Low-cost Field Methane Flux Chamber

A Design Project Report

Presented to the School of Electrical and Computer Engineering of Cornell University

in Partial Fulfillment of the Requirements for the Degree of

Master of Engineering, Electrical and Computer Engineering

Submitted by:
Dikshanya Lashmi Ramaswamy
Nicholas J. Ricci
Ao Ruan

MEng Field Advisor: Dr. Hunter Adams

Degree Date: May 2025

Table of Contents

Abstract

Master of Engineering Program

School of Electrical and Computer Engineering

Cornell University

Design Project Report

Project Title: Low-cost Field Methane Flux Measurement Chamber

Authors: Dikshanya Lashmi Ramaswamy, Nicholas J. Ricci, Ao Ruan

Abstract:

A low-cost (<$200) field-deployable methane flux measurement device is being developed to monitor methane (CH_4) and carbon dioxide (CO_2) emissions, as well as ambient temperature and humidity, from water bodies such as lakes and ponds. The collected data will support the analysis of greenhouse gas emissions by the Department of Biological and Environmental Engineering (BEE). Existing systems for this purpose are typically large, complex, power-intensive, and expensive. This project addresses these limitations by delivering a compact, affordable, and easily assembled solution accessible to researchers at Cornell University and beyond. The device consists of a floating frame and a collapsible chamber that periodically measures gas flux and purges the chamber between readings. Integrated electronics include a microcontroller, memory storage (SD card), and sensors for CH_4, CO_2, temperature, and humidity. The project encompasses the mechanical design, embedded software, and sensor interface development. Final validation will be conducted through field testing to confirm performance against design specifications. This system aims to offer a scalable and accessible tool for greenhouse gas research.

Executive Summary

The work is directed towards the design and build of a low-cost methane and carbon dioxide flux measurement chamber towards assisting the measurement of greenhouse gases in ponds and lakes. It was jointly developed with the Atkinson Center of Cornell as well as the Department of Biological and Environmental Engineering in efforts towards the replacement of the current systems that tend to be expensive, bulky, and of complex nature.

Background research emphasized the necessity of having inexpensive monitors of the CH_4 and CO_2 emissions of inland bodies of water. Early prototypes had theoretically proven viable but were pricey and impractical for deployment, leaving room for a more accessible and less expensive option.

The team laid down the following specifications: less than $200 cost, ease of assembly, minimal power consumption, self-sufficiency for a week of operation, and precise measurement of the amount of gas. It should be convenient for both professionals and hobbyists.

In order to fulfill these specifications, we constructed the system around a Raspberry Pi Pico with a Figaro NGM2611 methane sensor and a Sensirion SCD30 CO_2 sensor. Data is retained on an SD card, and a stepper motor moves a telescoping PVC chamber in to draw in samples of gases. A custom PCB and modular software platform enable the construction.

Sensor reading verification and proper logging of the data were confirmed by testing in the laboratory. Chamber mechanism performance under controlled test conditions performed as predicted. With them combined there should be tests on file for this summer.

The prototype is complete with all of the significant performance goals and is ready for the in-field validation. Future tasks lie in testing it in the real world, increased power efficiency, and access to off-site data.

Acknowledgement

We would like to thank Dr. Hunter Adams and Dr. Bruce Land for their guidance and support throughout our project. We would also like to thank the undergraduate students Grace Lo, Henry Sigel, and Alina Wang for helping us with software implementation and the mechanical design of the device. Furthermore, we would like to thank associates in the Cornell Agricultural and Life Sciences Department and the Atkinson Center, including Dr. Meredith Holgerson and others, who helped us to define project requirements, tailor design choices to the scientists' needs, and supported us in this endeavor.

Individual Contribution

Dikshanya Ramaswamy (dr655) contributed to the sensor research, software development and debugging for the sensor interface with the Raspberry Pi Pico, and maintained a Github repository for software and helped design the website. Nicholas Ricci (njr79) contributed to the sensor research, sensor interface software development, power budgeting, and the PCB design. Ao Ruan (ar2546) contributed to sensor research, software development, one draft of the hardware design, and power budgeting. The undergraduate students Grace Lo and Alina Wang contributed to the software development to interface the Raspberry Pi Pico to a microSD card for data storage. The undergraduate student Henry Sigel contributed to the project by designing and building the buoyant, mechanical frame. He also implemented a stepper motor that is used to raise and lower the chamber walls.

1. Introduction:

Methane emissions account for a significant portion of greenhouse gas emissions, which contribute to climate change. Past efforts have been made to develop devices capable of measuring the flux of methane being emitted from various bodies of water. However, these designs have shown to be expensive and take significant time to assemble [1]. Therefore, we, in the Cornell University ECE department in collaboration with the Cornell's Atkinson Sustainability Center and the Biological and Environmental Engineering departments, intend to design and build a methane flux measurement device that can be built for less than $200 in material cost and is capable of measuring both methane and carbon dioxide flux. By developing this device, we can ensure that environmental scientists and hobbyists have a low-cost, easy to build / use option for measuring methane and carbon dioxide emissions. This proposal explains the past efforts in this endeavor upon which we are building a new device, the methane emissions problem that environmental scientists are trying to study, our team approach to solving this problem and our progress. Our team includes, Dr. Hunter Adams, three M. Eng. ECE students (Dikshanya Lashmi Ramaswamy, Nicholas J. Ricci, and Ao Ruan), as well as undergraduate students Grace Lo, Henry Sigel, and Alina Wang. Also, we are in communication with Dr. Meredith Holgerson and her team to ensure that the design meets the requirements of the environmental team that will ultimately be using the final product.

