



Proposal Automated Trace Gas Trapping System (ATGTS)

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Abstract

Agricultural soils are the greatest source of human derived greenhouse gases to the atmosphere (Braswell, 1987). Because of this a number of efforts are underway to minimize the emissions of greenhouse gases from soils that include use of organic fertilizers and no-till practices. Such mitigation practices, however, require verification particularly at national and international levels where carbon credits can be bought and sold. For this reason, we propose the development of an autonomous soil gas flux chamber that, once deployed, automatically traps greenhouse gases (CO_2 and N_2O) being released from soils to the atmosphere for months at a time (an Automated Trace Gas-Trapping System or ATGTS). The ATGTS consists of a flux chamber to collect gas evolving from soils, chemical or molecular sieve traps to remove water and trap CO_2 and N_2O , a pumping system that periodically turns on and off to move gases through the chemical traps, a system for collecting and distributing rain-water within the flux chamber, and a power system consisting of a 24 V battery. This has been previously demonstrated by a prototype system that is capable of quantitatively trapping CO_2 and N_2O gases evolving from soils. Now there are two goals (1) to design an independent electronic control system and (2) to finalize the mechanical design for an autonomous system. A final ATGTS system could be sent to farmers and educators across the country as a basis for them to participate in greenhouse gas accounting programs.

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Introduction

Many scientists regard climate change as the most critical contemporary threat to the earth's ecosystem. In response, international Framework Convention on Climate Change has created etiquettes of diplomacy such as the Kyoto Protocol, for example. One major component of these protocols is to develop emissions trading schemes such as carbon crediting. Carbon crediting is one of several methods by which to reward a lowering of greenhouse gas emissions and penalize those who do not. An integral part of this drive is to both reduce greenhouse gas emissions and research new methods to quantify these emissions. More specifically, it is of great interest to develop a method by which to measure trace gas amounts of nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions from soil to the atmosphere.

The Biogeochemistry Environmental Research Initiative, or BERI, is funding a multi-disciplinary team whose task is to design and construct a prototype automated gas trapping system for N_2O and CO_2 efflux from soil. The device should take a sample of each gas using molecular sieves. These sampling events will occur in succession, each lasting approximately five minutes. After two sampling events occur, four hours must elapse before the next sampling events. This trend will continue, uninterrupted, for a one month period called the test span. The pump should operate sufficiently slowly during each five minute sampling event to allow scrubbing of N_2O and CO_2 from the 150ml and 20ml chambers respectively. At the end of the test span, all four traps included in the system should be easily replaced with new empty traps, and the

filled traps will be sent back to the lab for research. Furthermore, the four hour period separating sampling events should incorporate any rainfall and changes in ambient temperature to the sampling chamber. More specifically, rainfall that occurs during the four hour waiting period between sampling events must be caught in a reservoir atop the device and evenly dispersed on the soil covered by the device every 30 minutes. Each time this simulated precipitation occurs, outside air must be mixed with the air in the device to equilibrate the temperature of the sampling chamber with the ambient air. Lastly, the device must also measure and record the air temperature inside and outside of the device.

Background

CO₂ and N₂O are released from soil when it is tilled or otherwise disturbed. As a result, deforestation and the creation of farmland are leading contributors to the release of greenhouse gases into the atmosphere. Typically, levels of NO₂ and CO₂ in the atmosphere are modeled using techniques from meteorology, but we need measurements of a much finer resolution to improve these models.

The amount of N₂O that is released into the atmosphere by agricultural soils is not well understood (Hengeveld, 1995). More accurate measurements regarding these emissions are crucial to the understanding and control of greenhouse gas emissions, as well as global warming. While N₂O is much less prevalent than CO₂ in the atmosphere, it is also one thousand times more capable of retaining heat, rendering it an even greater contributor to heat retention in the atmosphere.

To measure the flux of these gases from the soil over time, a remote trapping system must be designed. Then, these collection systems must be analyzed in a lab. This trapping can occur using molecular sieve which traps gasses based on their volume.

The concept of a trace gas collection system has been proven by the prototype, seen in figure 1. It has successfully trapped N₂O and CO₂ gases over a 76 hour period using manual controls (Ostrom, 2007). These previous developments suggest that the concept driving the design of the ATGTS is feasible.

