To: Mr. Mike Hoffman, Dr. McAvoy

From: Haitham Alsubhi, Emma Eickert, Coulton Korosec, Bridgette Stegman

RE: Hydrogen Introduction into Natural Gas Turbines

Date: April 14, 2023

Dear University of Cincinnati Utilities team,

Edge Energy Consultants are pleased to provide you with a detailed report evaluating the blending of green hydrogen with natural gas to fuel the two SolarTurbine gas combustion turbines located in the University of Cincinnati Utility Plant.

This report includes:

- Recommended design for hydrogen transportation, storage, and blending
- Detailed list of government regulations and permitting requirements
- Economic and environmental analyses of the proposed system design including projected cost and estimated reduction of greenhouse gas emissions

Our team is dedicated to working with you on finding the best methods for introducing hydrogen to fuel the combustion turbines, and doing so in a reliable, economically sound, and safe way. Thank you for allowing us the opportunity to work with you. We understand the University of Cincinnati's commitment to reducing their carbon footprint, and we are excited to help work toward those sustainability goals.

Respectfully,

Haitham Alsubhi

Emma Eickert

Coulton Korosec

Bridgette Stegman

Hydrogen Utilization at the University of Cincinnati Utility Plant

University of Cincinnati Environmental Engineering Senior Capstone Design Proposal

Final Design Proposal and Future Recommendations

Edge Energy Consultants

Haitham Alsubhi

Emma Eickert

Coulton Korosec

Bridgette Stegman

April 14, 2023

Table of Contents

Executive Summary

The objective of this project is to analyze the feasibility of using hydrogen co-firing with natural gas at the University of Cincinnati Central Utility Plant. The goal is to reduce campus carbon emissions as part of the university's effort to be part of a solution to combat climate change and reduce the greenhouse gas effect. To achieve the objectives, Edge Energy Consultants was asked to evaluate potential hydrogen sources, locations for storing hydrogen on-site, operational adjustments needed to the existing Solar Titan 130 gas turbines, and to investigate government regulations and incentives applicable to this project. The team was asked to prioritize keeping the project low-cost and ensuring safety for the plant workers and the community. Edge Energy Consultants completed alternative analyses for hydrogen provider and storage location, as well as economic and environmental analyses. Based on our findings, the team has concluded that Air Products Inc. should be the hydrogen provider. The location of the hydrogen tanks should be on University of Cincinnati property at the southeast corner of Vine St. and Goodman Dr. with gas lines running underground to the Utility Plant. Retrofitting specifics should be acquired by UC Utilities from the turbine manufacturer, SolarTurbine, when they are available. The team concluded that introducing a 50% hydrogen blend would decrease carbon emissions by 20%, accomplishing the environmental goal set. According to the current market, future trends, and government incentives, the use of green hydrogen is not currently feasible, but is expected to be in the coming decades. In the short term, the university should begin testing cheaper forms of hydrogen (i.e. likely gray hydrogen produced from steam methane reforming) to test the current system's capability to cofire with hydrogen. It is for that reason that Edge Energy Consultants suggests that UC Utilities follows these recommendations and remains in communication with SolarTurbine and Air Products to complete this project in the future.

1 – Introduction

1.1 – Problem Statement

The University of Cincinnati Central Utility Plant (CUP) uses two SolarTurbine Titan 130 combustion turbines which are fueled by natural gas (NG) and provide over 50% of the main campus' electricity and 40% of the steam used on campus. Meanwhile, they contribute to 85% of the main campus' total carbon emissions. Given the University of Cincinnati's (UC) commitment to reducing its carbon footprint, this design is not sustainable. UC Utilities has requested Edge Energy Consultants to evaluate the feasibility of hydrogen co-firing with natural gas at the Central Utility Plant and to create a design and implementation plan for this endeavor. University of Cincinnati Utilities prefers that the current gas combustion turbines remain in use for this project with the likelihood of retrofitting to accommodate for the long-term use of hydrogen. This is to ensure the cost of the project remains low so as to not cause tuition rates at the university to increase.

1.2 – Background

The University of Cincinnati's Utilities Department is responsible for all electricity and steam demands for the university's uptown campus. The university typically experiences its highest demand in the summer months, exceeding 55 MW at peak power demand and 400,000 lbs of steam per hour at peak steam demand. At average demand, UC Utilities must accommodate 33 MW of power. Approximately 30% of the university's power demand is satisfied by the electric commodity market. Meanwhile, the Central Utility Plant provides for 50% of campus electricity and 40% of the steam. The university's uptown campus not only includes instructional buildings and laboratories, but also the extensive and growing network of university hospital facilities. Therefore, the university requires extremely reliable access to power to ensure the safety of its stakeholders.

The Central Utility Plant employs two 12.5 MW generators (see Figure 1-1) which provide electricity to the campus community. These generators are powered by two gas combustion turbines, specifically Solar Titan 130 turbines provided by Solar Turbines, Inc, which are fueled by natural gas. The natural gas comes into the plant via pipelines which the university leases from Duke Energy, although the natural gas itself is bought from other vendors. The two combustion turbines not only power the two 12.5 MW generators, they also power a 22 MW steam driven turbine that additionally contributes to the electricity demand. Overall, this equipment accounts for 85% of the University of Cincinnati's main campus carbon footprint.