2. Background

Climate change, primarily driven by greenhouse gas emissions, poses one of the most urgent challenges of our time. Among these gases, methane (CH_4) and carbon dioxide (CO_2) play a particularly critical role due to their potency and prevalence. Methane, while less abundant than carbon dioxide, is over 25 times more effective at trapping heat in the atmosphere over a 100-year period, making it a key target for climate research. Lakes, ponds, and other inland water bodies are now recognized as substantial and dynamic sources of these greenhouse gases, contributing significantly to global emissions. As such, understanding the flux, i.e., the transfer of methane and CO_2 from water to the atmosphere, is essential for accurate climate modeling and the development of mitigation strategies.

Methane ebullition and diffusion from inland water bodies are highly variable in both time and space, making it essential to deploy autonomous systems capable of high-frequency measurements [2]. Prior research has demonstrated the viability of low-cost, solar-powered systems for multi-week deployments with minimal maintenance, helping to broaden access to critical environmental data [3]. However, these systems must be carefully calibrated and robustly designed, as sensor drift and environmental interference can compromise data accuracy in uncontrolled field conditions [5]. Furthermore, traditional manual sampling methods have been shown to miss episodic CH_4 emissions, underscoring the need for fine temporal resolution in gas flux monitoring [4].

In response to this need, the Holgerson Lab at Cornell University has led a notable initiative to design, build, and deploy autonomous floating flux chambers for greenhouse gas monitoring on small lakes and ponds. These chambers were successful in collecting high-quality data on both diffusive and ebullitive methane emissions, validating the concept of low-cost, field-deployable monitoring systems. A total of eight prototype units were constructed and deployed with positive results in terms of data collection.

However, the initial design presented several practical challenges. Each unit cost approximately $450 to build, and required up to six hours of assembly time by a novice user. Additionally, the bulk and weight of the devices posed significant logistical difficulties during transportation and deployment, particularly in remote or rugged terrain—conditions commonly encountered in environmental fieldwork. These limitations emphasized the need for a more efficient and portable alternative.

Informed by these challenges and motivated by the importance of continuous greenhouse gas monitoring, our team has been tasked by the Cornell Atkinson Center for Sustainability, in collaboration with environmental scientists, to design and prototype an improved methane and CO_2 flux measurement system. The project's goal is to develop a device that matches or exceeds the scientific performance of the original flux chambers while offering significant improvements in:

- Cost-efficiency
- Ease of construction
- Power management
- Portability and user-friendliness

3. Problem Statement

The community of environmental scientists that are interested in this product require us to develop a methane and carbon dioxide flux measurement system that accomplishes the following objectives:

1. The device must accurately measure methane and carbon dioxide flux as it is emitted from the body of water upon which the device is deployed.
2. The overall cost to construct one unit should be no more than $200.
3. It must be possible to build the product using easily attainable devices and materials that anyone (even a hobbyist) can purchase and utilize.
4. The device should be able to perform for at least a week without any external support.
5. Data collected by the device should be organized, easy to collect from the device, and easy to understand.
6. The power consumption of the device should be minimal. (It currently uses a car battery and does last long.)
7. It must be simple and relatively quick to construct and deploy the final design.

4. Design and Implementation

We spent several weeks understanding the problem statement and clarifying detailed requirements from the environmental scientists. The project was segmented into three principal areas: Data Collection, Sensor Technology, and Mechanical Design, with parallel development efforts to ensure timely integration.

4. 1. Approach:

The core functional design of this methane flux measurement device centers on an extendable, collapsible flux chamber. This chamber will be lowered to the surface of a water body, forming an airtight volume to trap gases for analysis. After sampling, the chamber retracts, and ambient airflow flushes the chamber to reset conditions for the next measurement cycle.

A Raspberry Pi Pico microcontroller will serve as the central controller, interfacing with sensors for methane (CH_4), carbon dioxide (CO_2), temperature, and humidity. These measurements will be timestamped and written to a removable microSD card in .csv and .txt formats. The power will be supplied via a battery pack, and the chamber structure is primarily composed of lightweight PVC to balance durability and buoyancy.

To streamline development and isolate potential failure points, the project was divided into:

a. **Data Collection**: Ensuring reliable writing and formatting of sensor data into files that can be retrieved from a microSD card.
b. **Sensor Technology:** Selecting, calibrating, and coding sensor modules to output reliable readings.
c. **Mechanical Design:** Developing a structure that is watertight, airtight, buoyant, and energy-efficient.

4.2. Sensor Selection

Precise and reliable gas concentration readings are the key goal of our methane flux chamber. Due to this, we chose two main sensing modules to detect methane (CH_4), carbon dioxide (CO_2), temperature, and humidity. We based the selection of sensors to meet our requirements of high performance, low power usage, small size, low costs, and suitability for the Raspberry Pi Pico microcontroller. A detailed description of the two sensors that are part of our system is provided below.