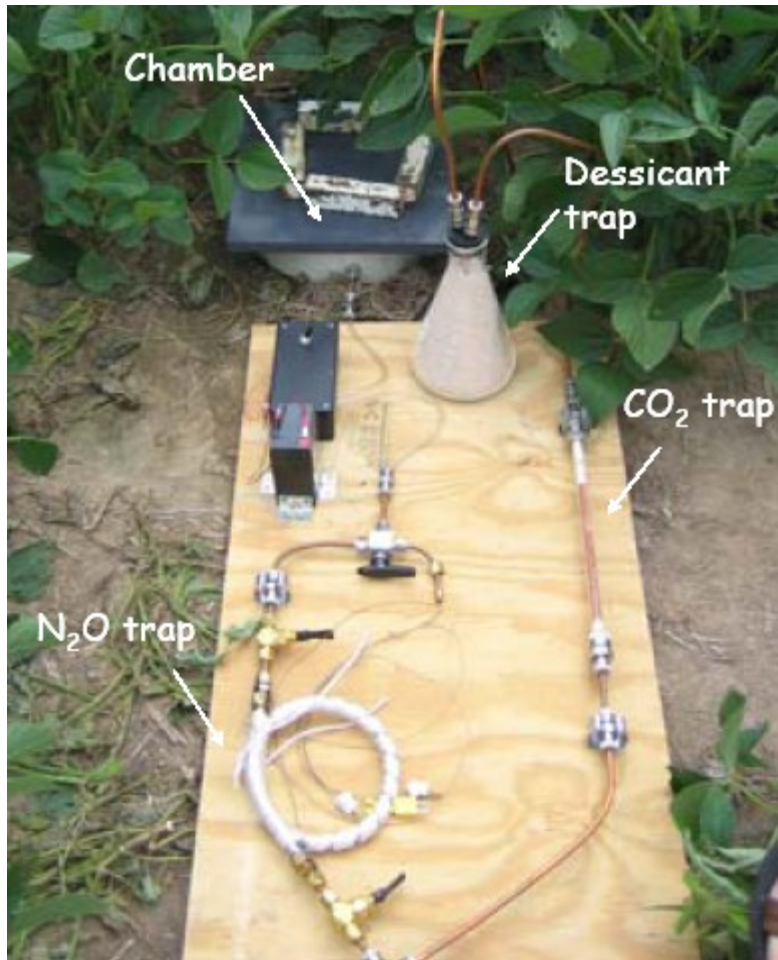


Figure 1. ATGTS Proof of Concept Prototype

Design Specifications

The system must be designed with the main goal to trap trace gases emitted from soil over a one month period. This will allow researchers to quantize the time rate of release of these trace gasses. To accomplish this goal, both a mechanical gas trapping system and electrical control system must be implemented.

Mechanical Requirements

The system must be designed to completely trap trace gas using molecular sieve. The main chamber will serve as a collection facility for gasses released by the soil. Then, CO₂ and N₂O must be collected from this chamber. There are many constraints on the system based upon the properties of the molecular sieve. The molecular sieve can not be exposed to any water vapor because the pores in the molecular sieve will clog with water instead of the desired trace gas. This provides the need for a desiccant trap to remove water vapor from the air before it reaches the molecular sieve. To maintain a closed system during trapping, a system of sub-chambers is used. It is important to realize that the sampling of gases must be in a closed system to control sample volume. Therefore, if a sub-chamber is to be used, it must be isolated from the soil flux chamber during the sampling process. Also, CO₂ and N₂O must be trapped in various stages. The molecular sieve filters these gases based on their molecular volume, and remain in the trap until they are removed in an offsite process. The molecule size of CO₂ and N₂O is very similar, and N₂O is thousands of times less abundant in the atmosphere than CO₂ (Halpert, 1996). If both gases

were to collect on the same trap, it would be impossible to measure the percentage of N₂O. It is because of this that the system must be designed to strip CO₂ from the sample prior to trapping the N₂O on the molecular sieve. The best way to strip the CO₂ from the gas without affecting the concentration of the N₂O is to use a chemical CO₂ trap.

