Research Article

# A SUSTAINABLE AND FUTURISTIC LANDFILL DESIGN

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May 20, 2021

*Research Project for:*

EMERGING INNOVATORS PROGRAM

**at**

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# ABSTRACT

16% of anthropogenic methane originates from landfills because of anaerobic decomposition and ineffective landfill gas (LFG) extraction. Leachate, or toxic water that permeates through trash, risks contaminating the groundwater by seeping underground. My solution mitigates this impact by using biomimicry, green chemistry, and industrial designing, and it ensures that different safety systems and protocols are present to make landfills into sustainable and reliable architecture. Not only does my solution address today's needs, but also takes the evolving future into consideration by creating annual revenue, utilizing modern technology, and bringing us one step closer to reducing climate change.

# INTRODUCTION

Over the past decades, climate change has been accelerating due to human infrastructure and ignorance. With anthropogenic $CH_4$ and $CO_2$ being 91% of the reason behind climate change, it is time we fight against global warming to save future generations; a considerable contributor of the emissions is from landfills. A landfill is a site of waste that is covered with soil to maximize the usability of a piece of land. It is responsible for 16% of methane emissions: Due to anaerobic reactions happening in landfill waste, huge amounts of methane are formed and accumulated. In addition to methane, carbon dioxide is also produced through aerobic reactions. The mixture of these gases creates landfill gas (LFG), which if abundant, can cause emissions, explosions, and a foul-smelling surrounding. Landfills also risk the contamination of the groundwater. Leachate, water with hazardous chemicals that percolate through permeable materials, travels through landfills and seeps underground to the point where it can contaminate the aquifer. Leaked leachate can also convert rainwater into an undrinkable substance and blacken the soil, spoiling vegetation around landfill sites.

Different systems and protocols are designed to protect the environment from landfills. For instance, to prevent a mass formation of LFG, pipes are inserted throughout a landfill to inject oxygen; by injecting $O_2$, the chances of anaerobic decomposition taking place decreases. To prevent emissions, there are more pipes inserted that collect LFG. Because of $O_2$ insertion, LFG mostly comprises of $CO_2$. Collected LFG is transferred to wells so that it can later be transported to treatment facilities and be converted to renewable gas. However, the landfill's extraction system is not exhaustive, which eventually leads to constant emissions and explosions.

Furthermore, in an attempt to protect our groundwater, landfill engineers have adapted the usage of a bottom liner system; this consists of a layer of puncture-resistant plastic. This liner is located under all the waste in a landfill so that the leachate that flows around is not able to cross the liner and reach the groundwater. However, the current bottom liner system risks the chances of leaks because of its lack of redundancy. To prevent a huge amount of leachate percolating around a landfill, pipes are placed throughout landfills to extract contaminated water; pipes, however, can burst amidst the waste and cause more leachate leaks. They can also disrupt other processes, such as the extraction of LFG because leaked leachate can block the entryways of landfill gas wells. Extracted leachate travels through pipes, ditches, and is finally deposited in a pond filled with more leachate; this pond is layered with sand or stone to avoid water leaching from it. Because landfills are underground and therefore cannot be visually monitored, operators have to place expensive equipment that checks the status of different components required.

Overall, a lot of time, money, and thought is spent on the maintenance and management of landfills, which still results in overt flaws.

**So, is there a way to efficiently redesign landfills so that we can decrease our greenhouse gas emissions while protecting our groundwater, soil, and vegetation from leachate?**

# DISCOVERY OF TOPIC

Since I was young, I was taught about the harm plastic entailed in detail; my question was always, “Then why is plastic so popularly used?” I have always wanted to understand the history behind plastic. While researching plastic, I came across a larger culprit: landfills. I always thought dumps and landfills were two synonymous words: An excavated piece of land that is simply where trash is disposed of. However, when I discovered the systems behind a landfill that make it function, I was extremely interested in the entire process. With this research, I quickly discovered the different flaws that landfills had. From wondering about alternatives to plastic, I started looking at the bigger picture and thinking about ways to redesign an entire landfill. Landfills are a significant factor towards the contribution of climate change, and I want to make a difference by minimizing some of these powerful threats.

# SOLUTION SCOPE

## 1. DEFINE

My solution is a multi-part system that focuses on municipal solid waste (MSW) landfills and helps minimize pollution. There are two different processes that my solution has to optimize the way landfills work. First, my solution focuses on reducing greenhouse gas emissions; in addition, my solution also addresses extracting leachate in a way that does not disrupt other processes or contaminate the environment's resources.

## 2. IDENTIFY

My solution focuses on MSW landfills and has the following features:

1. **Reducing greenhouse gas emissions:**
    - A better way of circulating air in buried trash to minimize methane formation.
    - An efficient way to capture LFG for energy, which aids in steering away from fossil fuel-based energy.
    - Utilizing appropriate vegetation to absorb $CO_2$, and $CH_4$ in the air that is around landfill sites.
2. **Proper extraction and management of leachate:**
    - Ensuring that leachate always stays separate from the groundwater by using a less risky barrier to create a blockade between leachate in landfills and groundwater.
    - Having a more efficient way of collecting leachate that does not disrupt other systems and does not get clogged by waste and soil.
    - Monitoring leachate extraction systems to ensure they are working properly.

# 3. INTEGRATE

My solution integrates the following life principles:

1. **Integrating development with growth:**
    - Different processes for separate causes have multiple units that range from being simple to complex, as a way to fit different components in a system.
2. **Adapt to changing conditions:**
    - Different systems that are aimed towards the reduction of gas discharges and efficient leachate extraction are decentralized. Although these components create a system, they are not reliable on each other and do not stop functioning if another process does malfunction.
    - Because there are different forms, processes, and systems to achieve efficiency, my solution is diverse and has different approaches in action.
3. **Evolving to survive:**
    - To ensure that leachate is being extracted effectively, the groundwater is monitored to catch any immediate changes that need to be made.
    - Emissions are also minimized if not avoided by monitoring LFG; this allows any further modifications that need to be made to make the landfill more effective.
4. **Being resource-efficient:**
    - The bottom liner system of my solution is made of HDPE, which is created from recycled plastic; this allows currently disposed of plastic to function for a long-term purpose, reducing plastic pollution.

- My solution's bottom liner system is also the shape of aligned hexagonal pockets. It uses this shape for a specific need, which is strengthening the bottom liner system to protect the groundwater.
- Not only does my solution use renewable energy to circulate oxygen and collect landfill gas, but the extracted LFG is also converted to renewable energy. This creates a surplus of renewable energy that can be used rather than fossil fuel-based energy.

5. **Being locally attuned and responsive:**

- My solution uses mostly readily available materials such as recycled plastic to achieve efficiency. In addition, my solution completely steers away from fossil fuel energy.
- My solution also relies on multiple future collaborations that work as win-win interactions, such as existing solutions for motors and eco-friendly decomposition of leachate.
- The leachate system takes advantage of the leachate's cycle of seeping down in waste by letting it occur naturally and holding the extraction underneath the waste to achieve fault tolerance.

# INSPIRATIONS FROM NATURE

## DISCOVER

### 1. Cork Warts and Aerenchyma of Mangroves

Mangroves are found in the tropics and subtropics; due to this plant growing in tidal zones, its remote roots barely receive oxygen and risk becoming anaerobic. To survive, mangroves have "developed a pressurized air system that moves oxygen molecules from the surface down to their roots. Air enters the leaves of the mangroves through cork warts. As it enters, the air collects in special airspaces within the leaf known as aerenchyma." Aerenchyma is found in many parts of the plant. When the air inside the aerenchyma is heated, it spreads out which causes internal pressure. This pressure is then used as energy to drive out oxygen from a set of aerenchyma to another until every single root is oxygenated.

Source: https://asknature.org/strategy/cork-warts-and-aerenchyma-pressurize-internal-airflow/

### 2. The Respiratory System of a Cockroach

Due to being a highly active organism, the Madagascar hissing cockroach needs more than just passive diffusion to live. This organism uses active ventilation to pump air in and out of its body. "In all insects, the respiratory system consists of a network of branching tubes, called tracheae, that develop from invaginations of the insect's exoskeleton. These tubes connect an insect's internal, metabolizing tissues to the outside air via pores, called spiracles, that line both sides of the insect's thorax (mid-section) and abdomen (rear section). Muscle-controlled valves enable the pores to open and close." This process creates a one-way airflow; whereas, in mammals, the same tubes are used to breathe in air and exhale. "To breathe in, the abdominal pores close and the abdomen expands, which sucks oxygen-rich air in through the open thoracic pores. This air then travels through respiratory tubes and reaches the cockroach's tissues. Oxygen is taken up, while carbon dioxide is released."

Source: https://asknature.org/strategy/respiratory-system-creates-one-way-airflow/

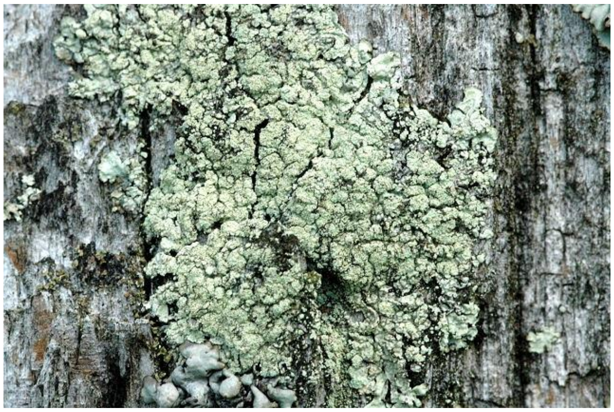
**3. Heart Valves of Humans**

Different valves located in the heart open and close as the heart muscle contracts and relaxes. "After the left ventricle contracts, the aortic valve closes and the mitral valve opens, to allow blood to flow from the left atrium into the left ventricle. As the left atrium contracts, more blood flows into the left ventricle. When the left ventricle contracts, the mitral valve closes and the aortic valve opens, so blood flows into the aorta."

Sources: https://www.livescience.com/34655-human-heart.html

https://www.columbiadoctors.org/condition/heart-valves-anatomy-and-function#:~:text=The%20valves%20prevent%20the%20backward,other%20side%20of%20a%20ventricle.