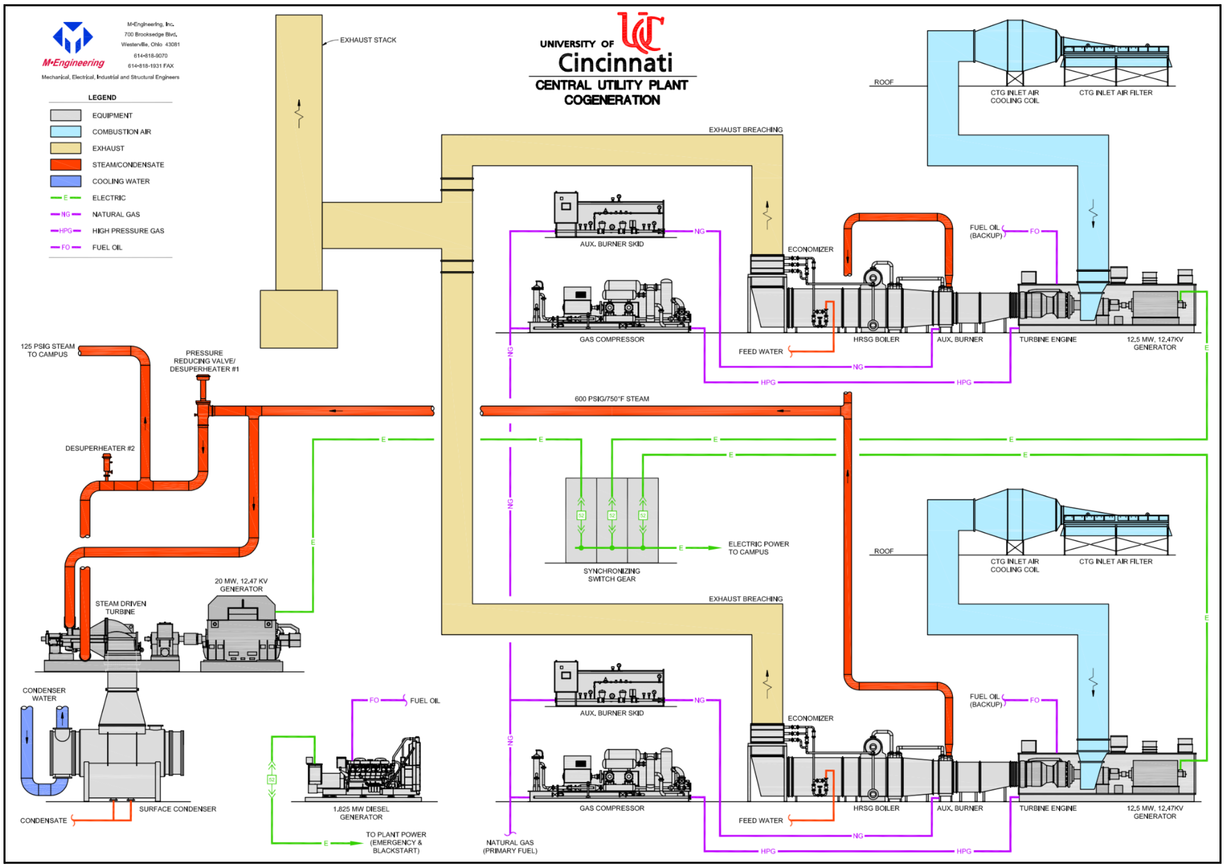

Figure 1-1: Central Utility Plant Schematic [1]

1.3 – Scope of the Problem

The intention of the University of Cincinnati is to reduce the overall carbon footprint, which refers to the amount of carbon being emitted by all functions of the university. A significant contributor to carbon emissions is the burning of fossil fuels, which releases carbon dioxide (CO_2) into the atmosphere and contributes to the amount of heat-trapping gasses called greenhouse gasses. Greenhouse gas in the earth's atmosphere works like a greenhouse, where the sun's heat is trapped in the troposphere and raises the average global temperature. Since the Industrial Revolution in the 1800's, when the burning of fossil fuels became a regular practice, the global average temperature has increased by about 1.1°C [2]. The human activity of burning fossil fuels has "raised atmospheric CO_2 by 50% – meaning the amount of CO_2 is now 150% of its value in 1750" [3]. Because this process has occurred over the duration of centuries, it is classified as climate change.

Climate change and global warming are commonly referred to synonymously. While they are closely related, there are key differences between the two. Global warming refers to the rising average global temperature due to the burning of fossil fuels, as discussed above. Climate change includes the global warming process, but has substantial impacts beyond temperature. The United Nations [2] emphasizes that "the consequences of climate change now include, among others, intense droughts, water scarcity, severe fires, rising sea levels, flooding, melting polar ice, catastrophic storms and declining biodiversity." The global temperature has risen due to human activity in the past couple centuries, and at the current rate of carbon emissions, that temperature is due to continue increasing at an exponential rate. Thousands of scientists and government reviewers agree that to avoid the worst impacts of climate change, the average global temperature should not increase more than 1.5°C above the pre-industrial average temperature. As stated previously, we are currently at approximately 1.1°C above that temperature. It is projected that at the current rate of emissions, by the end of this century the average global temperature will increase to 2.8°C above the pre-industrial average temperature [2].

As a result of this prediction, there is a worldwide push to get to net zero carbon emissions, which includes reducing carbon emissions to almost zero, and having the resources like forests and oceans naturally absorb the remaining emitted carbon. This would significantly slow the global warming rate and lessen the impacts of climate change. European countries especially are setting specific standards that aid the global temperature goal. While some governments may struggle with environmental legislation gaining traction, organizations have taken responsibility upon themselves to adopt new practices that lead to a more sustainable future. Such organizations include everything from manufacturing industries, agricultural industries, and educational organizations. The University of Cincinnati is one such organization that has continuously been making efforts to reduce its carbon footprint. There has been great progress on this front in the University's recent history, reducing total carbon emissions by 20% in the last ten years. Now UC must be creative in how carbon emissions are further reduced, and this project is one possible solution.

2 – Technical Background

2.1 – Brief Introduction into Gas Combustion Turbines

Combustion turbines can be used in many different applications, such as producing electricity when connected to generators or on jets to move planes through the air. For this project, the team focuses on gas combustion turbines to produce electricity.

In a combustion turbine, air first enters the air intake valve and moves through the compressor (Figure 2-1). As the air is pushed through the compressor, it compresses (as the name indicates) so the air is highly pressurized when entering the combustion chamber. In the combustion chamber, fuel enters through a valve and a flame ignites. At this point, there is highly pressurized and very hot air, and the fuel mixture is pushed through the turbine at extremely high speeds. This air-fuel mixture causes the turbine blades to spin, rotating a shaft which is connected to the generator. The generator then produces electricity via the turning of a magnet which is surrounded by copper coils. The electricity can then be used to power electric infrastructure [4].

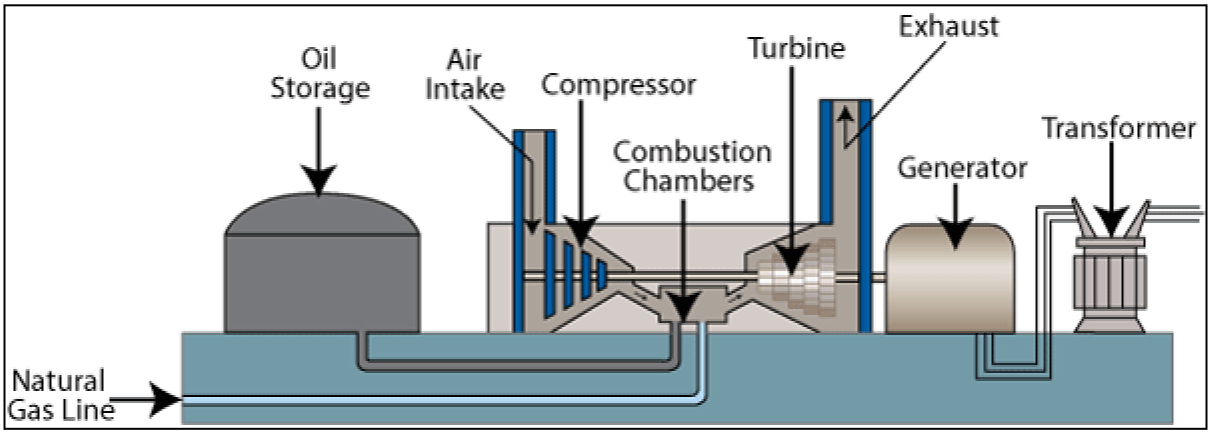

Figure 2-1: Schematic of a Gas Combustion Turbine, Tennessee Valley Authority [5]

The fuel used to cause ignition in the combustion chamber can vary. Most commonly used is natural gas, which produces carbon emissions when combusted. For every million British thermal units (MMBtu) of natural gas burned, approximately 117 pounds of CO_2 are produced [6]. On the other hand, when hydrogen is burned, it produces no carbon emissions. Any carbon emissions associated with hydrogen fuel are created from the actual production of the hydrogen, but this can be avoided by using renewable energy to produce hydrogen [7].

