layers.
4. **Funding:** Presentations to large businesses, hotels, apartment buildings, etc., are needed in order to acquire the appropriate funds needed to produce this device. Government funding is also a possibility because of the benefits to health.
5. **Energy:** Collaboration with creators of dye-sensitized solar cells is necessary in order to include it on the surface of the device.

Discussion

After observing the drastic effects of climate change, I realized that there needed to be action taken immediately. However, how could I tackle such a large problem with one solution? I started narrowing down the areas I wanted to focus on. Carbon dioxide emissions from burning fossil fuels were of major interest to me because from my research, I learned that carbon dioxide is the major contributor for global warming. Additionally, it lingers in the air longer than any other greenhouse gases, making it harmful for future generations to come. Besides that, eliminating carbon dioxide requires a great deal of energy. It occurred to me, however, that most people spend time indoors, whether it is inside a house, restaurant, or a building for work. If there is too much carbon dioxide in our environment in the space of our entire world, I figured there would be a concentrated amount of carbon dioxide in a small building compared to the scale of our world. With the inspiration that a small change can make a big difference, I turned to improving carbon dioxide and air pollutant levels inside infrastructures as my problem in order to address the overarching issue of climate change as well as the health issues caused.

Observing nature's astounding abilities to maintain a sustainable life gave me inspiration for my solution design. How do trees do it? How can they benefit from carbon dioxide and produce oxygen without destroying our environment? My research led me to study plants and their astonishing features to survive in harsh environments. Existing air purifiers perform various functions that allow the air to be rid of harmful pollutants, but they do not act completely like plants. They do not feed on carbon dioxide and produce oxygen, and that is why I was determined to create a device that removed harmful toxins from the air but also improved air quality by converting carbon dioxide to oxygen simultaneously.

Designing a device with numerous aspects (air purification, oxygen production, communication with systems) was quite challenging but it made me more passionate about solving the issues that excess carbon dioxide causes. The OPAP device ensures improved air quality by clearing the air of pollutants as well as enriching the air with oxygen with the byproduct of ethanol in an eco-friendly manner.

Acknowledgements

I would like to thank Ms. Shanti Balaraman for introducing biomimicry and the tremendous number of problems in our society that need to be addressed with urgency. Her passion for innovation and changing our world to be a better place inspired me to question the systems in our world and rethink the methods of every operation in our society.

Industries and Sectors

Here are some Industries and Sectors who would benefit from this solution:

- Health Management
- Medical Supplies
- Appliances
- Environment

References

1. Raines, et al. “Photosynthesis Makes Useful Organic Compounds out of CO2 : Plants.” *AskNature*, 1 Jan. 2003, asknature.org/strategy/photosynthesis-makes-useful-organic-compounds-out-of-co2/.

2. Team, AskNature. “Transport Processes Allow Arsenic Hyperaccumulation : Ladder Brake.” *AskNature*, asknature.org/strategy/transport-processes-allow-arsenic-hyperaccumulation/.

3. “Introduction to Indoor Air Quality.” *EPA*, Environmental Protection Agency, 3 Oct. 2019, www.epa.gov/indoor-air-quality-iaq/introduction-indoor-air-quality.

4. “Do Indoor Plants Really Clean the Air?” *LiveScience*, Purch, www.livescience.com/38445-indoor-plants-clean-air.html.

5. Smirnoff, N, and G L Wheeler. “Ascorbic Acid in Plants: Biosynthesis and Function.” *Critical Reviews in Biochemistry and Molecular Biology*, U.S. National Library of Medicine, 2000, www.ncbi.nlm.nih.gov/pubmed/11005203.

6. Shwartz, Mark. “Stanford Scientists Discover a Novel Way to Make Ethanol without Corn or Other Plants.” *Stanford University*, 9 Apr. 2014, news.stanford.edu/news/2014/april/ethanol-without-plants-040914.html.

7. “Plant-Pesticide Interaction.” *National Pesticide Information Center*, npic.orst.edu/envir/plantint.html.

8. BoninoApr, Steve. “Carbon Dioxide Detection and Indoor Air Quality Control.” *Occupational Health & Safety*, ohsonline.com/articles/2016/04/01/carbon-dioxide-detection-and-indoor-air-quality-control.aspx.

9. Marcob, AlessandraDe. “Air Pollution Removal by Green Infrastructures and Urban Forests in the City of Florence.” *Agriculture and Agricultural Science Procedia*, Elsevier, 23 Feb. 2016, reader.elsevier.com/reader/sd/pii/S2210784316300997?token=A19E09EAAA9FD950E9703E80E03F94209B26A970862C3B0FC5B1E884519406C9160A719B376141E12A0B6A05358E577B.

10. Lancaster, Sean. “How to Convert Carbon Monoxide to Oxygen.” *Sciencing*, 2 Mar. 2019, sciencing.com/convert-carbon-monoxide-oxygen-8559719.html.

11. "Converting CO2 into Usable Energy." *ScienceDaily*, ScienceDaily, 1 Mar. 2018, www.sciencedaily.com/releases/2018/03/180301094857.htm.

12. Freitag, Marina, et al. "Dye-Sensitized Solar Cells for Efficient Power Generation under Ambient Lighting." *Semantic Scholar*, 1 Jan. 1970, www.semanticscholar.org/paper/Dye-sensitized-solar-cells-for-efficient-power-Freitag-Teuscher/6c50d1f8fae45030fdc75757679f09466ad5ce5c.