**4. Pores on A Lichen Surface**



A species of lichen uses hydrophobic surfaces to prevent absorbing contaminated water. Its pores block interactions with water while efficiently achieving gas exchange. “When rain falls, the water molecules sit upon the topmost part of the lichen's rough, multi-layered surface. Below these top layers sit micropores that are coated in hydrophobic compounds. This design creates openings for gases to come through while preventing clogging by water. So even when a large amount of water is present, the lichen is still exchanging gases.”

Source: https://asknature.org/strategy/rough-hydrophobic-surface-allows-gas-exchange/

**5. Structure of Honeycombs**

The hexagonal structure of honeycombs has proven to be a shape that utilizes the most space with fewer materials; this shape is also extremely strong and durable. “And space-efficiency isn’t the only benefit of building with hexagons. Stacked together, hexagons fill spans in an offset arrangement with six short walls around each ‘tube,’ giving structures a high compression strength. Scientists and engineers have incorporated hexagonal designs into seemingly endless applications, including light-weight building materials, flexible panels for bridge construction, sound absorption, light diffusion, catalyst design, magnetic shielding, tissue engineering, and even building better surfboards."

Source: https://asknature.org/strategy/honeycomb-structure-is-space-efficient-and-strong/

## 2. ABSTRACT DESIGN STRATEGIES

My solution emulates the following strategies:

**1. Reducing greenhouse gas emissions:**

- The Gas Minimization Network ensures efficient air injection and gas collection to prevent the creation of methane and consequent explosions.
- The Gas Minimization Network consists of vertical pipes (Stems). Stems have a one-way airflow, which is inspired by the respiratory system of cockroaches and has enclosed junctions connected to them. These junctions can have RootPipes attached; RootPipes are inspired by the roots of mangroves. These extensions reach remote areas of landfills while also being flexible and strong.
- Because there are RootPipes placed all over a landfill, it is important to prevent the clogging of RootPipes by leachate. The pores on a lichen surface are used as inspiration to avoid water entering any pipe while allowing gas exchange without obstruction.
- Active Ventilator emulates the design of the valves of the heart. Active Ventilator allows RootPipes to alternately proceed with their functions. When air is injected, the motor turns off for RootPipes that extract gas; this also happens the other way

around. Active Ventilator knows when to alternate based on monitoring flammable risks of landfills.

- Ultrasonic height sensors are placed on top of Stems to check the amount of trash that has been collected. This data will be sent to notify operators with information on when to attach RootPipes at an appropriate location.
- Plants such as different types of Azalea, Boxwood, and Holly shrubs are planted around the landfill for their shallow roots. These plants absorb any carbon dioxide that does happen to release from the landfill.
- After extraction, the methane and carbon dioxide are sent for treatment; this landfill gas is then converted into renewable energy that can replace harmful sources of energy.

2. **Proper extraction and management of leachate:**

- There is a two-chamber system to manage the leachate. The top chamber is lined with a barrier and the bottom one has a double barrier, also known as the bottom liner system.
- The bottom liner systems used to prevent leachate from seeping and traveling to groundwater emulates the properties of a honeycomb’s hexagonal structure, giving it durability. Its material, HDPE, is impermeable which restricts water from contaminating the groundwater.
- There is a permeable layer, consisting of pebbles clustered above a porous surface, on top of the chambers as a way for the leachate to permeate through to the chambers and be separated from trash.

- Leachate Gatherer, the first chamber, is connected to external pipes and motors to extract the leachate from the landfills.
- Groundwater Protector, the bottom chamber, is also connected to external pipes; also, it serves as a backup mechanism, so that it can notify about potential damages in the first chamber to protect the groundwater.
- A sensor and robotic technology system, called Chamber Fixer, is used in the Groundwater Protector to identify and fix any cracks or holes in the Leachate Gatherer.
- The groundwater is monitored to ensure its safety and any further protection required in landfills.

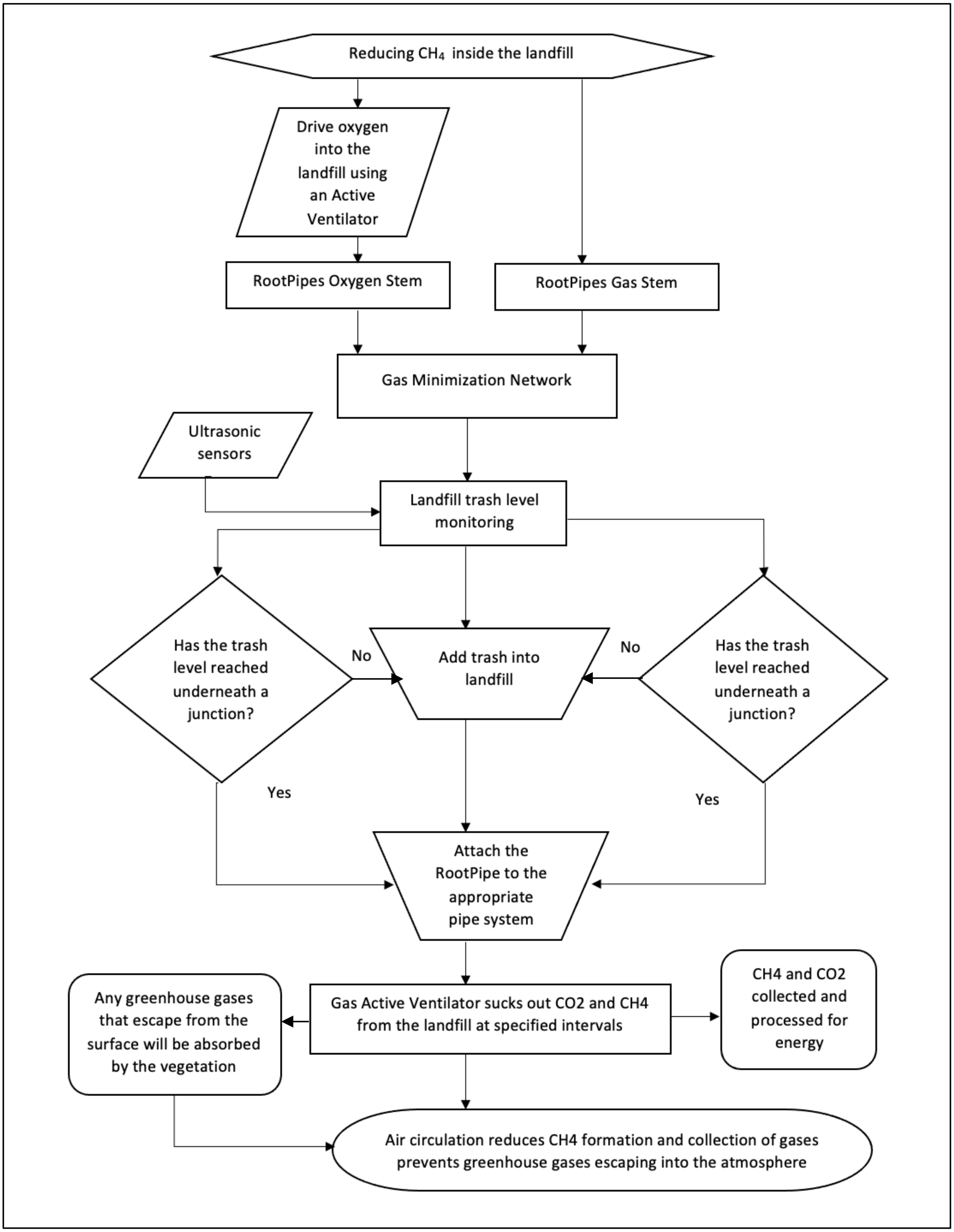
# SOLUTION DESIGN

The two-part solution maximizes the efficiency of landfills by reducing greenhouse gas emissions with the Gas Minimization Network and managing leachate effectively with the Leachate Manager. It has innovative designs to inject and distribute oxygen inside landfills and collect methane and $CO_2$ for energy production. The design takes advantage of the latest technology in various parts of the solution and makes each process fault tolerant. Furthermore, it utilizes eco-friendly measures such as protecting the groundwater and soil from contamination by leachate.

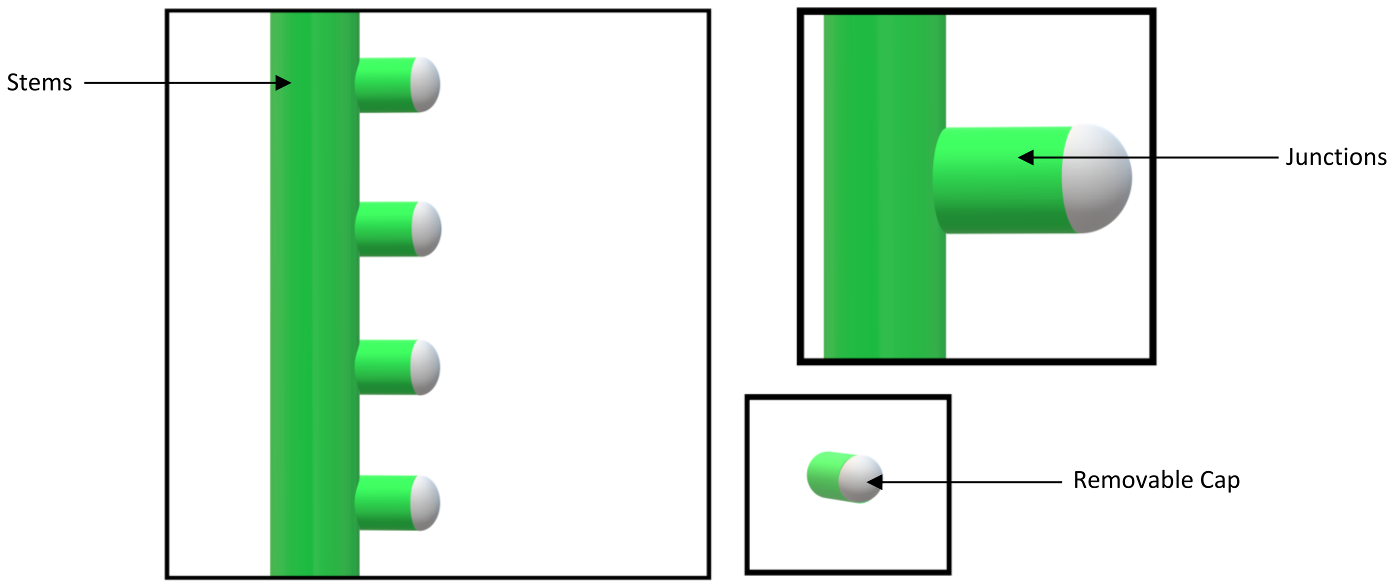
## GAS MINIMIZATION NETWORK

The Gas Minimization Network is going to minimize if not eliminate the emissions of methane and carbon dioxide into the atmosphere.