2.2 – Hydrogen Literature

Hydrogen energy is a relatively new concept in the technology world, but it has been growing rapidly in recent years. Hydrogen as a source of energy has been used popularly in fuel cell applications, particularly hydrogen fuel cell vehicles. There are relatively few projects that have used hydrogen co-firing with natural gas to produce electricity at a utility scale, and there are even fewer projects that have been successful in the United States. Part of this project is to establish pathways for the designing and implementation of a project of this nature.

Edge Energy Consultants has researched multiple hydrogen projects that have been successful in this field and have consulted with several experts in the field. Some of the more notable projects and industry leaders are listed below.

2.2.1 – NYPA Brentwood Project [8]

In 2022, the New York Power Authority (NYPA) partnered with the Electric Power Research Institute (EPRI) and General Electric (GE) to complete a hydrogen co-firing demonstration at NYPA's Brentwood, NY plant. They used a GE LM6000 gas combustion turbine, which was previously used with solely natural gas. This project was able to successfully fire hydrogen at a 44% blend with natural gas, resulting in a 20% CO_2 emissions reduction. The success of this project ensures this team that hydrogen co-firing is possible at utility scales. From researching the NYPA project, the main items EEC must consider for the UC project include:

- NO_x control measures need to be taken because of the high emissions associated with hydrogen co-firing with air. As hydrogen to natural gas (NG) ratios increase, NO_x emissions increase due to the higher amount of air required for combustion. Measures such as water injection systems can alleviate the NOx emissions.
- A hydrogen blending system and gas analyzer is necessary to ensure a safe and thorough operation. Before hydrogen enters the turbine, it is optimal to blend it with the natural gas and analyze the gas properties (pressure, weight, etc.). This is opposed to fueling the turbine with pure hydrogen and pure natural gas at two different influent valves respectively and allowing them to mix at the time of combustion.
- During initial startup, the hydrogen percentage can start low and increase as time goes on to ease the transition for the turbines. Startup for the NYPA project began with 100% natural gas and slowly incorporated hydrogen.

2.2.2 – Shanxi Liheng Steel Co. [9]

Shanxi Liheng Steel Co, Ltd. is a company in China that employs four Titan 130 gas combustion turbines, provided by Solar Turbines, Inc., to supply its plant with electricity. They have been able to achieve hydrogen blended with natural gas in these four combustion turbines, significantly reducing their yearly greenhouse gas emissions. Not only does this system produce electricity, it also produces steam with 80% efficiency. The plant has a total capacity of 55 MW, and is a combined heat and power system. This project is of particular interest to EEC because it employs Titan 130 combustion turbines, which are the same model used at the UC Central Utility Plant.

2.2.3 – Solar Turbines, Inc.

Throughout this project, EEC has been in consultation with Solar Turbines, Inc., which is the original equipment manufacturer (OEM) of the two Solar Titan 130 combustion turbines used at the CUP. In particular, the team has been coordinating with Mr. Jean-Luc Di Liberti, the Hydrogen Enterprise Strategy Manager at Solar Turbines. His team has informed us of a series of studies which Solar Turbines has been conducting on the ability of their turbines to be fueled in part by hydrogen. Their first study is referred to as Tier 1 and discusses the retrofitting and modifications required to be made to the turbine to accommodate for up to 4% hydrogen mix by volume. Their Tier 2 study discusses these aspects for anywhere from 4 to 20% hydrogen mix by volume. As far as EEC knows, these are the only current studies available as of right now, and more are being done to determine the modifications needed for higher mixtures of hydrogen. For the time being, this project will aim to achieve near 20% hydrogen by volume and can consider increasing this mixture if and when Solar Turbines releases subsequent studies for higher hydrogen mixtures.

2.2.4 – Air Products, Inc.

EEC recommends Air Products, Inc. as the source of hydrogen for this project due to their availability of bulk amounts, access to green and blue hydrogen, proximity to site location and their involvement in similar utility-scale hydrogen projects. Air Products currently has supplies of gray (produced with steam methane reforming) and green (produced with clean energy) hydrogen in Canada and Arizona respectively. They are currently developing green hydrogen plants in New York and Texas and a blue (produced with SMR and carbon capture and sequestration) hydrogen plant in Louisiana. In the team's discussions with Mr. Eric Schwartz from Air Products, it has become evident that Air Products is developing their hydrogen infrastructure, so EEC is hopeful that this infrastructure will be robust enough in the near future to feasibly support hydrogen co-firing at UC Utilities.

2.3 – Types of Hydrogen Sources

While hydrogen on its own can be used to produce electricity, it does not naturally exist in large quantities by itself as H_2. To produce H_2, energy must be used in the first place in processes such as steam methane reforming (SMR) or electrolysis. Some argue that this is the drawback of hydrogen, and that the energy used to produce it should be used directly for the end purpose which the hydrogen will be used for (i.e. hydrogen produced using wind power then produces electricity, or the wind power could itself be used to produce electricity). The main advantage of hydrogen is that unlike natural gas, it produces a fraction of the carbon emissions and, unlike most other renewable energy, it is not intermittent (i.e. the wind does not always blow, the sun does not always shine) but is a reliable source. Hydrogen is seen by many as more comparable to an "energy storage" mechanism as opposed to an actual source of energy. The other advantage of hydrogen is that it can be used in currently existing natural gas turbines, meaning "black" or "brown" energy equipment does not need to be a lost economic asset.

Hydrogen is characterized by the type of process which is used in its production. The different types are often referred to by different colors. The more prominent ones are green (produced using renewable energy), blue (produced using steam methane reforming with carbon capture and sequestration), and gray hydrogen (produced using steam methane reforming). Table 2-1, taken from the International Journal of Hydrogen Energy, shows the production of hydrogen by type.