The **Figaro NGM2611-E13** was selected to act as the methane sensor due to its sensitivity at the low parts-per-million level and cost-effectiveness compared to other available methane sensors. Moreover, this sensor has been used for similar experiences, so the accuracy and stability are trustworthy. The sensor measures the concentration of methane and is a good choice for environmental sensing where high precision is not critical but where the sensor needs to be reliable, have good availability, and be inexpensive. The sensor is already calibrated for general detection of methane, which minimizes the amount of laborious field calibration. The sensor is relatively small in size and has an analog voltage output, making interfacing with the analog-to-digital converter (ADC) on the microcontroller easier. Testing the sensor indicated a good response in the detection of high levels of methane in sealed environments. Power draw is about 280 mW at standard conditions due to the dominant internal heater element. Though this is more than with digital sensors, the power requirement is acceptable for short, cyclic sampling intervals and is within our overall system power budget.

For the measurement of carbon dioxide, along with the ambient temperature and relative humidity, we chose the **Sensirion SCD30** sensor module. The sensor compiles the three readings in a single digital module and communicates through the I²C interface, enabling efficient transmission of reliable data to the Raspberry Pi Pico. We chose the SCD30 due to high accuracy, minimal long-term drift, and support for low-voltage microcontroller platforms. SCD30 measures CO_2 using the principle of non-dispersive infrared (NDIR), with a normal accuracy of ±30 ppm in the 400–10,000 ppm range. Besides the concentration of the gas, the SCD30 also offers calibrated temperature data along with humidity data, which is important for estimating the gas flux based on varying environmental conditions. The module is calibrated at the manufacturer level and can also support automatic self-calibration, which is beneficial for long deployments. With regards to the energy requirements, the SCD30 normally consumes 19 mW in idle mode and 110 mW in the case of an active measurement, making the device good for battery-operated applications, provided that the duty cycling is done properly.

Both sensors were implemented into the system with emphasis on power efficiency and modularity. The Raspberry Pi Pico does the reading and processing of data from these sensors, which is later logged to a microSD card for offline analysis. Accurate timing of the sampling intervals to keep sensors running just for short measurement windows ensures that power is saved without reducing data accuracy. The two sensors in combination offer a well-rounded environmental profile, which allows quantification of greenhouse gas emissions from water bodies to be based on accurate data.

4.3. Software Implementation

The Raspberry Pi Pico, based on the RP2040 chip, was chosen for its flexibility, low power consumption, and availability of GPIO and ADC interfaces. The microcontroller runs firmware written in C/C++ using the official Pico SDK, supplemented with protothreads to allow concurrent scheduling of sensor readings, timestamp logging, and data writing without full RTOS overhead.

4.3.1. CO2 , Temperature and Humidity Sensor - Sensirion SCD30

The Sensirion SCD30 communicates via the I^2C bus. The I^2C interface was initialized using standard SDK calls, and a custom driver module was developed based on the manufacturer's interface datasheet. Key configuration steps, including enabling continuous measurement, setting the sampling interval, and activating automatic self-calibration, were implemented as specified in Table 1. The sensor periodically indicates readiness via a status register, after which a read command retrieves 18 bytes of measurement data encompassing CO_2 concentration, temperature, and relative humidity. These values are parsed using the IEEE 754 floating-point format defined in the datasheet as shown in Figure 1. To ensure data resilience, readings can be first stored in a circular buffer before being written to the SD card. This approach minimizes the risk of data loss in the event of power disruptions or file system write errors.

Operation	Action	Command (in hex)
I2C Address	-	0x61
Reset	Write	0xD3 0x04
CONTINUOUS MEASUREMENT	Write	0x0010
SET MEASUREMENT INTERVAL	Write	0x4600
AUTOMATIC SELF CALIBRATION	Write	0x5306
READY SIGNAL	Read	0x0202
READ MEASUREMENT	Write - Read	0x0300

Table 1. SCD30 I2C Command Table [7]

```c
// CO2 concentration
float co2Concentration;
unsigned int tempU32;

// read data is in a buffer. In case of I2C CRCs have been removed
// beforehand. Content of the buffer is the following
unsigned char buffer[4];

buffer[0] = 0x43; //  MMSB CO2
buffer[1] = 0xDB; //  MLSB CO2
buffer[2] = 0x8C; //  LMSB CO2
buffer[3] = 0x2E; //  LLSB CO2

// cast 4 bytes to one unsigned 32 bit integer
tempU32 = (unsigned int)((((unsigned int)buffer[0]) << 24) |
                         (((unsigned int)buffer[1]) << 16) |
                         (((unsigned int)buffer[2]) << 8)  |
                          ((unsigned int)buffer[3]));

// cast unsigned 32 bit integer to 32 bit float
co2Concentration = *(float*)&tempU32; // co2Concentration = 439.09f
```

Figure 1. SCD30 I2C Measurement Conversion Pseudo Code [7]

4.3.2. Methane Sensor - Figaro NGM2611

The Figaro NGM2611 provides an analog voltage output corresponding to methane concentration. This voltage is sampled using the onboard 12-bit ADC of the Raspberry Pi Pico. Since the NGM2611 includes a heating element with relatively high power consumption, measurements are taken intermittently to reduce energy usage. These periodic sampling tasks are managed using protothreads, which allow lightweight, cooperative multitasking without the need for a full real-time operating system. This enables the sensor to be powered and read only during short, scheduled measurement windows. ADC initialization occurs as shown in Code1.

```c
adc_init();
adc_gpio_init(26);
adc_select_input(0);
```

Code1. Sample code for adc initialization

Readings are taken every few minutes, averaged over a short burst of samples to reduce noise, and then they can be calibrated against known concentration curves using either a look-up table or polynomial fit or the data can be processed upon collection according to the requirements of the scientists. This strategy ensures both power efficiency and reliable data acquisition, even within the resource-constrained environment of a low-power embedded system.