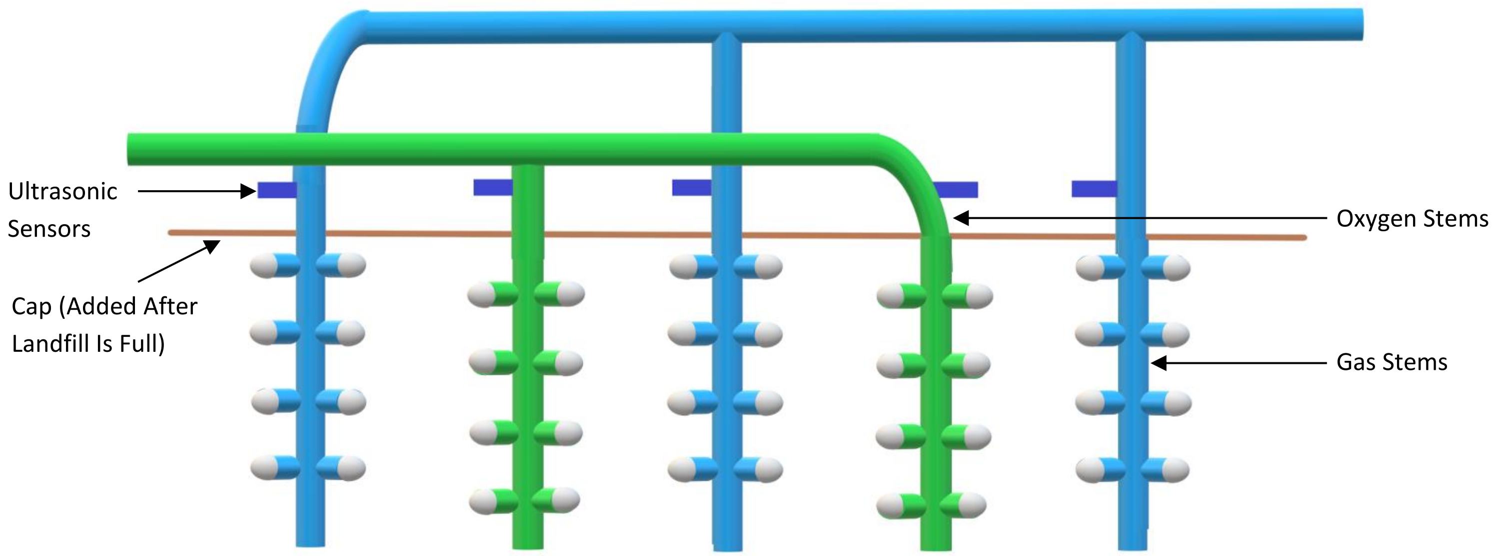

Reducing CH4 inside the landfill
Drive oxygen into the landfill using an Active Ventilator
RootPipes Oxygen Stem
RootPipes Gas Stem
Gas Minimization Network
Ultrasonic sensors
Landfill trash level monitoring
Has the trash level reached underneath a junction?
No
Add trash into landfill
No
Has the trash level reached underneath a junction?
Yes
Yes
Attach the RootPipe to the appropriate pipe system
Any greenhouse gases that escape from the surface will be absorbed by the vegetation
Gas Active Ventilator sucks out CO2 and CH4 from the landfill at specified intervals
CH4 and CO2 collected and processed for energy
Air circulation reduces CH4 formation and collection of gases prevents greenhouse gases escaping into the atmosphere

**Stems**




Stems

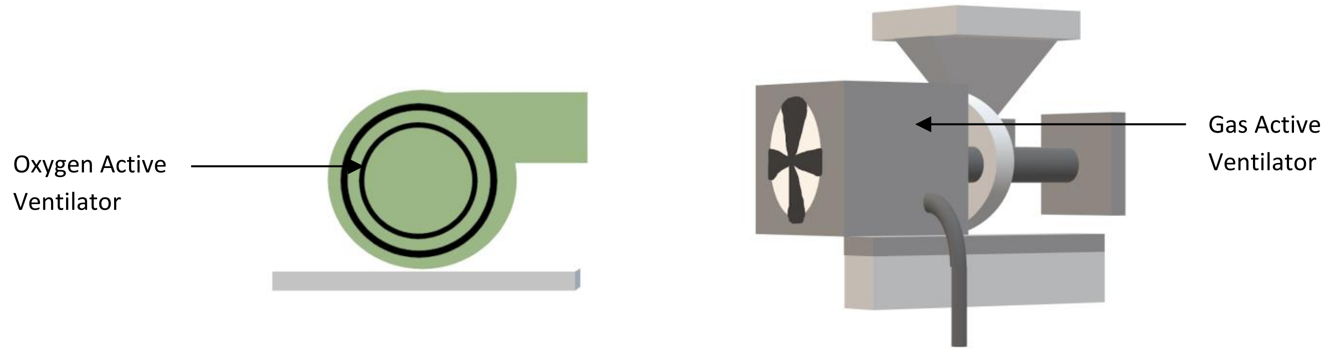
The first component of the Gas Minimization Network is evenly spaced pipes, known as Stems, inside the landfill. Stems are constructed from the base of the landfill to the outside of the final, impermeable cap. Each Stem has junctions on equidistant levels of the pipe with two on each side of the level; the level can range from 15-25 feet depending on the distance from the ground level to the aquifer. These junctions, called Extenders, are enclosed with removable caps and are designed to be durable and strong.




Stems have two categories: Oxygen and Gas. The Oxygen Stems' function is to inject oxygen into the landfill, and the Gas Stems' function is to draw out LFG from the landfill. The Stems are in juxtaposition with a Stem that has the opposite function to distribute each function's space evenly. The number of Oxygen and Gas Stems will be decided upon the dimensions of the landfill itself; if the number of Oxygen Stems is $n$, then the number of Gas Stems would be $n$+1. Gas Stems will be placed on both ends of the landfill so that gases can be pulled out optimally from areas where oxygen is unable to be injected.

**Active Ventilators:**

Because Stems stretch outside of the landfill, they will be connected to two powerful motors with the use of long, horizontal pipes. These two motors, also known as Active Ventilators, also have different functions.

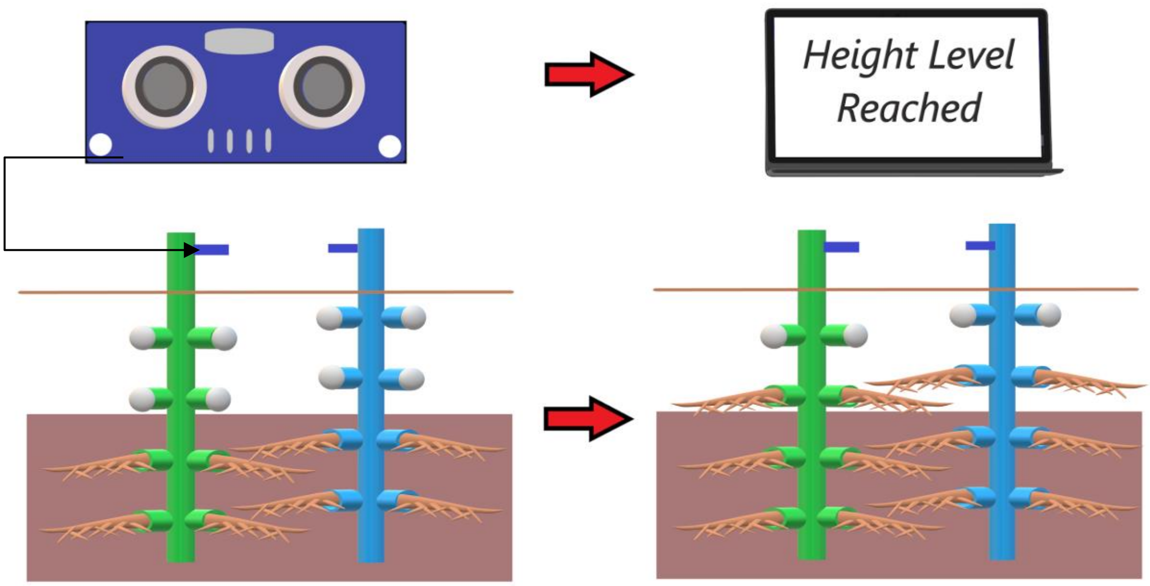



Motors

Connected to Oxygen Stems, one Active Ventilator is going to push oxygen into the landfill. The other motor's function is to vacuum out carbon dioxide, methane, and any other gases formed inside and is attached to the Gas Stems. The unidirectional flow of Stems through the use of motors is inspired from the respiratory system of cockroaches.

Both Active Ventilators also alternate in their functions. The circulation of oxygen is controlled based on the temperature inside the landfill, which is constantly monitored. In landfills, a large amount of oxygen can cause flammable risks; so, the Environmental Protection Agency (EPA) has limited oxygen levels from 10-35%. Consequently, the temperature of the landfill and oxygen correlate to each other, as it is important to stop injecting oxygen once the temperature reaches its limit. The Active Ventilator connected to the gas pipes stops acting as a suction when the Active Ventilator connected to the oxygen pipes starts functioning; gas pipes stop to avoid oxygen from being injected and extracted immediately without reactions taking place. This way, only one motor will work at a time, a process inspired by the human heart's valves.