Sub-chambers are required to provide different sample sizes for both gas trapping systems. CO₂ is much more prevalent in the atmosphere, and will require a smaller sub chamber than N₂O to operate within the constraints of the molecular sieve. Two sub-chambers are needed to have the device function in the same manner as the ATGTS proof of concept test.

Air flow is created by a pump and redirected by valves opening and closing. These control details are discussed further in the next section. Due to the effect of soil moisture on microbial processes, the mechanical design must also accommodate rain water collection. This system will dump the rain water into the main chamber to provide regular atmospheric moisture conditions. Following the sample cycle, the main chamber and sub-chambers are equilibrated with atmospheric conditions.

Mechanical Control

The control of the gas flow is critical to accurate sampling. This flow will be controlled by a pump and a series of solenoid controlled valves. A diagram detailing the flow of gases through the system is included in Figure 2. During the rest cycle, the system is off, and gases will accumulate within the main chamber. During sampling, the pump will switch on and begin to pull the sample from the

sealed sub-chamber through the system, with the N₂O trapping occurring first. A pair of 2-way solenoid valves will regulate airflow into and out of the N₂O sub chamber. This air will be pulled through the first 3-way solenoid valve into the H₂O desiccant trap. A second 3-way valve will redirect the air flow through a chemical CO₂ trap followed by a N₂O molecular sieve trap. This air will then flow through the pump and back into the N₂O sub chamber, maintaining a closed system.

The CO₂ trapping event is very similar to the N₂O trapping event. However, there are two major differences between the two flow paths. First, the CO₂ sub-chamber is much smaller than the N₂O sub-chamber. Second, after the second 3-way solenoid valve, the air will be redirected through a single CO₂ molecular sieve trap.

Moisture conditions within the flux chamber must be equilibrated with the atmosphere to ensure identical trace gas producing conditions. However, the gas seal between the collection facility and the atmosphere must be maintained. This means that rainfall must be collected in a reservoir atop the device and dumped into the chamber periodically.

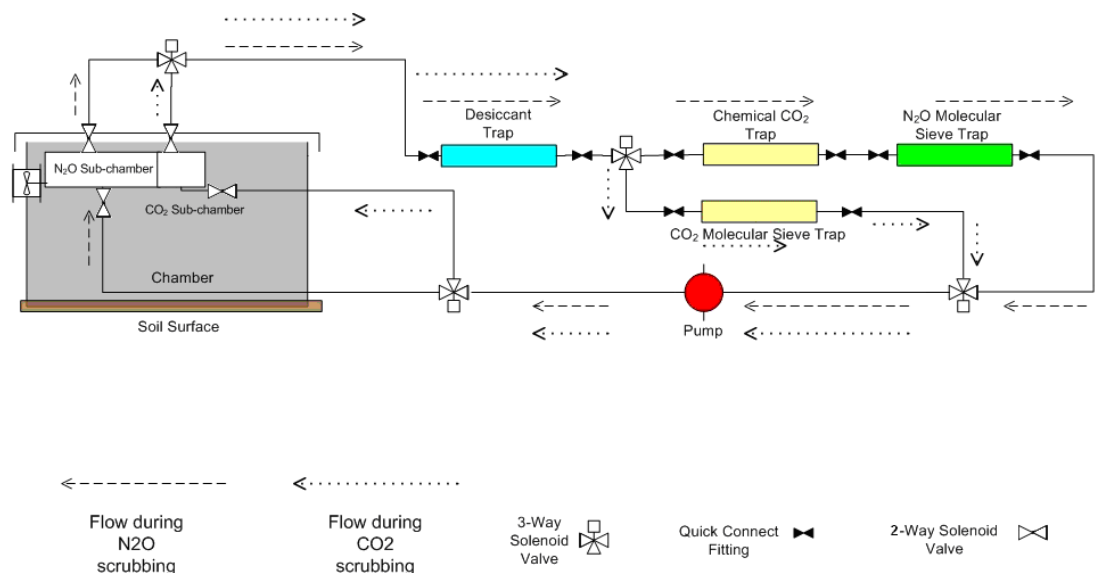


Figure 2. Trace Gas Trapping Flow Chart

Electrical Control

The electrical system will provide direction and power to the mechanical control while taking simple measurements. The CY3214-PSOCeval USB microcontroller is the backbone of this control system.