Table 2-1: Hydrogen Production by Classification, 2020 [10]

Source	Method	Color	Classification	2020 Production % [4][a]
Black Coal	Gasification	Black H2	High Carbon Footprint	19%
Lignite (Brown Coal)		Brown H_2		
Natural Gas	Natural gas reforming	Grey H_2		59%
Oil	Partial oxidation	Grey H_2		0.6%
Byproduct	Naphtha reformation	Grey H_2		21%
	Chlor-alkali electrolysis	White H_2	Clean	
Natural Gas + CCS	Natural gas reforming	Blue H_2		0.7%
Methane	Pyrolysis	Turquoise H_2		No commercial scale production
Nuclear Energy	Water electrolysis	Pink H_2		
Mixed Grid Electricity	Water electrolysis	Yellow H_2		
Renewable Energy	Water electrolysis	Green H_2	Green	0.03%

When designing projects that utilize hydrogen, it is imperative to look at the entire lifecycle of the project. The main objective of this project is to reduce carbon emissions at the

University of Cincinnati campus. Therefore, using gray hydrogen would not accomplish this goal. Ideally, green or blue hydrogen would be used as they correspond to lesser carbon emissions. The challenge is that there is much less available supply of green and blue hydrogen, whose production in 2020 combined was only 0.73% of all hydrogen production.

2.4 – Existing Hydrogen Transportation Infrastructure

Hydrogen can be transported either in liquid or gaseous phases, and methods of delivery include through pipelines and delivered on trucks. Pipelines can be used in industries such as refineries and chemical production factories (Figure 2-2). If pipelines are used, it is preferred to utilize existing gas pipelines since it has been proven that constructing new pipelines would significantly increase the cost of transportation [11]. Low cost and high efficiency are the driving factors for hydrogen transportation. Because of this, steel pipelines can be replaced by fiber reinforced polymer (FRP) to reduce the installation cost by 20% [11]. Another alternative for hydrogen transportation is pipeline infrastructures that blend hydrogen with natural gas up to 15%. This will lower the cost of having two separate lines to transport both hydrogen and natural gas.

Figure 2-2:Hydrogen Transportation Through Pipelines [11]

On the other hand, hydrogen gas is commonly transported via trucks in the form of compressed gas (Figure 2-3). The trucks that deliver hydrogen gas are also known as tube trailers. Within the tube trailers, hydrogen gas is compressed to a pressure of 2600 psig or higher [13]. Alternatively, liquefied hydrogen is transported in super-insulated tanker trucks. After hydrogen liquefaction, hydrogen is stored in large insulated tanks and then transported to different distribution sites. Hydrogen tanks have to be properly sealed to prevent both evaporation and boiling off [13]. Additionally, it has been proven that transporting liquified hydrogen in tankers is economically more efficient than transporting gaseous hydrogen. This is due to the tanker truck's ability to hold a larger volume of hydrogen (Figure 2-3) than the tube trailer (Figure 2-4).

Figure 2-3:Liquified Hydrogen Transportation Via Tanker Trucks [13]

Figure 2-4:Gaseous Hydrogen Transportation Via Tube Trailer Trucks [14]

2.7 – Volume of Hydrogen Required

This project will aim to burn the highest amount of hydrogen relative to natural gas as possible within certain technical and economic limitations. Based on the team's discussion with Solar Turbines, the original manufacturer of the Solar Titan 130 combustion turbines utilized at the Central Utility Plant, the turbines will be able to reach a capacity of 20% hydrogen by volume with some retrofitting (i.e. replacing some parts with steel). In the future, it may be possible to burn closer to 50% hydrogen by volume, which is why Table 2-2 includes that fuel mix for reference. For now, it is realistically feasible to begin burning between 4-20% hydrogen based on Solar Turbines' studies and hydrogen cofiring in this turbine mode. Included in this report are volume estimations at varying hydrogen percentages, calculated based on the weight of natural gas burned at peak monthly demand at the Central Utility Plant in 2021.

It is important to note that hydrogen has a lesser heating content than natural gas, meaning it produces less energy for the same amount of volume. Based on an article by POWER Magazine, hydrogen has about 40% of the heating content of natural gas [16]. Therefore, at a 50% volumetric mix with natural gas, hydrogen only produces 20% of the total energy. This has to be accounted for by increasing the volume of both hydrogen and natural gas used to fulfill the energy demand. Table 2–2 shows the estimated monthly volume of hydrogen and natural gas needed at 20% and 50% hydrogen by volume at the utility plant.

Table 2–2: Monthly Volume of Hydrogen Needed at the UC Central Utility Plant [16][17][18][19][20]

Percentage of Hydrogen	Volume of H2 (L)	Volume of NG (L)	Weight of H_2 (kg)	Weight of NG (kg)	Estimated CO_2 Reduction
20%	1.13 billion	4.55 billion	101,000	3,020,000	8%
50%	3.57 billion	3.57 billion	321,000	3,840,000	20%

These calculations (see Appendix 11.1.4 for detailed calculations) were done independently by Edge Energy Consultants. Mr. Jean-Luc Di Liberti, the Enterprise Hydrogen Strategy Manager at Solar Turbines, also did an estimation on the volume of hydrogen required for this system. His estimation was 59 tons per month per unit (2 units) at 20% hydrogen. This correlates to a total of 107,048 kg of hydrogen, which is relatively similar to our estimation of about 101,000 kg with about a 6% error. Since these calculations are only estimations meant to give the university a general idea of the amount and cost of hydrogen required, our team accepts this error as being negligent. It is important to note that these calculations were made using the energy generation at the month of *peak* demand, therefore most months will require lesser amounts of hydrogen.

3 – Proposed Design

This team has gone through many different design iterations, continuously adjusting them as limitations were discovered in research and discussions with Solar Turbines, Inc., Air Products, Inc., and Mr. Mike Hofmann from UC Utilities. The team has settled on what it considers to be an optimal design, which is pictured in the schematic in Figure 3-1. The final design involves the hydrogen being stored in tanks in a green space located on the corner of Goodman and Vine St., just down the road from the power plant. This gas will be transported via pipelines to the blend skid to be blended with natural gas. The blend skid is recommended to be placed next to the plant in a small cut-out from the building.