**Ultrasonic Sensors**

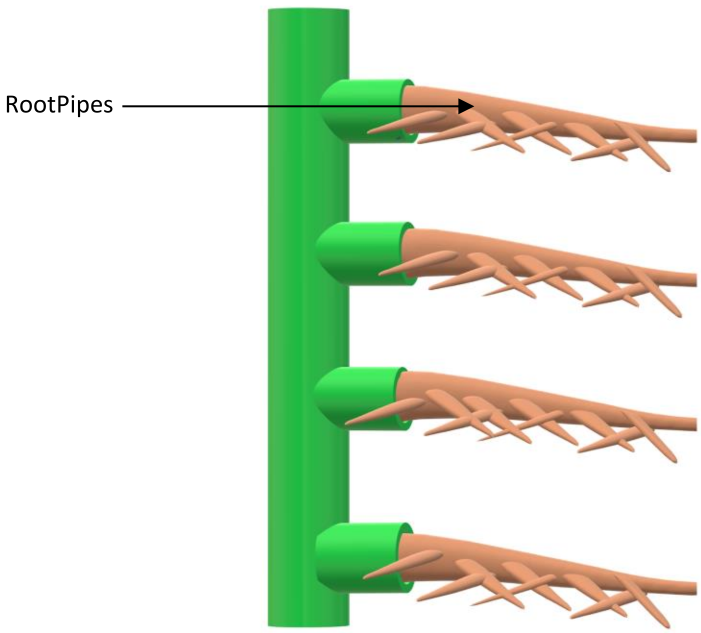



Ultrasonic Sensors Setup

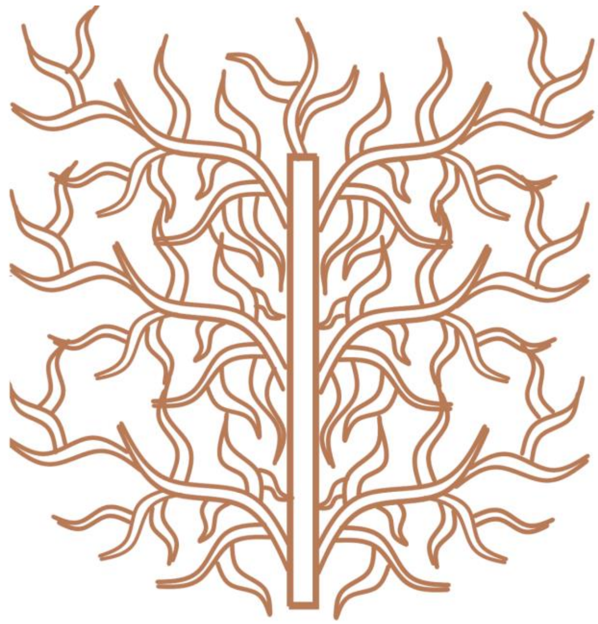
There are ultrasonic sensors attached to the top of every Stem. As waste is added into the landfill, these sensors detect the distance between the height of the waste and itself. When the height of the trash is right under an Extender, the sensor sends information to landfill operators through a software and notifies them about the action required. Landfill operators will then work on removing the cap of these Extenders; an extension, known as RootPipes, will then be attached to the Extenders of that level.

**RootPipes:**

RootPipes have mimicked many aspects of the roots of mangroves. With its root-like structure, RootPipes are designed to reach areas in the landfill that are remote. These extensions also emulate the strength and flexibility of a mangrove's roots so that they can withstand the weight of landfill waste.




RootPipes Front View



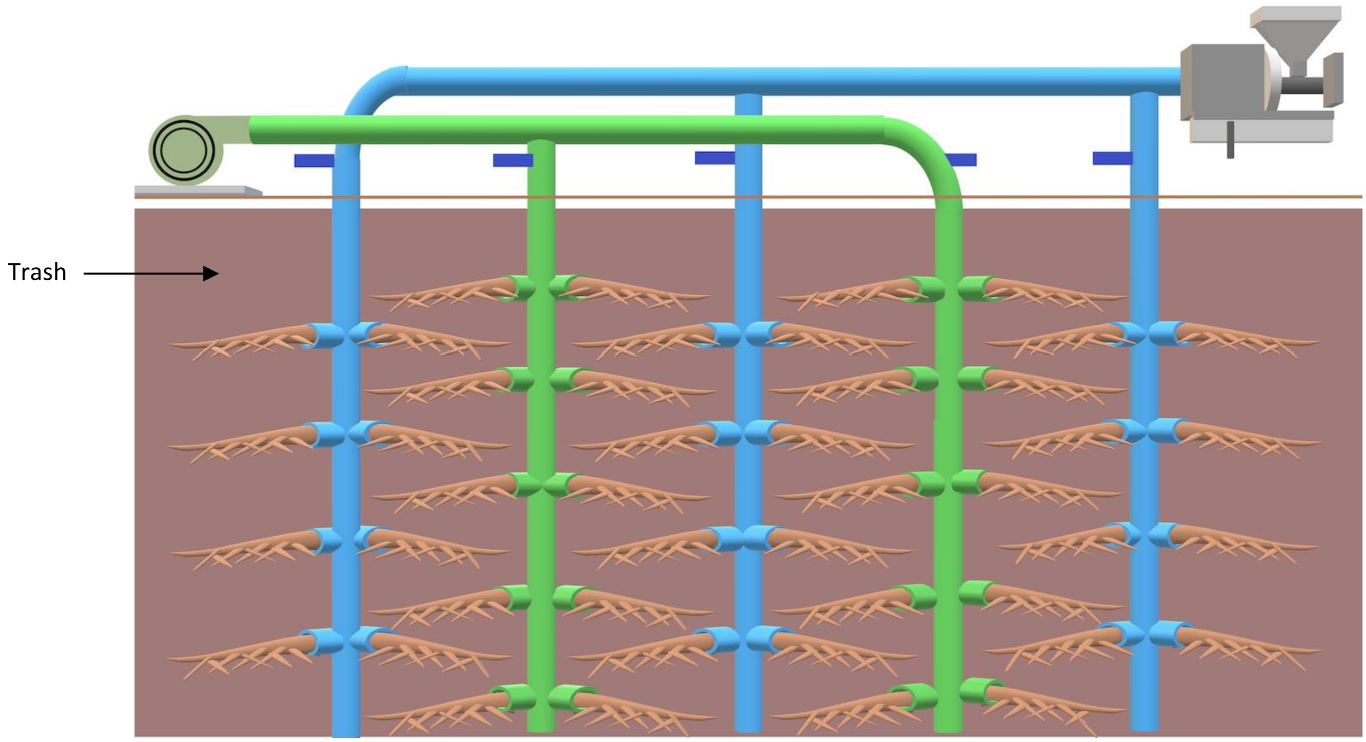
RootPipes Top View

The surface of RootPipes is exposed to leachate, soil, and waste, which risk clogging the RootPipes and obstructing gas exchange. To prevent this issue, the material of RootPipes should be semi-permeable. The material's properties, which are inspired by a lichen's surface, should be hydrophobic and allow gas exchange. It will have tiny and consistent bumps that can repel water and block matter other than gas.

The RootPipes are spread out well and are on top of the waste like casting a net; they are also layered in landfills rather than being pre-attached to be able to reach in between waste while also reducing the amount of spacing that has been taken.

Because RootPipes are extremely lightweight, landfill operators or workers can carry and attach these while walking on the landfill. The Extender's firmness, once the RootPipe is attached, allows the RootPipe to function properly. Once the RootPipes have been attached, other operations will resume.

**Process of the Gas Minimization Network**



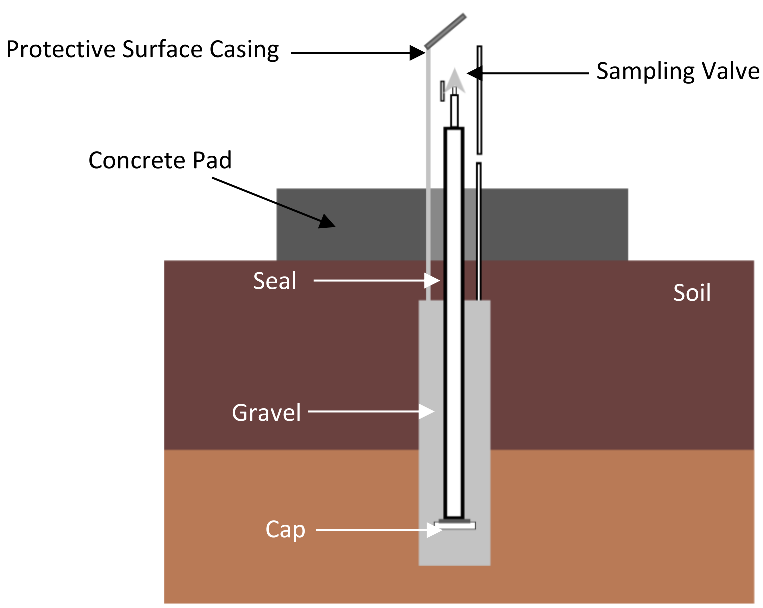

Overview of Gas Minimization Network

Once waste starts filling up a landfill, the Active Ventilators will also proceed with their functions. Injected oxygen travels through a horizontal pipe into the Oxygen Stems and then disperses out of RootPipes. The root structure of RootPipes will allow oxygen to enter more areas of the landfill; this oxygen will enable aerobic decomposition and prevent excessive formation of methane. Since Gas Stems work as a suction, RootPipes will vacuum LFG, which will travel upward to its corresponding Active Ventilator and be sent for treatment. RootPipes will be able to act as a vacuum in remote areas as well, minimizing the accumulation of gases, thus preventing internal explosions and emissions of carbon dioxide and methane. The pH levels of leachate will also be maintained due to landfill gases getting extracted quickly and efficiently.

### LFG Modeling/Monitoring

By monitoring the temperature of landfills, methane oxidation is regulated, and the amount of oxygen in landfills is also decided. The alternation process of the motors depends on this monitoring system since oxygen injection is halted once the temperature rises.

Although this solution minimizes landfill emissions, it is important to be aware of the presence of released landfill gas. There are two ways to detect landfill gas and avoid its risks. The first way is for landfill engineers to estimate these emissions, also known as LFG modeling. The other way is to monitor the LFG to receive exact numbers of emissions. By monitoring landfill gas, operators and engineers can predict the amount, the presence, and the areas of concentration.




Gas Monitoring Wells

There are many ways to monitor landfill gases; an effective way is through the use of narrow, permanent wells around the landfills. These wells measure out the amount from the middle to the low depth. Its function is to detect the concentrations of gases in the local environment. When sent to testing laboratories, the oxygen, methane, and nitrogen concentrations can also be deciphered.

A way to measure excessive amounts of methane or carbon dioxide is by using ambient air samplers. This is done to prevent any consequences of abundant amounts of harmful gases in the air.

A quick way to measure the analytes of landfills is through the use of flame ionization devices. Once a landfill is full, an operator has to pump a sample from the landfill; this sample can be read by the flame ionization device or also be sent to testing centers for more information.