The microcontroller will operate two electronic thermometers, measuring the temperature inside and outside of the chamber. Gas expansion and microbial activity both depend heavily on temperature, thus, accurate readings are important to BERI's soil research. The data gathered from these sensors will be stored electronically in the microcontroller. The unit will provide a digital, downloadable file at the end of the month cycle that details temperature cycles over the course of the month.

The microcontroller will also control the flow cycle and air equilibration process of the entire system. This entails regulating the air pump and each of the

solenoid valves through electronic actuators to provide the gas flow as described in the mechanical control section.

The microcontroller will provide logic signals for these actions. However, the power is provided by a battery system via reed relays. This battery must power the closed system for the duration of one month. This battery system will also require a fault LED. This fault LED will display to the user that the battery is low. The electrical control of this system must be robust enough to operate uninterrupted for the duration of one month.

Fast Diagram

(Not due until Oct 08)

Conceptual Design

The design of this system has to provide a deployable self contained unit shown in figure 3 that is robust enough to operate for the duration of one month. This provides a triage in the design of the system that defines some parameters as more immediately important. For this reason, the exhaust fan, pump, and traps are designed first. The desiccant, chemical CO_2 , N_2O , and CO_2 traps are designed with quick connect fittings at each end of the trap so they can be easily taken off and replaced at the end of the one month test span.

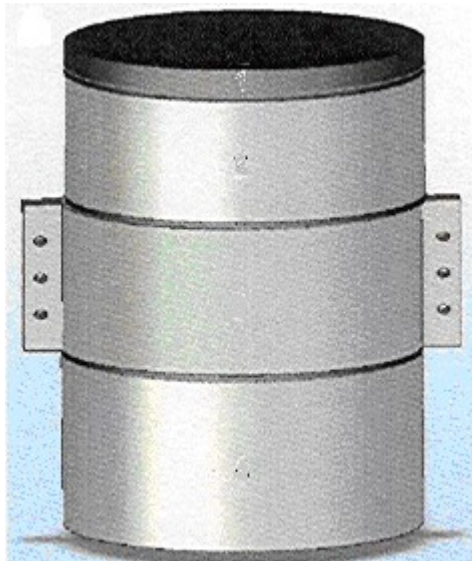


Figure 3. Basic Outer Case Design

There are several designs for the two sub-chambers; one of the designs has two separate sub-chambers and a door on the soil flux chamber that opens to let gas circulate inside each of the sub-chambers. The door would be opened and closed by a servo motor. Each sub-chamber will have two valves; one of the valves will open to the trap system and the other will open to the pump. For the

purging process, the trap valve will close and the pump valve will open allowing fresh air to circulate through the sub-chambers.

Another design includes the two sub-chambers in a single housing with a wall dividing the two chambers. The sub-chamber housing design consists of a cylinder inside of another cylinder. Holes will be machined along the side of each cylinder as shown below in figure 4.



Figure 4. Design Two Sub-Chamber Casing

A servo motor will rotate the outside sub-chamber allowing the holes to line up with each other, allowing air to circulate inside the two sub-chambers. A valve between the two sub-chambers will be mounted on the dividing wall. It will open when the purging process begins, allowing the air to circulate from both sub-chambers through the pump valve, while the trap valves will be closed. There are five valves (two valves lead to the traps, two valves lead to the pump and one valve is on the wall) in this design.

The last design is a plastic cube sub-chamber housing. This design still incorporates a wall dividing the two sides, but it does utilize a valve. There will be four valves that connect to the housing, two that lead to the traps and two that lead to the pump. This sub-chamber design allows for the elimination of the purging procedure. This final design was chosen for this reason and because it is less costly to manufacture.

Conceptual Design Ranking

The feasibility of the described prospective designs is ranked in table 1. Point values for each component denote the importance of each component. The more important the component is, the higher point value it is assigned. The design with the lowest point value total is the most feasible.

