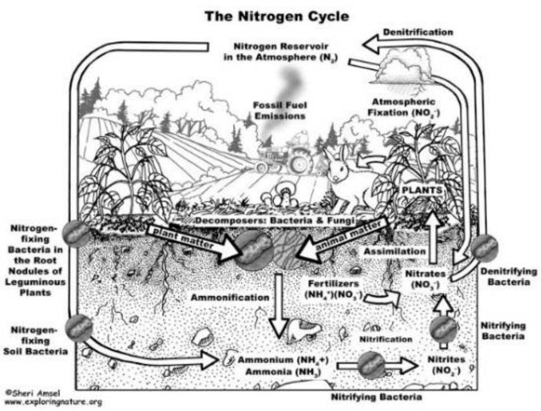
Problem Statement

Nitrogen, like oxygen, is an essential element for supporting life. Its presence extends from the expansive atmosphere, which is 78% nitrogen, to the microscopic proteins that make up our DNA. Unfortunately, human activities have contributed to the disruption of the nitrogen cycle and have become a problem in recent times. Specifically, the emission of nitrogen oxides (NOx) is a key contributor to the hindrance of the nitrogen cycle. Power plants, one of the biggest sources of NOx, release these gases in vast quantities into the atmosphere, leading to drastic effects on our health and climate. Power plants also use the most water of any industry in the US and often aren't efficient enough, as much water gets lost in the form of steam. Nitrogen oxides released in the atmosphere react with water forming nitric acid. When this acid precipitates, it poses danger to all living organisms including humans and causes skin burns and cancer. Acid rain can also be harmful to plant growth and their survival. The same acid rain (HNO3) can also precipitate in water bodies and cause eutrophication (excessive enrichment of foreign particles which lead to algal blooms). It can lower the pH of the water and increase nitrogen levels, polluting the water and resulting in an imbalance of aquatic life. This can disrupt aquatic food chains, potentially leading to the mass extinction of multiple species.



Our Solution :Neutralization of Nitric Acid from Nitrogen Oxide (NNANO)

NNANO 2.0 will be installed on power plant exhausts and consists of a main chamber along with smaller compartments for storing chemicals. Semi-permeable membranes selectively absorb NOx, which is then oxidized into NO2 and stored in the main chamber. At the same time, steam from the exhaust is collected and condensed into water in a side compartment. This water is released into the main chamber, where it reacts with NO2 to form HNO3 and HNO2 in the airtight environment. A pH sensor monitors acidity and triggers the release of NaOH from another compartment, neutralizing the acids to produce NaNO3, NaNO2, and water. Hence, we can convert NO_x into pure water that can be repurposed.

Chemical Verification:

$3Cu + 8HNO_3 \rightarrow 3Cu(NO_3)_2 + 2NO + 4H_2O$
In this reaction Copper Nitrate ($Cu(NO_3)_2$) and water (H_2O) are the byproducts which will not be needed any more in this process. The NO gas (colorless) released will escape Flask 1 through the pipe into Flask 2.

Figure 1: Flask 1 (right), Flask 2 (left)

Step 2:
Now, with our nitric oxide, we were able to start the real chemistry verification.
As shown in Figure 2, we left Flask 2 uncovered so the NO will be able to react with oxygen in the air to form Nitrogen Dioxide (NO_2) in Flask 2.

Figure 2: Flask 1 (right), Flask 2

Step 3:
Since NO_2 is denser than air, the gas will not escape. However, since the reaction is exothermic, the gas will rise slowly because of the heat produced. Now by pouring water into the flask, we react NO_2 with H_2O and oxygen (O_2) which forms Nitric Acid (HNO_3). Figure 4 shows the HNO_3 produced. **Reaction:**
$4NO_2 + 2H_2O + O_2 \rightarrow 4HNO_3$

Figure 3: Flask (NO_2), Graduated Cylinder (H_2O)

Figure 4: Flask (HNO_3),

Step 3:

In this step, HNO_3 is neutralized with Sodium Hydroxide (NaOH) to form Sodium Nitrate ($NaNO_3$) and H_2O. To ensure that both reactants are neutralized, Phenolphthalein is mixed in with HNO_3. Phenolphthalein is an indicator that turns pink as pH increases. The image on the left shows HNO_3 being titrated with NaOH. As NaOH is discharged into the mixture of Nitric Acid and Phenolphthalein, the solution turns pink for an instance for every drop of Phenolphthalein as seen in Figure 5. As more NaOH is discharged, the pink color is visible for a longer period, until the solution turns into a very slight pink color. The final solution ($pH \approx 7$) is depicted in Figure 6, composed almost entirely of H_2O and $NaNO_3$.

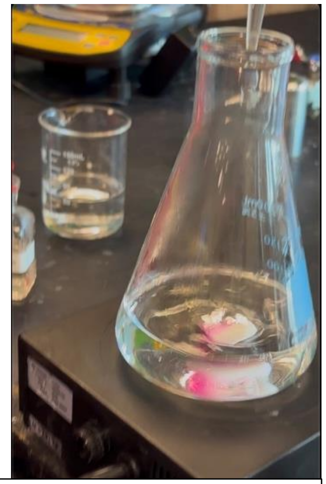


Figure 5: Flask (HNO_3)

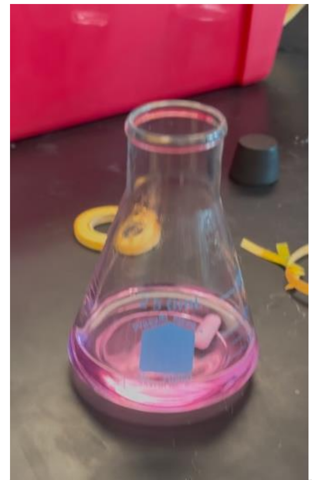


Figure 6: Flask (H_2O + $NaNO_3$)

First Prototype Testing:

For this level of testing, we constructed a manual prototype with piping, faucets and plastic containers. Through the use of superglue, we were able to ensure that our model was airtight. We followed the same workflow as the chemical verification when testing our prototype model.