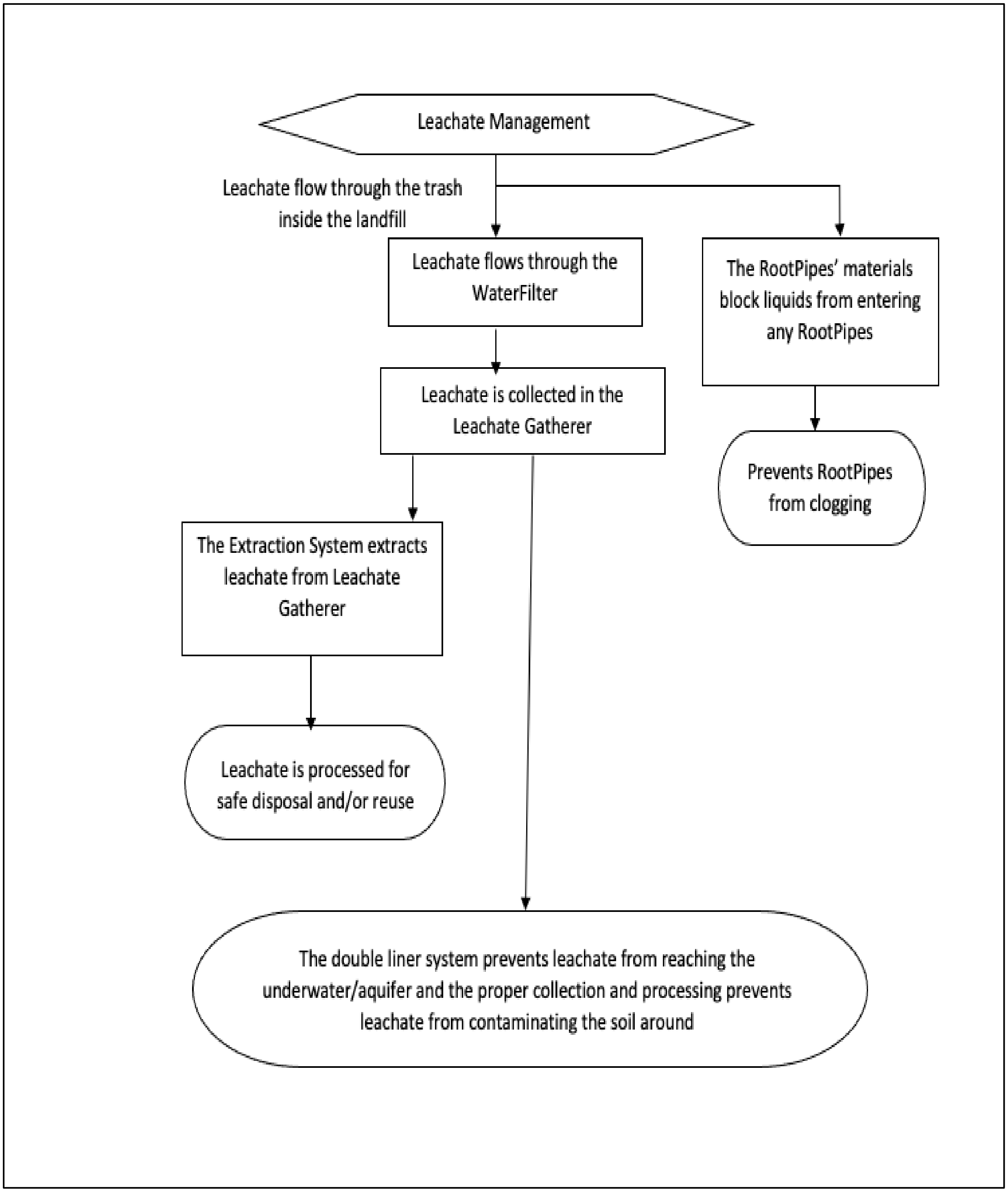
Through these processes, a landfill's oxygen and gas concentrations, temperature, nitrogen concentration, and pressure are measured.

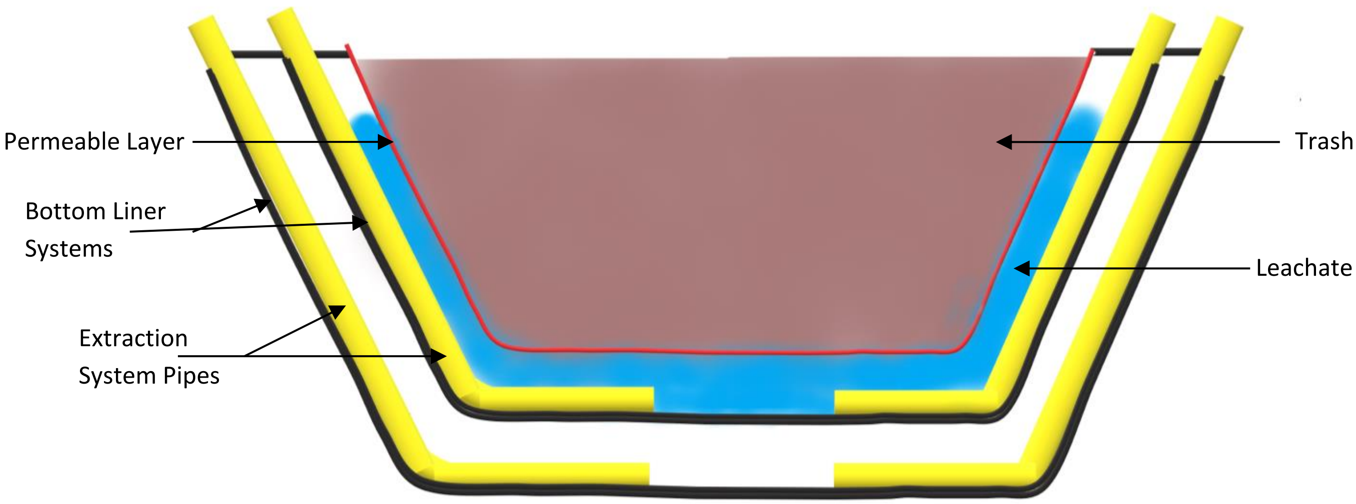
### Treatments

The captured landfill gas can be treated in different ways. In this solution, the gas will be sent to a blower/flare treatment to reduce the gas's flammable risks. After being treated, this gas can be used for a variety of tasks: electricity, vehicle fuel, pipeline gas, or industrial purposes.

## LEACHATE MANAGER

The Leachate Manager is going to protect the groundwater by efficiently extracting leachate from landfills and keeping it away from obstructing the Gas Minimization Network.

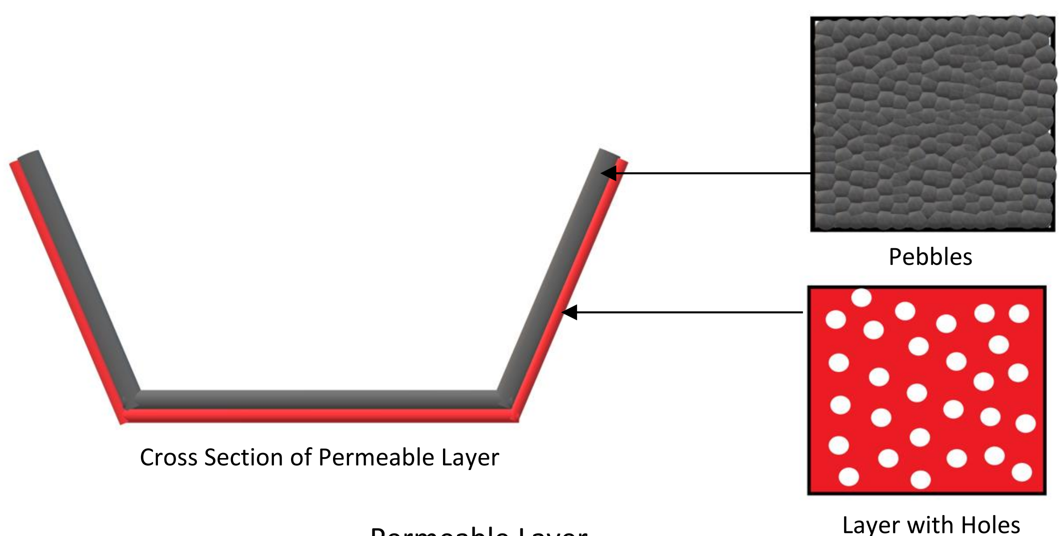

Leachate Management
Leachate flow through the trash inside the landfill
Leachate flows through the WaterFilter
The RootPipes' materials block liquids from entering any RootPipes
Leachate is collected in the Leachate Gatherer
Prevents RootPipes from clogging
The Extraction System extracts leachate from Leachate Gatherer
Leachate is processed for safe disposal and/or reuse
The double liner system prevents leachate from reaching the underwater/aquifer and the proper collection and processing prevents leachate from contaminating the soil around




Cross Section of Leachate Chambers

To achieve an optimal solution, the Leachate Manager consists of a double chamber system. This chamber system is constructed at the bottom of the landfill before waste is dumped and is going to be where leachate is collected. The double chamber system consists of the WaterFilter and two bottom liner systems, which create the Leachate Gatherer and Groundwater Protector.

**WaterFilter:**



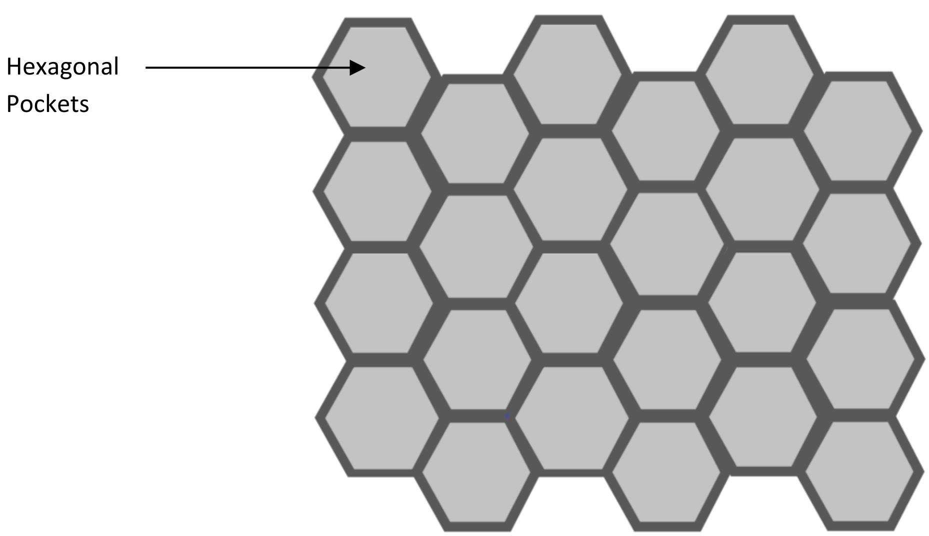

Permeable Layer

WaterFilter is the first and permeable layer of the landfill. Its purpose is to allow leachate to permeate while obstructing waste from entering. The landfill will have a layer of pebbles on the bottom to allow the leachate to flow through while obstructing waste and soil. The pebbles will lie on a surface with pores so that the surface can support the pebbles while also letting leachate pass through into the first chamber. This leads to a more efficient process because when leachate is extracted, the extraction pipes have a 0% chance of getting clogged by waste.