Table 1: Design Matrix for Feasible Designs

	Design 1	Design 2	Design 3	Point values for each component
Quick connects	8	8	8	1
3-way valves	3	3	4	2
4-way valve	1	1	0	3
Fans	1	1	1	2
Pump	1	1	1	3
Sub-Chamber casing	2	1	1	4
2-way valves	4	5	4	1
Servo motors	3	2	2	2
Point totals	40	35	33	

In conclusion, the third conceptual design is best suited for the projects requirements. The details of this design will be further discussed in the proposed design solution section.

Proposed Design Solution

Current design solution for the ATGTS consists of a 300mm diameter PVC cylinder outer casing, which will be separated into four separate levels. The outer casing is oriented vertically and the levels are divided by 6.35mm PVC sheet. The first level will consist of the soil flux chamber, volume sampling sub-chamber, rainfall dispersal grate, and a fan with access to ambient air to equilibrate the flux chamber. The second level will contain all four chemical or sieve traps and an access door for trap removal/ replacement. The third level will house the pumps, valves, power supply, and microcontroller, while the fourth level will serve as the rainfall reservoir.

First Level Physical Component Design:

The first level, or the soil flux chamber, is approximately 200mm in height, will sit atop the soil being tested, and is the support for the device. 50mm of this chamber height will extend into the soil to aid in stability of the ATGTS. Contained within this soil flux chamber is the sub-chamber housing. Two sub-chambers will be formed out of 3mm thick PVC rectangular housing, and will serve as the gas sampling volumes. The N₂O and CO₂ sub-chambers will be 150ml and 20ml volumes respectively and divided by a 3mm thick PVC wall. Located on the sub-chamber housing will be a single servo controlled gate that when opened will expose the sampling chambers to the flux chamber. The gate will be sealed with 3.175mm thick rubber gasket, will be oriented horizontally, and located 15mm from the soil flux chambers apex.

Located 15mm below the sub-chamber is the rainfall dispersal grate. When rain is released from the fourth level rainfall reservoir, it must be evenly distributed over the sample soil. This is achieved with two sloping perforated circular discs made out of PVC which may be viewed in figure 5.

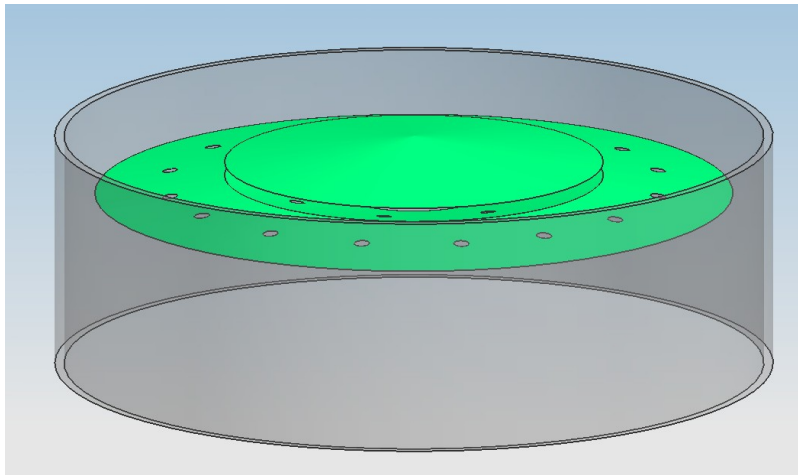


Figure 5. Preliminary Design of the Rainfall Dispersal Grate

The last item contained within the soil flux chamber is the equilibrate fan. This fan will be approximately 60mm in diameter and mounted on the outer case wall between the end of the sub-chamber housing and a valve. The valve will allow access to the ambient air, and will be opened after the sampling cycle. The valve and fan will serve to equilibrate the soil flux chamber with the ambient air, and their operation will be discussed later in the device operation section.