4.3.3. SD Card Data Logging

Data from both sensors is compiled into a timestamped record using a real-time clock module or system uptime counter as shown in Figure 2. .csv line format is used:

```
timestamp,CH4_voltage,CO2_ppm,temperature_C,humidity_RH
```

This is written to an SD card using the SPI interface. FatFs was used for filesystem support, allowing structured directory management and compatibility with standard file readers.

Typical Output Sample:

```
2025-04-22 14:35:10,1.34,412.6,25.3,57.8
```

An LED status indicator blinks once per successful write cycle, and a longer blink indicates sensor failure or SD card write error. Watchdog timers are used to restart the microcontroller in case of I²C communication stalls.

```
>>sd_spi_go_low_frequency: Actual frequency: 398089
V2-Version Card
R3/R7: 0x1aa
R3/R7: 0xff8000
R3/R7: 0xc0ff8000
Card Initialized: High Capacity Card
SD card initialized
SDHC/SDXC Card: hc_c_size: 60872
Sectors: 62333952
Capacity:    30436 MB
sd_spi_go_high_frequency: Actual frequency: 15625000
>>setdate 2024-11-19 10:00:00
Setting RTC to 2024-11-19 10:00:00
>>setfreq 1000
Logging frequency set to 1000 ms
>>write test25.csv
ID is: E661640843238522
writing to file...
writing to file...
writing to file...
Exited while loop
>>print test25.csv
Pico ID,E661640843238522
DATETIME,CH4,CO2,TEMP,HUM
Tuesday 19 November 10:00:12 2024,12.2,10,70,45
Tuesday 19 November 10:00:14 2024,12.2,10,70,45
Tuesday 19 November 10:00:15 2024,12.2,10,70,45
```

Figure 2. SD Card output in terminal

4.4. Hardware Implementation

4.4.1. Electronic Design

The SCD30 sensor measures carbon dioxide, temperature, and humidity. It interfaces with the Raspberry Pi Pico using the I2C protocol. It is powered and grounded by the Pico, and connects to GPIO pins 12 and 13, which correspond to actual pin numbers 16 and 17, respectively, and are the SDA and SCL pins for the I2C protocol. The debugger shown in Figure 3 is used to program the Raspberry Pi Pico.

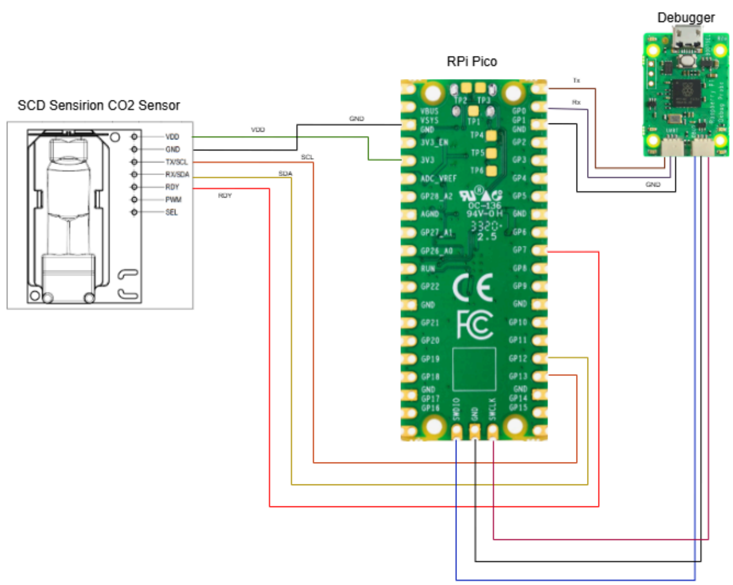

Figure 3. Sensirion SCD30 to RPI PICO Microcontroller Circuit Diagram

The NGM2611 E13 methane sensor is connected to the Raspberry Pi Pico, but does not interface via I2C. This sensor communicates its reading via an analog voltage signal, which the Raspberry Pi Pico translates into a reading. It connects to ground, bus power, and to pins 31 and 35, which respectively are ADC0 and ADC_VREF. This connection is shown in Figure 4.