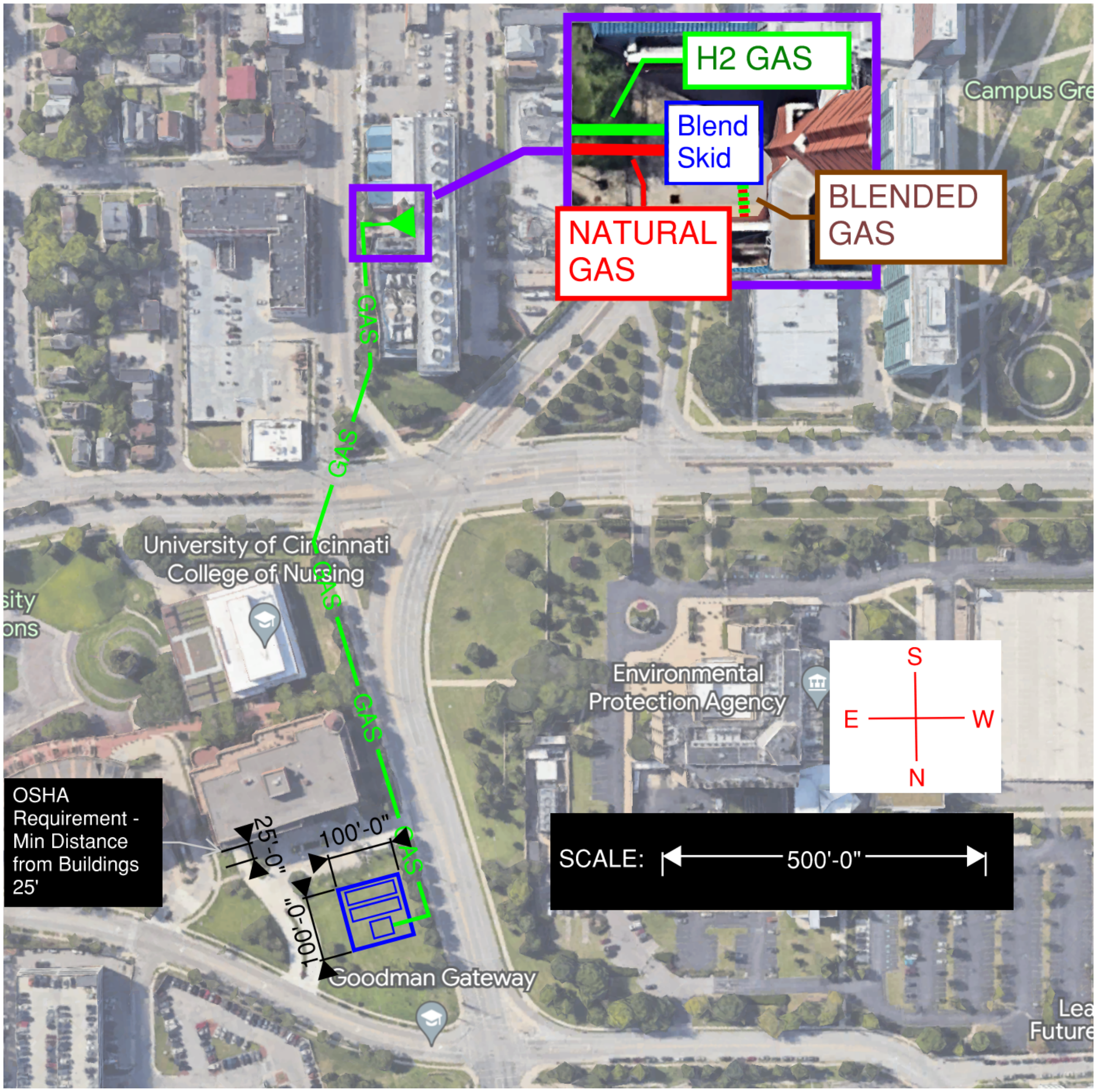

Figure 3-1: Proposed Hydrogen Storage and Blending Design (Drawing made in BlueBeam)

3.1 – Hydrogen Sourcing and Transportation

As discussed in Section 2.2.4, Edge Energy Consultants has recommended that UC Utilities source its hydrogen from Air Products, Inc. EEC has discussed the project plans with Mr. Eric Schwartz, a representative at Air Products. Mr. Schwartz has informed the team that Air Products can source bulk amounts of hydrogen to the Central Utility Plant on a periodic basis and refill the plant's hydrogen storage tanks as needed. The hydrogen would be delivered on trucks as a liquid in cryogenic tanks and would then be vaporized on-site. Mr. Schwartz's estimates for prices of gray and blue hydrogen were roughly 25 USD per 1000 SCF (standard cubic foot) and 50 USD per 1000 SCF, respectively. These prices and how they will impact the project are further discussed in Section 6: Economic Analysis.

3.2 – Hydrogen Storage and Blend Skid

In prior design iterations, EEC planned to store the hydrogen tanks on location at the utility plant in the alcove of the plant next to Short Vine St (where the blend skid is currently recommended to be placed). In discussion with Mr. Schwartz from Air Products, the team realized hydrogen is required to be stored at least 25 ft. from the nearest building. These regulations are discussed further in Section 4: Regulations. Therefore, it was determined that the storage location would likely be off of the plant's property. Looking at a map of the university's main campus as in Figure 3-1, there is a green space very close to the plant at the southeast corner of Vine St. and Goodman Dr. This space is on university property and allows for ample room for a 100' by 100' concrete pad (Mr. Schwartz' estimation of the hydrogen storage footprint based on UC's power demand), including well-over 25 ft. margins surrounding the proposed storage footprint. In addition, the large footprint of the space will allow for the university to expand its storage capacities in the future if they decide to cofire hydrogen at higher percentages by volume, such as 50% or more.

Air Products has informed the team that they will provide and install hydrogen storage tanks, a vaporizer to change the hydrogen from liquid to gaseous state, and a blend skid to mix hydrogen with natural gas. The university is required to install the 100' by 100'concrete pad which will house the elements that Air Products will provide. Anything outside of this concrete pad is the responsibility of the university. Transporting the hydrogen from the Goodman Dr. storage location to the utility plant will therefore be the Central Utility Plant's responsibility.

As discussed in Section 2.4: Existing Hydrogen Transportation Infrastructure, it is common to transport hydrogen through pipelines. Gas pipelines can therefore be constructed from the green space on Goodman Dr. to the plant. While constructing these pipelines will add to the cost of the project, the distance of the piping from the proposed storage location to the plant is estimated to be only about 1,000 ft. Cost can be decreased by 20% by installing fiber reinforced polymer pipes as opposed to steel pipes [11].

As seen in Figure 3-1, the natural gas pipelines currently enter the plant at the aforementioned alcove on Short Vine St. Therefore, the team proposes that the blend skid is placed in this alcove to avoid routing natural gas to the hydrogen storage location and then transporting the mixture back to the plant. The alcove is an approximate 30' by 30' footprint and should therefore be large enough to house a blend skid. While EEC does not know the exact dimensions of the required hydrogen blend skid, it is not expected to be of significant size. Figure 3-2 provides an example of a hydrogen blend skid used by Enbridge Gas, Inc. in Canada [21]. These gas blend skids are typically able to analyze flow and pressure to ensure the H_2 and NG mixture is at the appropriate pressure specified by Mr. Hofmann (~300 psi). Once blended, the gas mixture can then easily be routed into the plant and to the turbines.