Second Level Physical Component Design:

The second level of the ATGTS is approximately 380mm in height and contains all four chemical and sieve traps. They are the desiccant trap, chemical CO₂ trap, and two molecular sieve traps for the N₂O and CO₂. The desiccant traps sole purpose is to remove moisture from the air before the sample air

reaches the other traps. The trap consists of Nafion tubing wrapped inside a desiccant filled PVC pipe with end caps. The Nafion tubing allows moisture to be extracted out by the desiccant while not affecting the air content of the tube. The chemical CO₂ trap consists of a stainless steel tube filled with Carbosorb, and will extract CO₂ from the sample air prior to its arrival in the N₂O trap. The two molecular sieve traps for N₂O and CO₂ quantification will also be composed of stainless steel tubes, but filled with molecular sieve 5A. These traps differ from the former in that their contents are of interest after the one month test span for data collection. At both ends of the N₂O and CO₂ traps, two manual shutoff valves will operate to contain the sample prior to shipment. In addition, these traps will also have quick connects on each end to ease removal.

All four traps are oriented vertically in the second level, and are designed to be removed after each one month test span by opening an access door. The PVC door is 350mm in height and spans half the outer case's circumference. The door is mounted with small brass hinges and locked with a brass hasp. To prevent moisture from entering the level, the door will be sealed with basic home weather-stripping.

Third Level Physical Component Design:

The third level will be approximately 150mm in height and its contents will be supported by a 6.35mm thick PVC sheet. Powering the system is a Cypress PSoC microcontroller and a 12V battery. The microcontroller will control the fan and servo motors located in level one, as well as the solenoid valves and the

pump located in level three. The specifics of the microcontroller timing to run all electro-mechanical components will be discussed in the device operation section later. Since packaging is a concern in this level, micro inert solenoid valves were chosen for both 2-way and 3-way applications because they are relatively small, 33mm in length and 9mm in diameter. In addition, a micro diaphragm gas sampling pump was chosen due its low power consumption, small size, and high flow rate of .3L/min. All plumbing connections in the device will use 1.5875mm outer diameter PEEK tubing. PEEK tubing was chosen due to its excellent tensile strength, 90MPa, and because it is chemically inert.

Fourth Level Physical Component Design:

The fourth level contains the rainfall reservoir. This level consists of a funnel which spans the diameter of the device to collect and drain rainwater onto the soil, thereby simulating the ambient environment. Linking the rainfall reservoir and dispersal grate found in level one is a 6.35mm diameter PVC pipe regulated by a one way check valve. This valve is open only when a sufficient amount of precipitation is collected, and minimizes the volume of air which contaminates the devices samples. Covering the rainfall reservoir is a cone shaped stainless steel screen which will stop debris from plugging the ambient environment rainfall simulator.

Device Operation:

All electro-mechanical components will be controlled by the Cypress PSoC microcontroller. The microcontroller will be turned on and off by an external clock to save on power consumption. In the first stage of operation, the gate providing the seal of the soil flux chamber to the ambient environment will open and the fan will equilibrate the two environments. After a two minute period of the fan pushing and pulling air into and out of the chamber, it will turn off and the outside gate will close. The fan's operation will be accomplished by switching polarity of the voltage across the leads of the fan every 20seconds. Following this equilibration process, the device will rest for four hours in which time trace gases will be emitted by the soil. While this waiting period is occurring, the rainfall reservoir valve will allow any precipitation into the device. Once four hours has elapsed, the fan will turn on for approximately 20seconds to mix the air in the soil flux chamber and sub chambers. Once this process is complete the sub chamber casing will close following a 15seconds wait for the sample air to become un-turbulent. Once the sub chambers are sealed, the pump will start the first five minute sampling cycle of the N₂O gas.