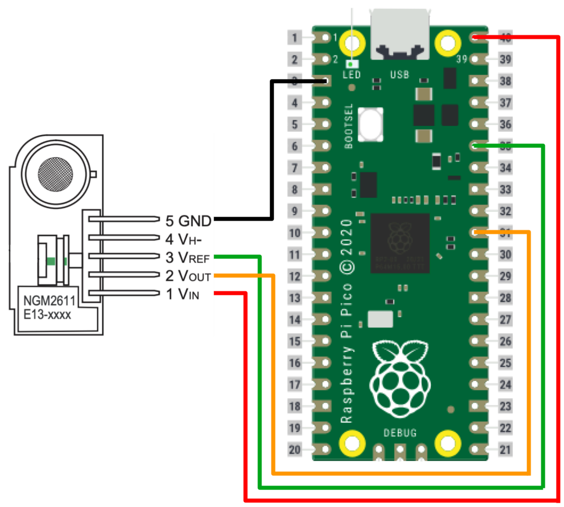

Figure 4. NGM2611 E13 to RPI PICO Microcontroller Circuit Diagram

The microSD breakout board is interfaced to the Raspberry Pi Pico via the SPI protocol. As is shown in Figure 5, GPIO 2, 3, 4, and 5 are connected to the breakout board. These pins are designated for the SPI0 channel. Using the SPI protocol, the Raspberry Pi Pico stores sensor data on the microSD card, which is inserted into the microSD breakout board.

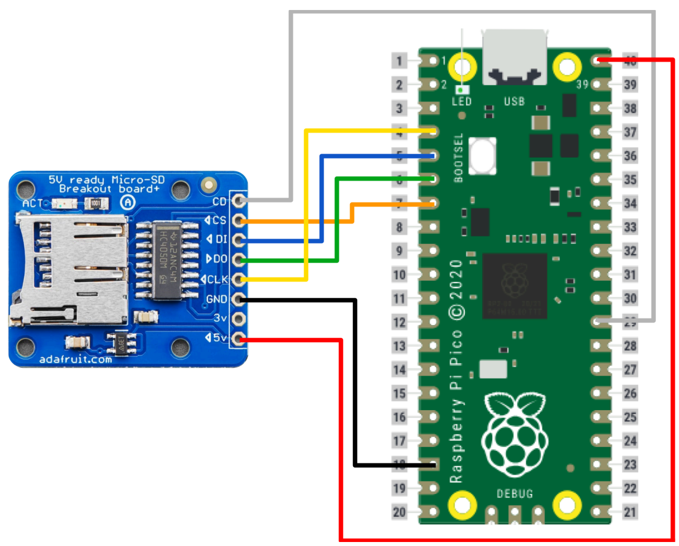

Figure 5. SD Card to RPI PICO Microcontroller Circuit Diagram

Figure 6 shows the complete electronic system on a single PCB. We designed this custom PCB to make connecting the components easier for the user. This PCB connects to each device using male and female header pins. This makes it very easy for the scientists (or even the hobbyist) to plug in the components and quickly assemble the device without having to solder all of the components together. As an added benefit, the plug-and-play style of this PCB allows for easy replacement of any electronics in the event that any given component fails. The Raspberry Pi Pico is connected in the center of the board with the following components connected around it. In the top left corner is the microSD breakout board. Going clockwise around the edge of the board are the methane sensor, the TMC2209 stepper motor driver chip, and the SCD30 sensor. This PCB is intended to be affixed to the inside roof of the flux chamber.

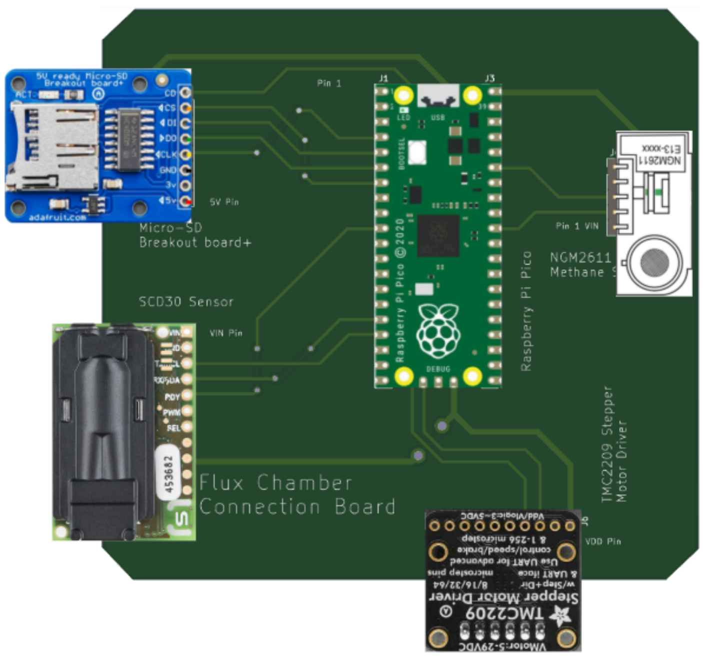

Figure 6. Integrated PCB Design for Electronic System.

4.4.2. Mechanical Design

One of the key elements of our methane flux measurement device is the mechanical system that provides reliable periodic sampling of greenhouse gases released from water surfaces. The objective of the mechanical design was to produce a collapsible, sealed, buoyant chamber that can function independently in outdoor environments. The structure was also required to be lightweight for transport but sturdy for repeated field deployment.

The chamber is constructed using PVC piping as the main structural framework due to its water resistance, ease of access, and low price. Central to the design is a telescoping vertical motion system actuated by a stepper motor controlled through the Raspberry Pi Pico. This telescoping system brings a cylindrical housing down to the water level to create an airtight seal with the water surface. The enclosed space captures a sample of gas being released from the water body so sensors within the chamber are able to measure the amount of methane (CH_4), carbon dioxide (CO_2), temperature, and humidity under controlled conditions. Following data acquisition, the chamber is brought back up so fresh air is introduced and the system is renewed for the next measurement cycle.