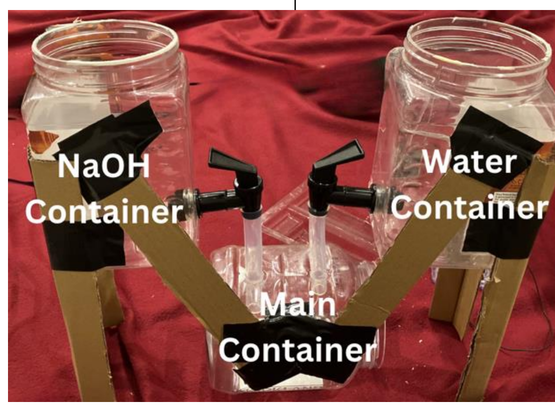


Figure 7: Scaled-Down Model

Step 1:

Firstly, to create the NO conditions present at power plants, we used the same reaction as in chemical verification. Using 7.0 M HNO3 and Cu, we were able to create NO and NO_2, as shown by the red gas in Figure 8. The similarity between Figure 1 and Figure 8 indicates that our scaled-down model was able to replicate the NO and NO_2 at powerplants accurately.

Figure 8: Model with Nitric Oxides

Step 2:

Next, we flipped the water faucet to represent the steam filters we'll be implementing in our final prototype. Since we can't generate steam at a mass volume in a room-temperature setting, we're using water as a substitute. After adding the water, we can see how the red color has decreased to a yellow similar to the yellow in Figure 4, indicating that HNO_3 has formed. Note that the blue color represents copper nitrate, a side product of the reaction we used to make NO and NO_2. In our chemical verification, we were able to transport the nitric oxides to another container. However, in our model testing, we must do it all in the same container, so the copper nitrate will be present. The copper nitrate doesn't interfere with any reactions.

Step 3:

Lastly, we flipped the NaOH faucet to balance out the HNO_3 in the main container. After testing the pH of the main container, we found a pH of ~6.5, which means that the water is suitable for repurposing for the powerplant.

Figure 9: Model After Adding Water and NaOH

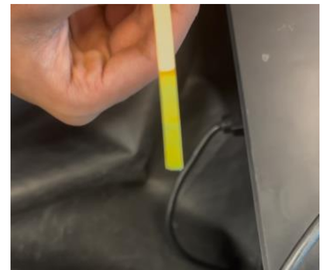
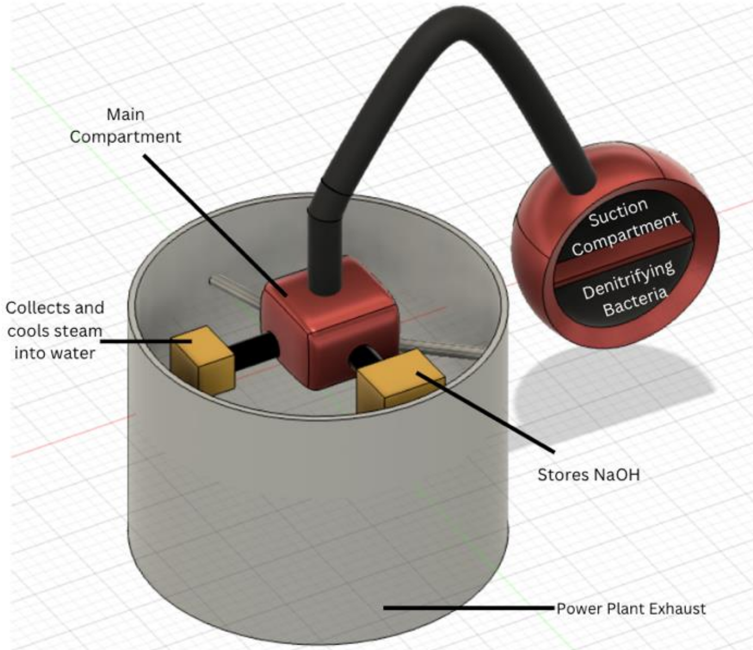


Figure 10: pH Strip of Main Container

Scaled-Down Model Improvements:

Below is a picture of our final version of the scaled-down model. We added a pH sensor and the NaOH motor, but we couldn't add filters.

Initial Large-Scale Prototyping:



The initial prototype of NNANO 2.0 was designed to neutralize nitrogen oxides (NOx) from power plant exhaust gases. The model featured a main compartment attached directly to the exhaust, where chemical reactions would occur. Two yellow modules handled key processes — one stored NaOH for neutralization, while the other collected and condensed steam back into water. The system also included a red external sphere, which contained *Pseudomonas* denitrifying bacteria intended to further reduce nitrogen compounds into harmless forms. However, while the concept was scientifically grounded, it had several practical and structural challenges:

- The external bacteria chamber made the system more complex and unstable, both in mass distribution and maintenance.
- Keeping bacteria alive outside an exhaust environment while maintaining effective chemical flow added significant engineering difficulties.
- The overall design was mechanically top-heavy, with uneven weight distribution that would make large-scale deployment difficult.
- Internal reaction control was limited by the lack of a closed, regulated environment for precise gas and liquid handling.