Figure 3-2: Example of a Hydrogen Blend Skid [21]

It should be noted that hydrogen is safer to transport once it is blended with natural gas. However, pure hydrogen alone can still be transported, but further safety measures may need to be taken into account due to hydrogen's high reactivity and flammability. Due to this consideration, UC Utilities may determine that it is more feasible to first route the natural gas to the hydrogen storage location in order to blend it there. That way, the fuel being transported from the storage location to the plant will not be pure hydrogen and may be easier to transport. This decision should likely be made upon further consultation with Air Products and/or the installers of the gas pipeline who likely have expert opinion on the optimal alternative. Edge Energy Consultants' opinion is that if the hydrogen can be safely routed to the plant without first blending it with natural gas, this is likely the more economical option as UC Utilities will avoid re-routing the natural gas from its original path straight into the plant.

3.3 – Retrofitting of Gas Combustion Turbines

The retrofitting phase of this project has not been explored as in-depth as the sourcing, transportation, storage, and blending aspects. This has been due to several legal limitations not allowing EEC access to the Tier 1 and Tier 2 studies performed by Solar Turbines, Inc. Therefore, this report cannot discuss required modifications to the turbines in great detail. However, Solar Turbines has expressed they can likely provide these studies directly to UC Utilities and will work with them on making these modifications. As discussed further in Section 8: Recommendation, Edge Energy Consultants therefore strongly recommends that Mr. Mike Hofmann and the UC Utilities team begin collaborating with Solar Turbines on these plans. EEC recommends making special note of the NO_x emissions and how these will be addressed. Solar Turbines did mention that they have a mechanism for controlling NOx emissions. As discussed further in Section 4.2, there are government regulations which specify the allowable amount of NO_x emissions.

While not much detail can be given about the modifications, Edge Energy Consultants has acquired helpful information from Mr. Tim Harris from EnTrust Solutions Group. Mr. Harris is a specialist in renewable energy, hydrogen projects, and natural gas. From discussions with him, it appears that the main required modifications in these types of projects involve replacing materials with sturdier, less corrosive materials. For example, many turbines are built with steel components that should be replaced with aluminum components when using hydrogen. This is due to hydrogen's high reactivity. Essentially, any materials which the hydrogen touches throughout the entire system (from storage to combustion) must be compatible with hydrogen and able to withstand long-term contact with hydrogen without corroding. This also includes the seals and welding between materials, which must be able to contain the hydrogen. Another major point which Mr. Harris mentioned was the flame speed at which the fuel mixture is combusted. Hydrogen burns much faster than natural gas, therefore a continuous flow of fuel supply is needed that exceeds this flame speed in order to avoid flashback.

4 – Regulations

4.1 – Regulations on Storage [23]

Due to its low volumetric density, it is significantly hard to store hydrogen gas. However, The Department of Occupational Safety and Health Administration (OSHA) had initiated rules on how hydrogen can be stored in different conditions. These conditions cover indoor storage, outdoor storage, and special rooms storage. The following is a summary of the regulations for storing hydrogen.

- Storage and delivery information follow OSHA regulations (29 CFR Part 1910 Subpart H – Hazardous Materials).
- Storage tanks should be located in an accessible location for maintenance and authorized personnel access.
- Liquified hydrogen storage tanks should be properly labeled with a sign of danger and potential risks. ("Liquefied Hydrogen - Flammable Gas - No Smoking - No Open Flames.")
- If the liquified hydrogen was stored in above-ground storage tanks, it is important to keep it far from other liquified products such as oxygen.
- Storage areas should be fenced and closed and only allow access for authorized personnel.
- Legible instructions should be provided for maintenance and operating purposes.
- A qualified person should be at the location at the unloading times.
- Each liquefied hydrogen supply unit should be properly secured to prevent movements.
- Mobile liquified storage units shall be grounded for static electricity.
- Maintenance for each liquified hydrogen unit should be performed in safe conditions.

- For maintenance, combustibles are not permitted within a radius of 25 feet from any liquified hydrogen unit.
- When storing hydrogen, it is important to consider the distance of other materials found on the storing location.

The minimum distance the stored hydrogen could be located from other items became a large issue in the team's decision making due to the Utility Plant's small and compact campus. It is for this reason the team needed to look elsewhere for a long term solution. Table 4-1 shows the distances for different size containers that have to be taken into consideration when implementing and constructing the hydrogen storage area.

Table 4-1 - Minimum Distance (Feet) From Liquefied Hydrogen Systems to Exposure (OSHA)

Type of exposure	Liquefied hydrogen storage (capacity in gallons)		
	39.63 (150 liters) to 3,500	3,501 to 15,000	15,001 to 30,000
1. Fire-resistive building and fire walls[3]	5	5	5
2. Noncombustible building[3]	25	50	75
3. Other buildings[3]	50	75	100
4. Wall openings, air-compressor intakes, inlets for air-conditioning or ventilating equipment	75	75	75
5. Flammable liquids (above ground and vent or fill openings if below ground) (see 513 and 514)	50	75	100
6. Between stationary liquefied hydrogen containers	5	5	5
7. Flammable gas storage	50	75	100
8. Liquid oxygen storage and other oxidizers (see 513 and 514)	100	100	100
9. Combustible solids	50	75	100
10. Open flames, smoking and welding	50	50	50
11. Concentrations of people	75	75	75

1- The distance in Nos. 2, 3, 5, 7, 9, and 12 in Table H-4 may be reduced where protective structures, such as firewalls equal to height of top of the container, to safeguard the liquefied hydrogen storage system, are located between the liquefied hydrogen storage installation and the exposure.

2- Where protective structures are provided, ventilation and confinement of products should be considered. The 5-foot distance in Nos. 1 and 6 facilitates maintenance and enhances ventilation.

4.1.1 – Indoor and Special Rooms Storage (> 50 gallon containers)

- Containers should be located 20 feet from other flammable liquids and combustible materials.
- Containers should be located 25 feet from electricity equipment and other ignition sources.

- Containers should be located 50 feet from ventilation intake and air-conditioning equipment.
- Containers should be protected against damage or injury due to falling objects.
- Containers should properly be secured and stored.
- High heat practices are prohibited while oxygen is in the room.

4.1.2 – Outdoor Storage

- Storing location should not be enclosed by more than two walls set at appropriate angles with the ability to provide ventilation spaces.
- Roadways and the ground surface of the storing location should be constructed from non combustible materials.
- If applicable, protective walls should be constructed from non combustible materials.
- A properly installed lighting should be provided for nightime transfer operations.