For the actuation system, we chose the Adafruit TMC2209 stepper motor driver for low power consumption and high precision control. A simple pulley or rack-and-pinion drive lifts or lowers the chamber, providing repeatable vertical travel. The vertical travel and sealing time are both programmable in order to accommodate varying sampling times. For maintaining the quality of the air sample, the chamber should form a watertight and airtight seal for every sampling operation. This was done by employing soft silicone or foam gaskets along the bottom rim of the telescoping chamber. These gaskets are adapted to irregular water surfaces to reduce the possibility of leakage or contamination of the sample. The weight has been kept low in the frame to achieve buoyancy and horizontal stability on the water.

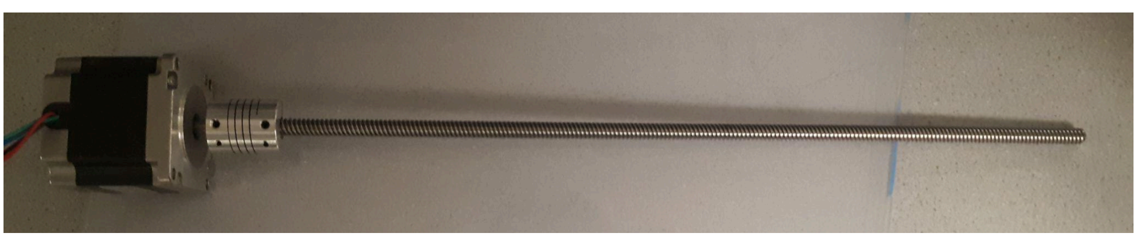

Figure 7. Stepper Motor with threaded rod

All the electronics, the PCB, sensors, and battery system, are placed in a waterproof housing mounted on the top of the chamber. This location places sensitive components above the waterline where they are protected from possible splashes, but also provides easy access for service or data recovery.

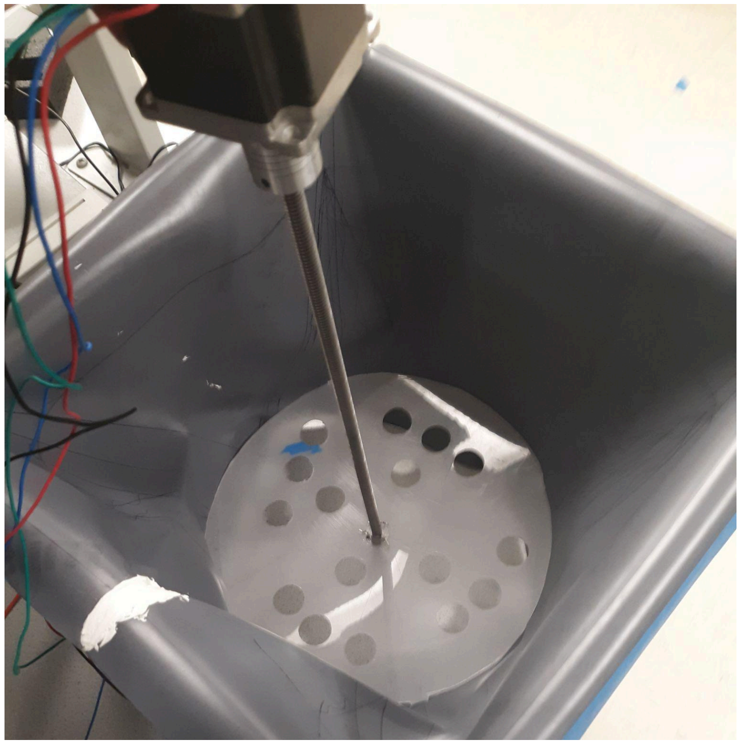

Figure 8. Inside view of chamber with threaded rod in place to move chamber walls

During the process of prototyping the mechanism, we had to overcome a number of different problems. Smooth vertical and consistent motion without significant power usage required both software-controlled motor regulation and free-body mechanics design. Early designs also had some static instability in the simulated wave flow, so their base was lengthened to add more buoyant material. We also added handles and removable joints to the design for easier in-field assembly and transport for researchers in rough environments.