**Leachate Gatherer**

As leachate travels through the WaterFilter, it reaches the Leachate Gatherer. In here, the leachate is blocked from seeping further because of the chamber's bottom liner system. The Extraction System, which consists of leachate extraction pipes and a jet pump, will draw out the trapped leachate from the chamber.

**Bottom Liner System**



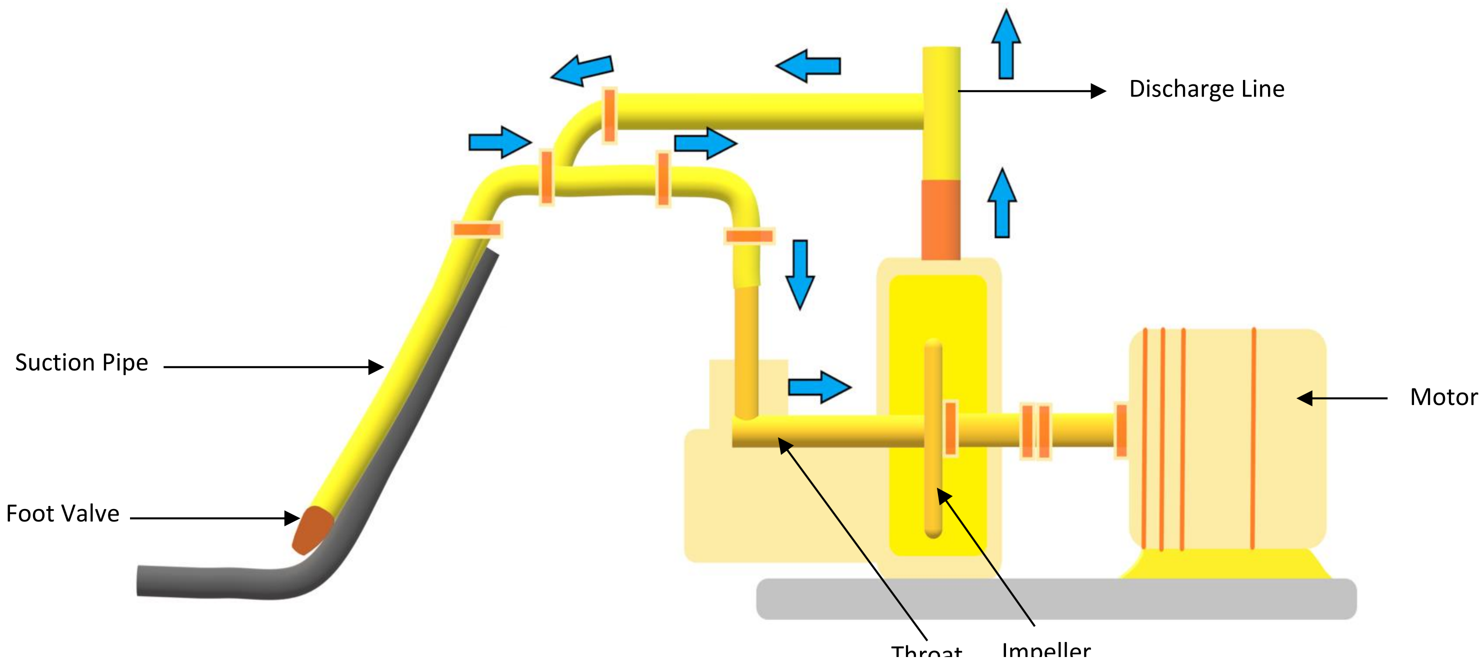
The bottom liner system's purpose is to block leachate (liquids) from traveling downward even further. It has to be durable and impermeable to proceed with its function effectively. The structure of a bottom liner system mimics the structure of honeycombs to achieve strength and durability. A honeycomb's hexagonal pockets allow it to be firm while also reducing its thickness, causing the bottom liner system to be a lightweight layer. It is the type of strength the bottom liner system needs to hold the weight of waste and leachate while also blocking liquids. Its impermeability is brought from HDPE. HDPE, or polyethylene, is an impermeable and hydrophobic material. With strength from the structure of honeycombs, HDPE bottom liner systems are ideal to serve their function.

Even though the bottom liner system is designed to be thorough, different processes are established to fix punctured liners to incorporate redundancy. The HDPE material has self-healing properties that can regenerate the plastic to seal small cracks. Inspired by a squid's teeth's genetic code, the self-healing plastic has been created by a team of researchers in Penn State. This property calls for lesser maintenance as a manual operation would only be held for larger cracks.

**Groundwater Protector**

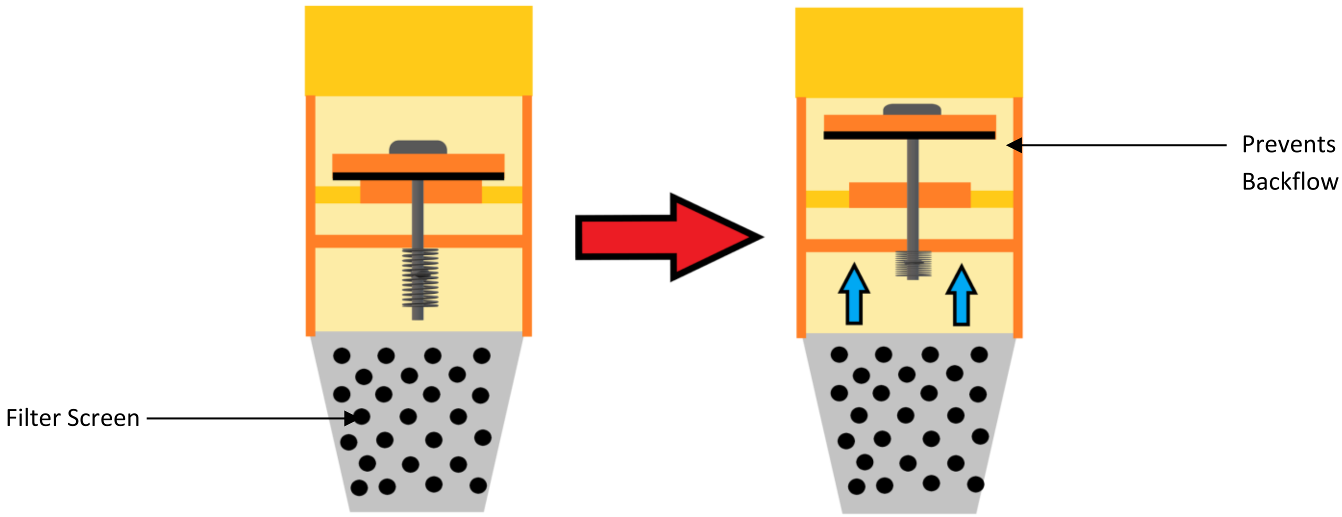
The Groundwater Protector is the second chamber underneath the Leachate Gatherer. The base of this chamber has two bottom liner systems stacked on top of each other to create another barrier. The Groundwater Protector functions as additional protection against accidental leaks from the chamber above; it also provides access to proceed with maintenance and fixing in the Leachate Gatherer's bottom liner system.

**Extraction System**




Extraction System

The Extraction System consists of jet pumps that will use energy and pressure to pump out leachate continuously. The centrifugal pump uses energy to draw out the leachate and is powered by the attached motor. Once the leachate reaches above the landfill, it passes through the pump and is either resent back to the main pipeline due to pressure or sent out by the discharge line.