4.1.3 – Special Rooms

- All floors, walls, and sellings should have fire resistance for at least two hours.
- The locations should be securely closed unless for personnel access.
- Openings to other parts of the buildings should be allowed.
- Windows and doors should be available to use in the case of emergencies.
- The storage room should have a properly installed ventilation system.
- The venting areas should not be less than 1 square foot per 30 cubic feet of the volume of the storage room which can consist of: noncombustible materials for walls, light fastned hatch covers, lightly fastned swinging doors open outwards, lightly fastened roofs to lower the maximum pressure of 25 pounds per square foot.
- No source of ignition is allowed in the area.
- If heat was provided, it should be in the form of steam, hot water or other indirect means.

4.2 - Regulations on Equipment

Due to the dense population of the Clifton area, the project is likely to be elevated under the Environmental Justice initiatives by the U.S. EPA. These initiatives include both regulations and limitations for the use of the equipment located on the site. Some of these regulations are for emissions associated with co-firing processes that are anticipated to increase NOx emissions, a potent greenhouse gas. Under high temperatures, nitrogen and oxygen located in ambient air will react with each other to form NOx. The reason for having NOx limitations is because this project is based on burning hydrogen with natural gas at high temperatures. Although the process will reduce the carbon footprint in the site and the surrounding areas, NOx emissions will increase as the combustion temperature increases. Table 4-2 includes all equipment that will be utilized in the burning process. In addition, Table 4-2 includes the regulations associated with all the equipment for the hydrogen combustion process.

Table 4-2: Equipment Regulations

Equipment	Corresponding Regulations
Boilers & HRSGs**	*New Source Performance Standards 40 CFR Part 60, Subpart Db* ● NOx emissions must not exceed (0.20 lb/MMBtu) *National Emission Standards for Hazardous Air Pollutants 40 CFR Part 63, Subpart DDDDD* ● Gas 1 boilers, no changes in limits would be required since it is compatible with hydrogen
Turbines	*New Source Performance Standards 40 CFR Part 60, Subpart GG* ● Subjected to NOx limits ● If limits were exceeds, controls must be installed *National Emission Standards for Hazardous Air Pollutants 40 CFR Part 63, Subpart YYYY* ● No requirements

*** HRSGs are considered boilers for regulatory purposes*

Since the combustion of hydrogen and natural gas will result in a high amount of NOx emissions, more controls and permits would be required to satisfy all the regulations listed in (Table 4-2). Due to The federal New Source Review, higher emissions would require air dispersion modeling and BACT measures. The emissions analyzer would likely be changed from Predictive Emissions Monitoring System (PEMS) to Continuous Emissions Monitoring System (CEMS) to be more compatible with the hydrogen and natural gas fuel mixture.

5 – Environmental Analysis

5.1 – Emissions

Natural gas is one of the most significant fuels negatively impacting the environment. Running the combustion turbines found in the UC Utility Plant requires natural gas fuel to be burned. Pollutants such as carbon dioxide are released as a result of this combustion process. According to the EPA, the emission factor value of carbon dioxide when burning natural gas is 110 (lb/MMBtu) which is considered a major pollutant produced in NG combustion. Other less notable emissions from burning natural gas include methane (CH_4), nitrous oxide (N_2O), and volatile organic compounds (VOCs). Table 5-1 includes other pollutants associated with natural gas combustions and the emission factors associated with each pollutant.

Table 5-1 - Natural gas pollutants and emissions factors in stationary combustion engines [15]

Pollutant	Emission Factor (lb/MMBtu)
NOx	3.20E-01
CO	8.20E-02
SO2	0.94
VOC	2.10E-03
PM (condens.)	4.70E-03
PM (filterable)	1.90E-03
CO2	**110**
N2O uncontrolled	0.003
PM total	6.60E-03
TOC	1.10E-02
Methane	8.60E-03
1,3-Butadiene	4.30E-07
Acetaldehyde	4.00E-05
Acrolein	6.40E-06
Benzene	1.20E-05
Ethylbenzene	3.20E-05
Formaldehyde	7.10E-04
Naphthalene	1.30E-06
PAH	2.20E-06
Propylene Oxide	2.90E-05

Toluene	1.30E-04
Xylenes	6.40E-05

5.2 – Emission Calculations of CO_2

Table 5-2 estimates the associated emissions of each phase of hydrogen blending. These calculations were done by Edge Energy Consultants Team to find the reduction of carbon dioxide at different blending phases. The team was provided with the amount of the natural gas that the utility plant consumes on a monthly basis (See Table 2-7). Additionally, the team was provided with the rate values of combustion at the utility plant which were utilized in these calculations. The three phases of blending were 0%, 20%, and 50% of hydrogen by volume and the associated emissions of CO_2 were 5.62 E+11, 5.10 E+11 and 4.01 E+11 ton/year, respectively.

Table 5-2 - Carbon Dioxide Emissions at Different Hydrogen Percentages

Hydrogen Percentages	Amount of Natural Gas (kg/month)	CO_2 Emissions (ton/year)
0	4230000	5.62 E+11
20	3840000	5.10 E+11
50	3020000	4.01 E+11

Figure 5-1 is a graphical representation of the emissions associated with each phase of hydrogen percentage added to natural gas. The graph shows the reduction of carbon dioxide after introducing hydrogen at 20% and 50%. The reduction percentages of carbon dioxide were calculated to be 9% reduction at 20% hydrogen and 28% reduction at 50% hydrogen.