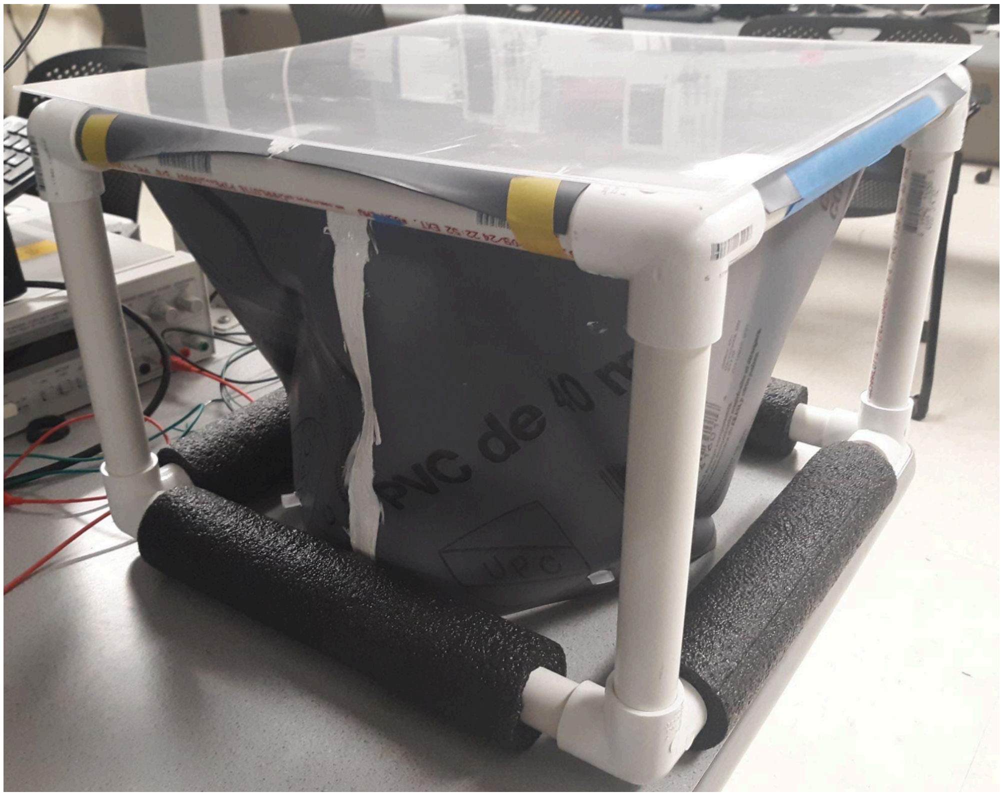

Figure 9. PVC frame and chamber

Overall, the mechanical system serves well to meet the requirements of the design. It provides for periodic, low-power sampling while it is made from budget and readily available materials. It also has a modular design that may be enhanced for the next generation. This mechanical design, when coupled with the electronic and sensor subsystems, is a functioning platform for the measurement of methane flux with good performance and reasonable cost.

5. Results

The results of our efforts on this project are promising. We managed to design a system that fulfills the given requirements as described previously in this report. The first requirement is that the device must accurately measure methane and carbon dioxide. We have tested our system in a lab setting to show that it is capable of taking such measurements. Prototype testing by our scientist associates will verify this in field testing.

Component	Estimated Cost	Vendor
SCD 30 Sensor	32	Sensirion
Figaro NGM2611	25	Alibaba
SD Card	10	Amazon
Mechanical Assembly	20	Homedepot
Power Supply	30	Amazon
MicroSD breakout board	8	Adafruit
TMC2209 Motor Driver	9	Adafruit
Raspberry Pi Pico 2	5	Adafruit
Stepper Motor	14	DigiKey
PCB	~10	Undecided
Misc	~17	Undecided
Total	**180 (Before Tax)**	

Table 2. Estimated Cost of Components

We managed to keep our overall cost to approximately $200 in materials and components as shown in Table 2, so we are within the desired budget. All components are easily attainable from either a hardware store or from an online electronics distributor. The only exception to this is the PCB that we designed to allow for easy component connections. While this makes assembly and maintenance easier, it is not required since wires can be manually soldered between the electronic components. If one wishes to use the custom PCB, it can be made to order by a PCB manufacturer.

Reading	CO2 (ppm)	Temperature (°C)	Humidity (%)	CH4 (ppm)
1 - Laboratory Conditions	1056.3	25	47.53	41
2 - Continuous Measurement	1054	24.99	47.78	38
3 - Continuous Measurement	1044.93	24.99	46.58	42
4 - Exposure to exhaled air	2534.34	25.2	50.1	41
5 - Continuous Measurement	3450.12	25.12	49.59	41

Table 3. Laboratory Measurements of different sensors.

The device is currently powered by a battery pack, and since it consumes a small amount of power overall, it should be capable of running for at least a week. The power budget below shows the total calculated consumption, which equates to approximately 6.5 W maximum. Furthermore, the data is organized in a file format that can be opened in an Excel spreadsheet and is stored on an easily accessible microSD card. Lastly, the device is simple to construct and easy to deploy. The frame is a PVC construction, and the electronics (if using the PCB) are effectively plug-and-play connections since they are connected to the PCB using simple header pins.

Component	Max Power Consumption (W)
Raspberry Pi Pico	0.309
SCD30 Sensor (CO2, temp, humidity)	0.248
NGM2611 Methane Sensor	0.95
Micro SD	0.75
Motor	4.2
Total Power Consumption	**6.457**

Table 4. Power budget of electronic components

While we developed a design that meets the requirements, there were some obstacles that we met while completing the project. First, a significant amount of time was spent in establishing which sensors would be used in the device. This was a necessary step since we wanted this device to be as useful as possible to the scientists that will be using it. Nevertheless, it pushed back our expected development schedule.

	A	B	C	D	E
1	Pico ID	E661640843238522			
2					
3	DATETIME	CH4	CO2	TEMP	HUM
4	Tuesday 19 November 10:00:12 2024	12.2	10	70	45
5	Tuesday 19 November 10:00:14 2024	12.2	10	70	45
6	Tuesday 19 November 10:00:15 2024	12.2	10	70	45

Figure 10. Sample Output stored in SD card of Integrated System

Furthermore, when interfacing the Raspberry Pi Pico with the SCD30 sensor (temperature, humidity, and CO2) we started with a working micropython program. However, this needed to be written in the C programming language in order to be properly integrated with the rest of the software that runs on the Raspberry Pi Pico. Converting the program to C was difficult and led to a few bugs, which took up much of our time in debugging work. One bug has been persistent and has affected our ability to read measurement from the SCD30 sensor. Nevertheless, the device has been developed to a point where it will be field tested this summer.