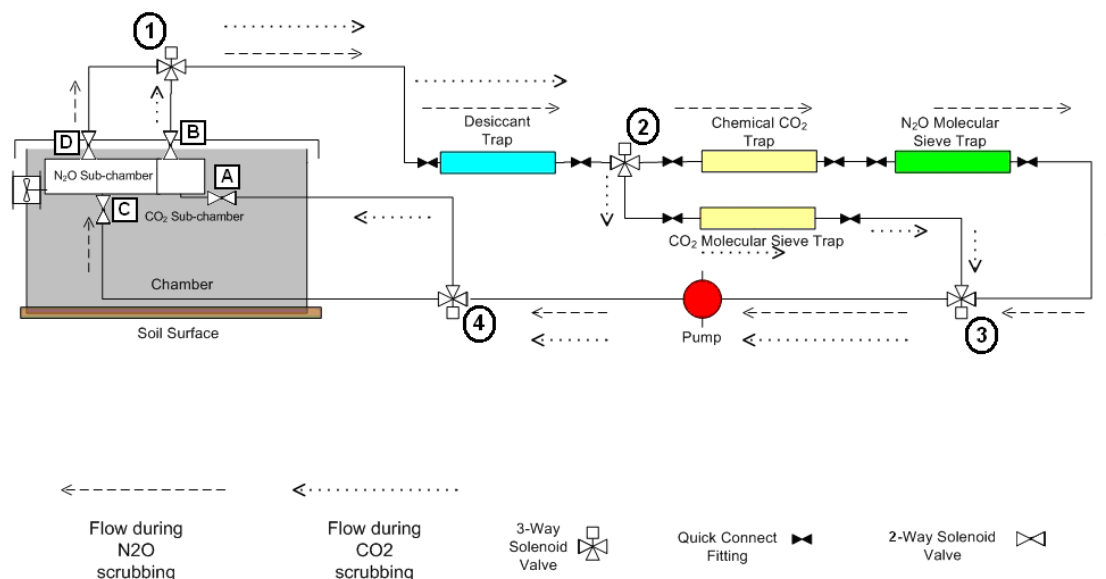


Figure 6. Trace gas trapping flow chart with solenoid valves labeled

The pump will switch to an on state and begin to push the sample volume through the system. Simultaneously the 2-way solenoid valves C and D will open and then the 3-way solenoid valves 1, 2, 3, 4 will open for the N₂O path which is the dashed line in figure 6. This process will continue for five minutes and collect the N₂O sample. When this process is complete the 2-way solenoid valves C and D will close and the 2-way solenoid valves A and B will open. Simultaneously the 3-way solenoid valves 1, 2, 3, 4 will open for the CO₂ path which is the dotted line in figure 6. This process will also continue for two minutes and collect the CO₂ sample. Once this process is finished the pump will shut off and all the 2-way solenoid valves and the 3-way solenoid valves will be closed. When this is finished everything will restart with the equilibration process after four hours of rest.

Risk Analysis

During the testing process, integrated electronics will be operating outdoors in a range of temperature and humidity conditions. Failure to adequately seal the electronics chamber from the outdoors or rain water collection facility could destroy the prototype. To counteract this risk, the electronics chamber of the device could be completely sealed, however this would make monthly maintenance of the device extremely time consuming and difficult.

The electrical system will integrate low current, low voltage digital electronics and higher voltage, higher current actuators. These two systems must stay electrically isolated. Having all components in the same chamber runs the risk of creating a short across the system; however creating another chamber would add cost to the device.

The mechanical design of the device is complex because the system must be air tight. This constraint demands very tight tolerances, and allows no room for error in machining or part compatibility. Different manufacturers build parts to different specifications. The Integration of these different manufactured parts and hand machined parts into a functional air tight system presents the risk of sample contamination in the system. As a method for eliminating this risk, despite increased cost, adapters and fittings used in the design will be purchased and not manufactured by team members if at all possible.

Project Management Plan

This section will outline the allocation of resources throughout the design period. First these resources need to be identified. To begin there are seven capstone students involved in the project: Dan Cashen, Chris Gliniecki, Thomas Hancasky, Alex Esbrook, Adam Grisdale, Josh Kowalski and Alex Kerstein. These students will be serving both technical and non technical roles. Dan Cashen is the manger and will specialize in solid state fabrication. Tom Hancasky will design the website and will specialize in microcontroller selection and integration. Chris Gliniecki will assist Tom with website design and will lead the team in power management. Alex Kerstein will provide document preparation services, and will specialize in high level design and purchasing. Josh Kowalski will assist Alex with document preparation services and specialize in part fabrication and machining. Adam Grisdale will lead the presentations for the mechanical engineers and be the lead mechanical designer. Alex Estbrook will lead the presentations for the electrical engineers and will specialize in electrical control.