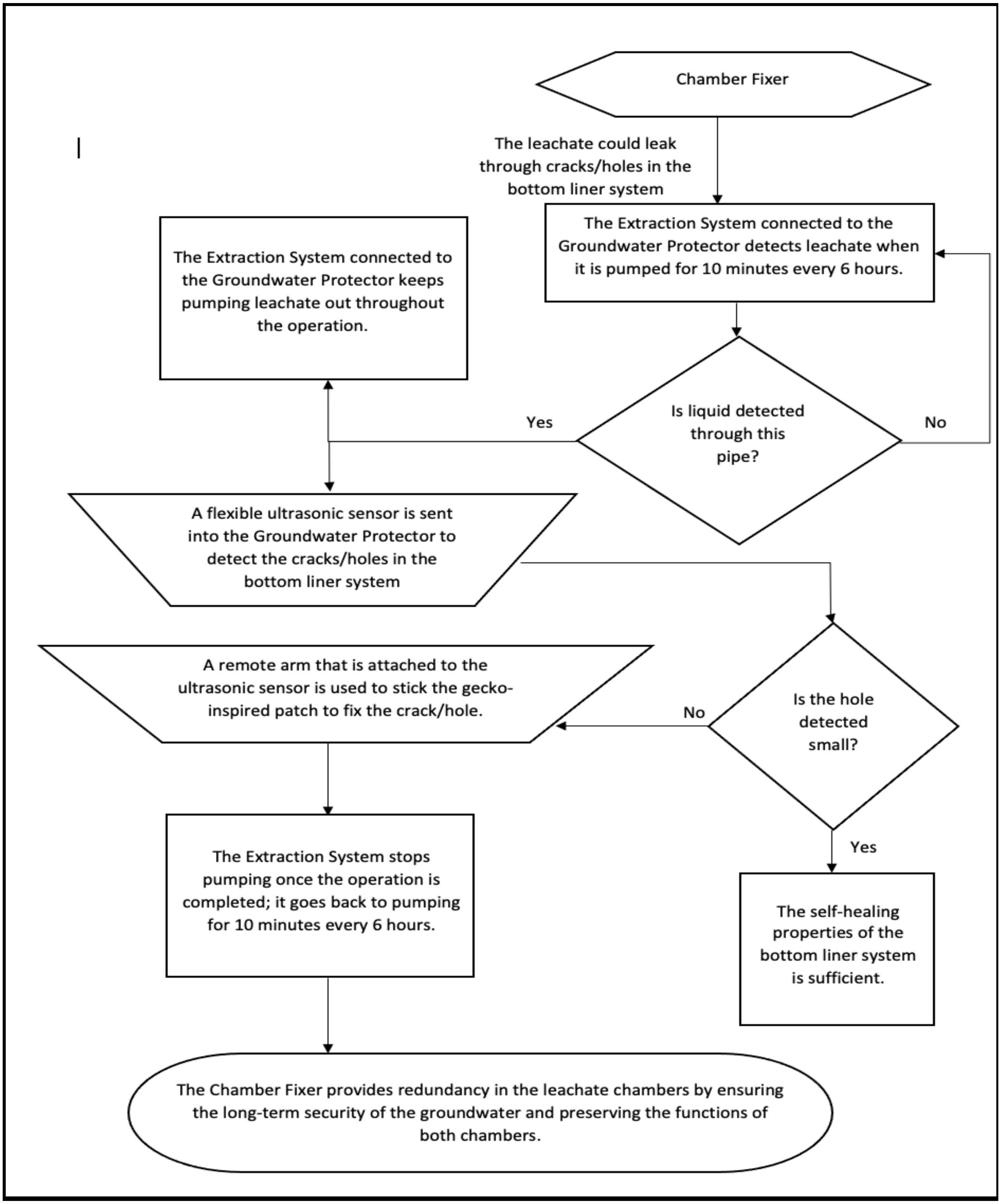

Foot Valves

The end of the pipe that reaches the chambers has a foot valve mounted to it. This foot valve is the first thing that interacts with the leachate and allows the leachate to enter the pipe seamlessly through holes. The spring on the back of this foot valve prevents the backflow of the leachate and aids the centrifugal pump with extraction.

Under the chambers, there will be compacted clay for further protection. The height of this clay depends on the height from the last bottom liner system to the groundwater.

**Chamber Fixer:**

The flowchart below depicts the functions of the chamber fixer.


Chamber Fixer
The leachate could leak through cracks/holes in the bottom liner system
The Extraction System connected to the Groundwater Protector detects leachate when it is pumped for 10 minutes every 6 hours.
The Extraction System connected to the Groundwater Protector keeps pumping leachate out throughout the operation.
Yes
Is liquid detected through this pipe?
No
A flexible ultrasonic sensor is sent into the Groundwater Protector to detect the cracks/holes in the bottom liner system
A remote arm that is attached to the ultrasonic sensor is used to stick the gecko-inspired patch to fix the crack/hole.
No
Is the hole detected small?
Yes
The Extraction System stops pumping once the operation is completed; it goes back to pumping for 10 minutes every 6 hours.
The self-healing properties of the bottom liner system is sufficient.
The Chamber Fixer provides redundancy in the leachate chambers by ensuring the long-term security of the groundwater and preserving the functions of both chambers.

If any punctures in the Leachate Gatherer are too large to regenerate, the Chamber Fixer will be used to fix the holes. Every six hours for ten minutes, the Extraction System connected to the Groundwater Protector will pump from the chamber to check whether any leachate has leaked. If leachate is extracted from the Groundwater Protector, then the Chamber Fixer operation will take place. The Chamber Fixer uses a sensor with a camera and a robotic arm for fixing purposes. Firstly, the sensor with a camera attached will be sent down to the Groundwater Protector to identify the shape, size, and layout of the hole in the Leachate Gatherer. Once pulled back out, the sensor's information will be assessed. If the identified hole is too small, then the operation will be halted as the self-healing plastic will regenerate. If not, the information will be used to manufacture a patch for the punctures. With the help of a flexible robotic arm, the customized piece will be attached to the bottom liner system. A gecko-inspired adhesive (Northwestern University & Kensey Nash) will be applied to the corners of the patch so that it is seamless once glued to the bottom liner. During this process, the Groundwater Protector's Extraction System continually extracts leachate from this chamber. After the bottom liner is sealed, the Groundwater Protector's Extraction System extracts out all the remaining leachate in its chamber. Once no leachate comes out, the Groundwater Protector Extraction System will stop pumping.

The Chamber Fixer is incorporated into this solution because fixing the Leachate Gatherer promptly conserves renewable energy, since the Extraction System of the Groundwater Protector is not pumped continually. Because landfills are long-term, this reduction adds up to a lot of energy saved.

**Hexagonal Pillars**

To hold the chambers from sinking, pillars will be placed between each chamber appropriately. The number and placement of these pillars will be decided by landfill engineers. These pillars also emulate the structure of honeycombs for more strength.

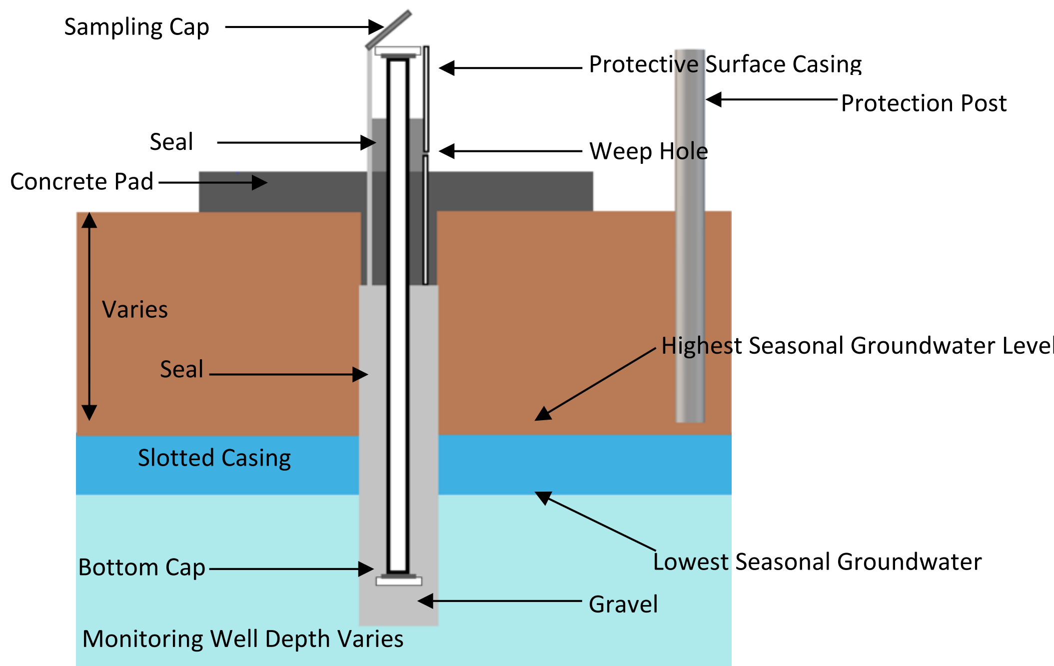
**Leachate Treatment**

Once leachate is extracted, it can be processed in several ways. A way to treat leachate is by using Poo-Gloos (Wastewater Compliance Systems, Inc.), which is wastewater treatment using bacterial biofilms; the bacterial biofilms consume the leachate as it is a tasty meal for them. Using Poo-Gloos is a cost-effective and chemical-free treatment. Although it is bio-utilization, the bacteria used are given a comfortable home since they enjoy consuming leachate.

Leachate can also be sent to standard wastewater treatment facilities. Depending on its pH levels, leachate can face aerobic treatments such as aerated lagoons and activated lagoons. Leachate can also go through anaerobic treatment processes such as anaerobic lagoons and reactors. Lastly, physicochemical treatment such as air stripping, pH adjustment, chemical precipitation, oxidation, and reduction can also be applied. If the pH levels of leachate are on the higher side of neutral or even basic, then the leachate is sent to a waste treatment plant to reduce costs.

**Groundwater Monitoring**

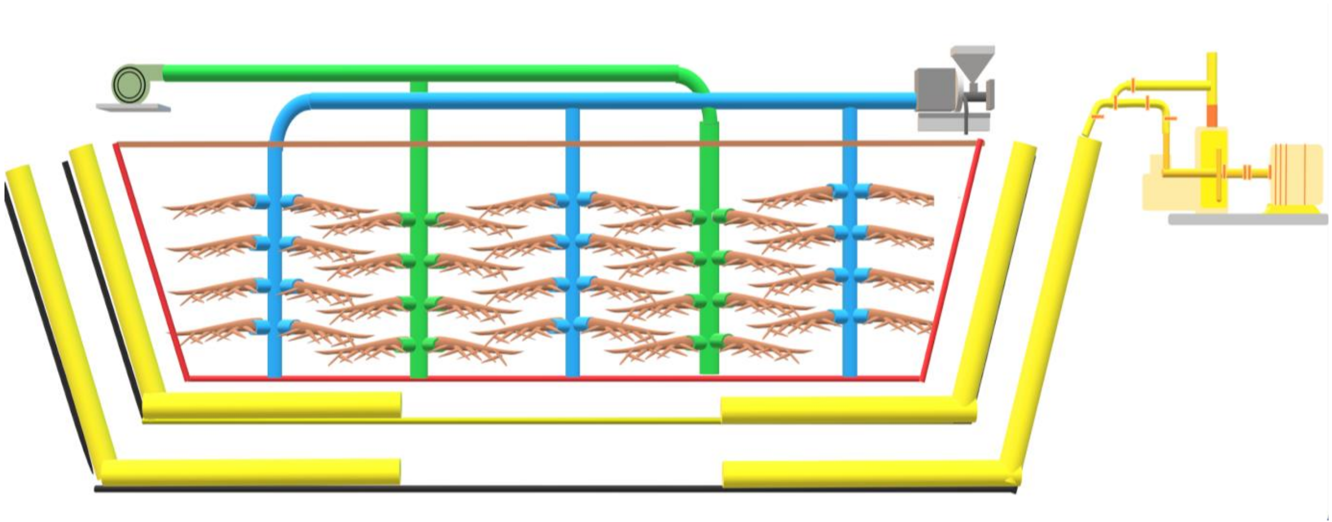



Groundwater Monitoring

Monitoring groundwater is important to see if chemicals from leachate have contaminated it; if it is contaminated, then the groundwater will be considered unusable, and operators will ensure that the water is not extracted for consumption. To monitor groundwater, wells with a small diameter are placed around the landfill site. The depth of this well will depend on the place it is being drilled in. In this solution, the wells will be artesian and will use gravel in the bottom to create pressure and draw out groundwater for testing. Groundwater will be sent for tests in independent testing laboratories, which will send back information on the pH levels and toxicity of the aquifers. This process will keep taking place every quarter of the year, even after the landfill is closed. The reports are also sent to the EPA, which requires landfills to have groundwater monitoring systems.