6. Conclusion

Overall, we managed to design and develop a low-cost, field methane flux chamber within our given requirements. Nearly every part of our design is successfully implemented. The main control software and interfacing with the microSD card is functional. Also, we are able to read successfully from the methane sensor. We have interfaced with the SCD30 sensor although a software bug has inhibited us from correctly reading measurement values. This will be resolved soon. The mechanical design has been successful since we have a PVC frame with a flexible, airtight lining that acts as a chamber wall. The stepper motor with a threaded rod has been able to open and close the chamber to flush out air. Also, the design is buoyant, portable, and easy to assemble.

Potential risks to the success of this product were as follows:

1. The final product cannot float on the surface of a body of water.
2. The device does not have enough power (or is not power efficient enough) to last more than a week in operation.
3. The data cannot be easily retrieved due to programming errors.
4. The product might be too top-heavy and tip over while on the water, causing the device to capsize and submerge the electronics.
5. Device performance may be affected due to various environmental factors.

This summer, the prototype is to be tested in both controlled environments and in the field if it passes indoor testing.

7. Future Work

Though the existing version of the methane flux chamber has reached several key benchmarks like cost-effectiveness, sensor incorporation, machine prototyping, and proof-of-concept verification in the lab, there is still plenty of room for further development and improvement to meet the requirements for readiness in the field, reliability, and scalability. The first step in our second phase is field testing. Until now, all validation has been on small scales under controlled interior conditions. Testing the chamber in real-life settings like lakes, ponds, or wetlands at several different test sites and weather conditions will enable us to test the structural toughness, buoyancy, and waterproofness. These tests will also offer insight into sensor drift over time periods, battery life, and the possible effect of wind or waves on the measurement capability of the chamber. Another step is remote data transmission and remote monitoring. The existing design has data storage in the form of an SD card, but the addition of a wireless communication module would enable the device to do real-time transmission of data. This is critical for long-term operation in remote sites where physical data recovery is inconvenient. Wireless capability would also allow future researchers to have multiple chambers monitored at once, which provides more data for their studies.

We also plan to improve the power management system. The device is currently driven by a simple battery system, but we see potential to cut down further on power usage through deep-sleep modes and wake-on-interrupt sensor capabilities. For the mechanical part, we can see that there is potential for improvement on the material for the chamber and the structure. As the PVC construction is currently done, the chamber is serviceable but can be made more efficient through the implementation of composite materials or 3D-printed waterproof enclosures. Sealing reliability, energy expenditure, and wear could also be enhanced with improvements in the motor-actuated telescopic mechanism.

8. References

[1] H. Adams and M. Holgerson, "Low cost field methane sensors for deployment in variable conditions worldwide," Cornell Flux Chamber Project Proposal,

[Online]. Available: https://cornellfluxchamber.github.io/Literature/Proposal.pdf

[2] J. Sø et al., "Original prototype design: Self-made equipment for automatic methane diffusion and ebullition measurements from aquatic environments," Journal of Geophysical Research: Biogeosciences, Vol 129, Issue 6, 2024.

[Online]. Available: https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2024JG007018

[3] J. Sø et al., "Methane and carbon dioxide fluxes at high spatiotemporal resolution from a small temperate lake", Science of the Total Environment, vol. 878, Pages - 162895, 2023.

[Online]. Available: https://www.sciencedirect.com/science/article/pii/S0048969723015115

[4] D. Bastviken et al., "Facilitating the use of low-cost methane (CH_4) sensors in flux chambers – calibration, data processing, and an open-source make-it-yourself logger," Biogeosciences, vol. 17, no. 13, Pages 3659–3667, 2020.

[Online]. Available: https://bg.copernicus.org/articles/18/685/2021/

[5] J. Barcelo-Ordinas et al., "Self-calibration methods for uncontrolled environments in sensor networks: A reference survey", Ad Hoc Networks, Vol 88, 2019, Pages 142-159

[Online]. Available: A reference survey - ScienceDirect

[6] V. H. Adams, "Sample reports from past ECE 6930 projects," Personal Website.

[Online]. Available: https://vanhunteradams.com/6930/Past_Projects.html

[7] Interface Description Sensirion SCD30 Sensor Module : Online

This report has been prepared in accordance with the guidelines outlined in MEng Design Project Report Requirements, with additional reference to sample reports in [6] for structure and formatting guidance. AI tools were utilized to enhance clarity, coherence, and overall quality of writing.

9. Appendix

All project materials are fully open-source and publicly accessible. The following resources support the work presented in this report:

1. H. Adams and M. Holgerson, “Low cost field methane sensors for deployment in variable conditions worldwide,” https://cornellfluxchamber.github.io/Literature/Proposal.pdf
2. Project Website and Documentation: CornellFluxChamber/CornellFluxChamber.github.io
3. Sensirion SCD30 Sensor code: Github Code
4. Presentation to Atkinson Sustainability Center Overview Atkinson Project Presentation 2025
5. Sensor Selection Presentation: Sensor Presentation Slides