The project is funded by BERI whose interests are represented by Dr. K. Smemo and Dr. N. Ostrom. As a secondary resource the team has been appointed an academic advisor and a facilitator, Dr. R. Mukherjee and Dr. J. Deller, respectively.

The attached Gantt chart describes the tasks and their respective completion dates. The major tasks will be completed by the team as a whole,

however each task will have one person who is a specialist in that area who will lead completion or practice of said designated endeavor.

Budget

The funds approved for this project will come from three primary sources. The electrical and mechanical engineering departments will contribute, \$500 and \$1000 respectively, and the sponsor will provide a grant for \$4000. The total allowed budget for the project is \$5500, and the table below details the expected expenditures.

Table 2. Budget analysis

Item	Quantity	Cost per unit	Total cost
3 way solenoid valve	4	160	640
2 way solenoid valve	4	140	560
36inch 304 stainless steel tube	1	22	22
Servo motor	2	20	40
ADDA Waterproof FAN	1	30	30
Cypress Microcontroller	1	120	Donation
Pump	1	90	90
Quick Connects	6	40	240
Peak Tubing (25 feet)	1	60	60
2*4*1/8 PVC	1	30	30
Weather Screening	1	25	25
Battery	1	500	500
PVC Box Sub Chamber	1	50	50
Manual Shutoff Valve	6	60	360
Miscellaneous Supplies(fittings and gaskets)	1	500	500
		Total:	\$ 3147

According this table, our estimated total cost will be ~\$3200. Included in this table are anticipated miscellaneous supplies which should account for the gasket and fitting material. A donation from Cypress Semiconductor of a CY3214-PSoCEvalUSB micro-controller reduces projected costs by \$120. The total estimate of ~\$3200 falls well below the allotted \$5500 total funds that can be used for building an ATGTS system.

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Appendices

CO ₂ Chemical Trap Volume Calculation		
CO ₂ concentration in air (L of CO ₂ / L of air)	0.01	Inputs
N ₂ O sub chamber volume (L)	0.15	
Hours between cycle (hrs)	4	
Cycles per month	186	
Volume of CO ₂ in sub chamber (L)	0.0015	
CO ₂ density (g/L)	1.799	
Mass of CO ₂ in sub chamber (g)	0.00270	
Mass of all CO ₂ extracted over 1 month period (g)	0.5019	
Mass of CO ₂ removed from 1g of Carbosorb (g)	0.4	
Mass of Carbosorb needed for Chemical CO ₂ trap (g)	1.2548	
Mass of Carbosorb w/ safety factor of 2 (g)	2.5096	
Volume of Carbosorb in 1g (L)	0.0015	
Volume of Carbosorb needed for chemical CO ₂ trap (L)	0.0038	Output

N ₂ O Molecular Sieve Trap Volume Calculation		
N ₂ O concentration in air (L of CO ₂ / L of air)	0.00002	Inputs
N ₂ O sub chamber volume (L)	0.15	
Hours between cycle (hrs)	4	
Cycles per month	186	
Volume of N ₂ O in sub chamber (L)	0.000003	
N ₂ O density (g/L)	1.799	
Mass of N ₂ O in sub chamber (g)	0.00001	
Mass of all N ₂ O extracted over 1 month period (g)	0.0010038	
Mass of N ₂ O removed from 1g of Sieve 5A (g)	0.4	
Mass of Sieve 5A needed for Chemical N ₂ O trap (g)	0.0025096	
Mass of Sieve 5A w/ safety factor of 2 (g)	0.0050192	
Volume of Sieve 5A in 1g (L)	0.0015	
Volume of Sieve 5A needed for chemical CO ₂ trap (L)	7.529E-06	Output

Volume of water collected in one month

For 100% relative humidity at 20°C the mass of water

in 1 liter of air during each cycle (mg)

8.6

Mass of water in a 3 liter volume (mg)

25.8 Input

Density of water at 20°C (g/L)

1000

Time between each cycle (hours)

4

Number of cycles per month

186

Mass of water in a 3 liter volume after one month of cycles (g)

4.7988

Volume of water collected in one month (mL)	4.7988	
Volume of water collected in one month considering a factor of safety of 2 (mL)	9.5976	Output