# OVERALL LANDFILL



# MANUAL OPERATIONS

**Adding in Trash**

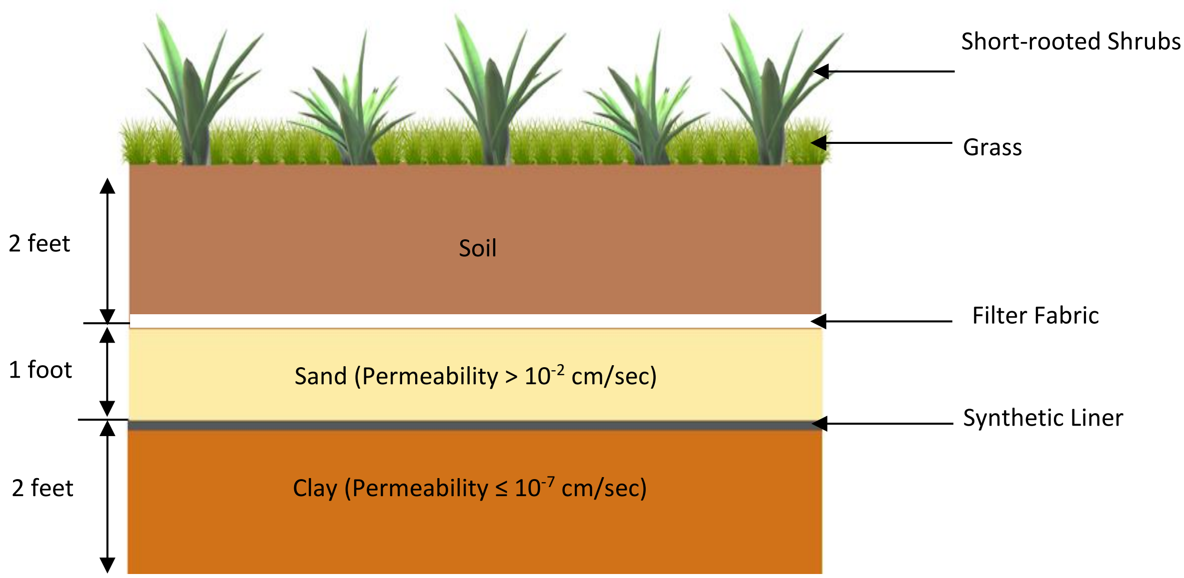
Before trash is placed in landfills, it will be compacted into cubes with the use of specialized gadgets. This way, more waste can be added to one landfill and also provide necessary airspace. Compacting trash also reduces health risks because fewer pests and scavengers are likely to try to enter and consume waste. After compacting, waste is then disposed of inside landfills.

Layers of Soil and Trash

**Using Soil to Create Layers**

In current landfills, the soil is layered between waste for various reasons. After adding waste for a day, a layer of soil is added. This is done to prevent pests and scavengers from entering the waste, which poses health risks for home communities built around landfills.

## AFTER CLOSURE



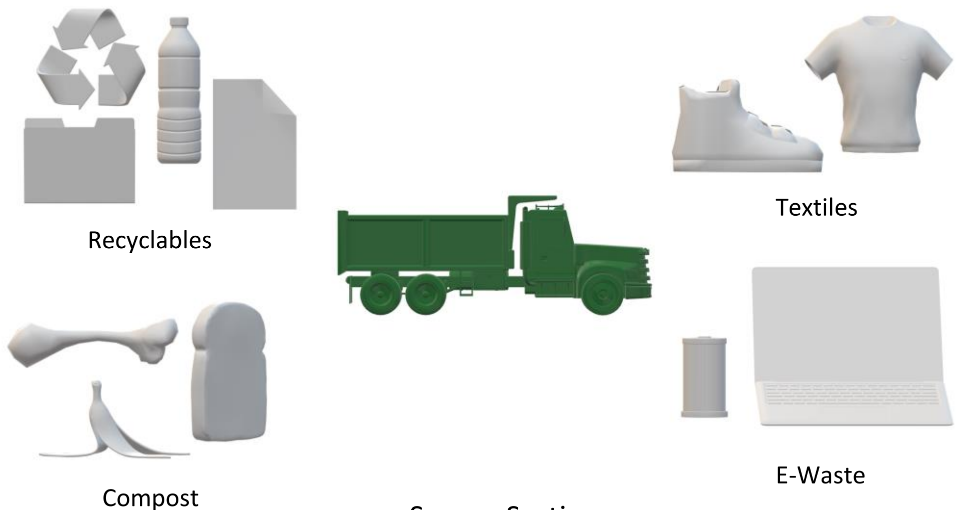

Layers of Impermeable Cap

After the landfill is full, an impermeable cap with multiple layers is added to the top to avoid various problems. For instance, the impermeable cap reduces the chance of rainwater going into landfills after closure; this reduces the amount of leachate formed exponentially and reduces risks towards the groundwater. The impermeable cap also prevents LFG from freely emitting outside, and it blocks pests from entering, which reduces health risks for people living around.

To also reduce carbon dioxide in the air, short-rooted shrubs will be planted on the top of the impermeable cap. These shrubs include Azalea, Boxwood, and Holly shrubs. Although this is a part of the design, it can be modified to fit needs such as constructing community buildings.

## RECOMMENDATIONS

*Source Sorting*




Source Sorting

A more proactive approach to preventing unnecessary waste from entering landfills is through sorting. Raising awareness for the benefits of sorting and how it helps the environment is vital now; it will decrease the amount of waste entering landfills. Currently, waste that goes into landfills also consists of recyclables, compostable products, and other treatable garbage. Food waste and plastics are major components of landfills right now. On average, 22% of the landfill is food waste and 19% is plastics. By sorting waste, landfills will get filled up slower than before, reducing the number of landfills constructed; this will reduce construction and maintenance costs. Consequently, the toxicity level of leachate will also decrease, making leachate treatments less costly and less risky. Here are a few types of wastes that can be avoided from entering MSW landfills:

- Recyclables
- Compostable food waste
- Textiles and shoes
- Hazardous wastes such as electronic wastes and batteries
- Paint cans if there is paint inside

# NEXT STEPS: PREPARING FOR PROTOTYPE

1. **Technology**

   - **Ultrasonic Sensors and Mobile App**

   The process of the ultrasonic sensors communicating via the mobile app needs to be created and tested.

   - **Chamber Fixer**

   The robotic arm and ultrasonic sensors need to be chosen and configured for the Chamber Fixer. The gecko-adhesive patch needs to be tested.

2. **RootPipes' material**

   Based on the RootPipes' properties identified, I will need to collaborate with a green chemistry scientist and material engineers to create an appropriate material. In addition, the dimensions of RootPipes will be deciphered with the help of landfill engineers. The material of Extenders also has to be identified, which should work well with RootPipes.

3. **Motors**

For tabletop prototyping, the substitution for motors must serve the exact functions as Active Ventilators. An existing motor that works the best with Stems and RootPipes will be configured in an actual landfill.

4. **Funding**

To build a small-scale model of the landfill, I will ask for help from my friends and family. After the prototyping starts coming along, I will request funding on Kickstarter or GoFundMe. With a tabletop prototype ready, my next step would be to reach out to larger organizations for funding, which includes Waste Management, Republic Services, and environmental nonprofit foundations.

5. **Permission from City Departments**

If my solution starts preparing for a big-scale prototype, I will have to ask permission from the local city's department that handles environmental protection and landfill overseeing. I would also have to get my solution approved by the EPA since they monitor landfills and the environment's protection.

6. **Leachate Manager Testing**

The process of leachate permeating through pebbles and getting trapped in a chamber needs to be tested to protect the groundwater once the project becomes big-scale. The prototype will test the two-chamber system.

7. **Future Feature Considerations**

- **Rainwater Harvesting**

Being able to collect rainwater for usage in the future will be resourceful and also protect the landfill from generating excess leachate at a time.

- **Source Sorting**

Educating communities about the importance of separating waste carefully and composting correctly will decrease the amount of waste that goes into landfills.

# DISCUSSION

My solution is designed to fight against climate change and reduce the 16% of methane emissions that source from landfills. Throughout the creation of my solution, I have relied on biomimicry to solve different aspects of the problem, green chemistry for future material considerations, and industrial designing from ideation to persuasion. Going back to my initial question, my solution addresses all of the requirements to achieve a better landfill. It solves the inadequate use of vertical pipes that led to emissions and a missed opportunity of producing more energy. As a result of this quick and exhaustive extraction, the pH levels of leachate are maintained; furthermore, leachate is successfully collected without extreme risks posed to the groundwater.

Firstly, rather than small, non-exhaustive pipes, RootPipes allow more insertion of oxygen and efficient collection of gas; because of more amounts of extracted gas, more renewable energy can be created to serve as electricity for homes or fuel for cars. With respect to my essential question, this process drastically minimizes emissions. In addition, leachate is handled more safely through the double chamber design, and the separation of leachate from pipes and waste calls for less clogging. This eventually protects the groundwater, soil, and surrounding vegetation from leachate. My solution exceeds my initial question by adhering to various EPA requirements and essential processes, such as monitoring the groundwater and LFG, and also adopting the use of an impermeable cap to avoid excess leachate production and methane outflow.

Now more than ever, it is time to reduce the climate impact that a landfill brings. As explained previously, the incorporation of my solution drastically reduces the risks of landfills, while also being cost-effective; in addition, with increased energy production, there will be an annual revenue generated as well. When implemented, not only will my solution minimize risks, but it will benefit society by creating additional renewable energy and preserving the groundwater for the accelerating population.

# INDUSTRIES AND SECTORS APPLICABLE FOR THIS SOLUTION

- Environment
- Waste management
- Energy sector
- Mining

# ACKNOWLEDGEMENTS

I would like to thank Ms. Shanti Balaraman, my mentor, for guiding me through the biomimicry world and assisting me throughout my design formation. I would also like to extend my gratitude to Ms. Kathleen Klein and Mr. Joseph Read, who are community relations representatives from Waste Management; while interviewing them, they gave me more insight into how the landfill works and provided feedback on my solution.

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