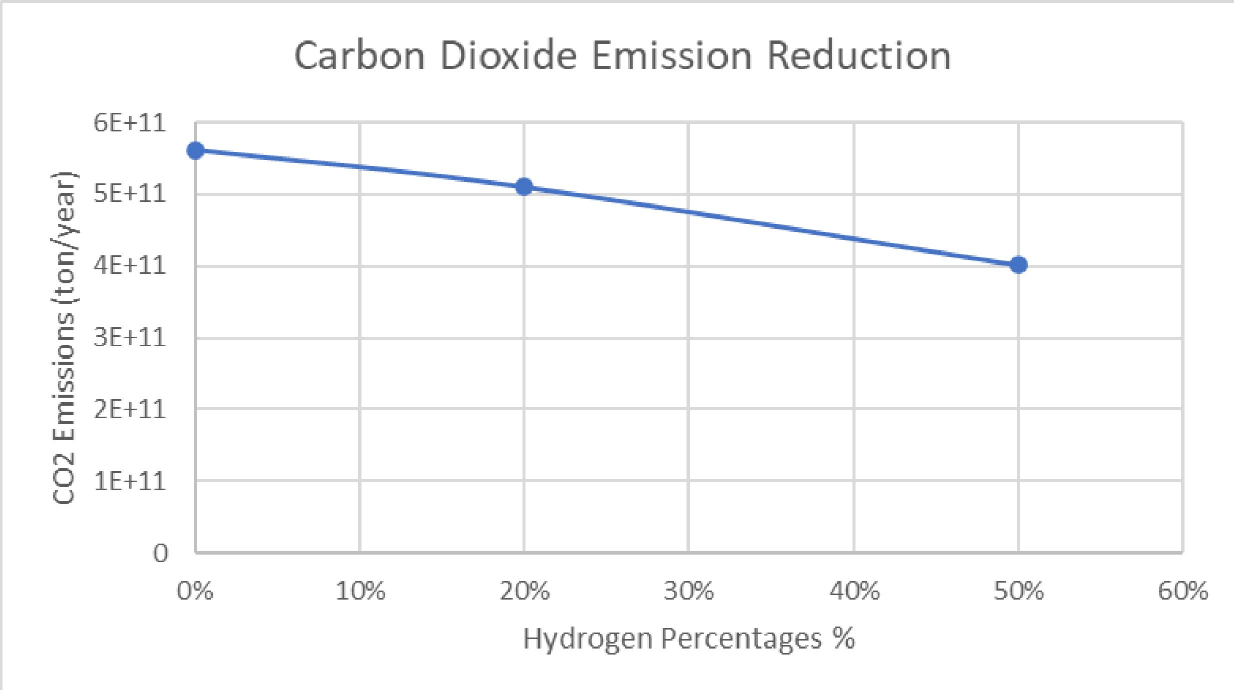

Figure 5-1: Carbon Dioxide Emissions Reduction per Hydrogen Fuel Mixture

5.3 – NO_x Emissions

The combustion of natural gas and hydrogen mixture emits nitrogen oxides. The combustion process is being performed at high temperature which is a suitable environment to generate NO_x emissions. Due to the lack of time, the team has not performed any environmental analysis of NO_x emissions that may occur from the combustion process. However, the team anticipates that NO_x emissions will increase due to the high temperature at the combustion process.

6 – Economic Analysis

6.1 – Initial Cost

There are certain significant initial costs to consider for this project. While the sums are unknown, they are anticipated to be high due to the construction involved. These include the concrete storage tank skid, the gas line, and turbine retrofitting.

6.1.1 – Storage Tank Skid

As stated in the final design plans, the hydrogen will be stored on a concrete skid located on University of Cincinnati property, approximately 900 feet north of the Utility Plant. The University will be responsible for laying the required 100 ft by 100 ft area of concrete to house two 25,000 gallon tanks as well as the vaporizer. The tanks and vaporizer will be provided by Air Products. The only costs for the University will be to construct the concrete skid. After construction, Air Products will be responsible for implementing the tanks and vaporizer, future routine maintenance, and any other situation regarding what is located on the skid.

6.1.2 – Gas Line Construction

Because of the regulations surrounding hydrogen storage, there is not enough room on the Utility Plant site to be able to house tanks large enough for this project. For this reason, the hydrogen will be stored down the street, and will require underground gas lines to be constructed to connect the tanks to the Utility Plant building. These gas lines will also be paid for by the University, and will be the responsibility of the University if anything should happen to them or need repair. This process will require government permitting, and a plan regarding traffic control due to it crossing a busy intersection. The construction cost will include the required materials and labor.

6.1.3 – Turbine Retrofitting

The cost of retrofitting both of the combustion turbines is unknown due to the confidentiality of the studies done by SolarTurbine. It is known that the Tier 1 Study which analyzes 4% hydrogen blending does not require a significant amount of retrofitting due to the dilution of hydrogen in the natural gas. The cost of retrofitting under these circumstances is expected to be relatively minimal. The Tier 2 Study would introduce 20% hydrogen, making the blend less diluted and requiring more retrofitting. This would likely be switching any corrosive stainless steel hardware with non-corrosive aluminum parts. Another feature likely to be included in this tier of retrofitting would be to add cooling controls within the system to ensure NOx emissions are under control. These items would make this round of retrofitting to be more expensive. Again, because the studies done by SolarTurbine are confidential, the team was not provided with approximate costs on these operations.

6.2 – Recurring Costs

There are two anticipated recurring costs that will be billed on a monthly basis. The main recurring cost will be fuel, as well as the maintenance Air Products will provide to the gas tanks and vaporizer.

6.2.1 – Fuel

From the alternative analysis completed by EEC in the fall semester, the chosen hydrogen provider was Air Products, Inc. The team was able to contact them to gain insight about this project, and they provided the team with approximate costs for gray and blue hydrogen. Gray hydrogen was estimated to be $25 per 1,000 SCF and blue hydrogen was $50 per 1,000 SCF. Based on those estimates and the monthly volume of fuel used by the Utility Plant, approximate monthly costs for implementing gray and blue hydrogen at 20% and 50% of the volume are found in Table 6-1. Those sums are significantly higher than what UC currently pays to run the combustion turbines on natural gas. Although Air Products is one of the leading producers of hydrogen gas in the United States, they are only beginning production of green hydrogen. An approximate for green hydrogen cost with Air Products was not available.

Table 6-1 - Blue and Gray Hydrogen Monthly Cost Estimations

Percentage of Hydrogen by Volume	0%	20%	50%
Volume of H_2 per month	0%	1.13 billion L	3.57 billion L
Volume of NG per month	5 billion L	4.52 billion L	3.57 billion L
Estimated CO_2 Reduction	0%	8%	20%
Cost of Blue H_2 per 1,000 SCF (USD)	$50		
Cost of Gray H_2 per 1,000 SCF (USD)	$25		
Cost of NG per 1,000 SCF (USD)	$13.47		
Cost of Blue	NA	$2 million	$6.3 million
Cost of Gray	NA	$998,000	$3.2 million

Total Cost (Using NG and Blue H2)	$2.4 million	$4.2 million	$8 million
Total Cost (Using NG and Gray H2)	$2.4 million	$3.1 million	$4.9 million

It is a fact that hydrogen gas is more expensive than natural gas. In order to achieve the goal of reducing carbon emissions from the UC Utility Plant, green hydrogen is the recommended fuel. This requires that the hydrogen be produced using renewable energy or low emission methods. According to the International Energy Agency (IEA), in 2019 the cost of producing green hydrogen was as high as $7.70 per kg [22]. The IEA predicts that by the year 2060, the cost of green hydrogen production will decrease to around $3.30 per kg, as found in Figure 6-1. This is a plausible trend because of new tax credit systems, and generally more incentives to utilize green energy. Similarly, the cost of hydrogen electrolyzers are expected to continue decreasing. Global eProcure (GEP), a supply chain consulting company, has shared that the capital cost of electrolysis has fallen by 60% since 2010. In addition, the Inflation Reduction Act, published in 2022 under the Biden Administration, provides generous tax credits for the production of clean hydrogen [24]. These tax credits will even further decrease the cost of clean hydrogen as shown in Figure 6-1, and will hopefully make hydrogen prices competitive with natural gas. All these points together predict a very bright future for the accessibility of green hydrogen.

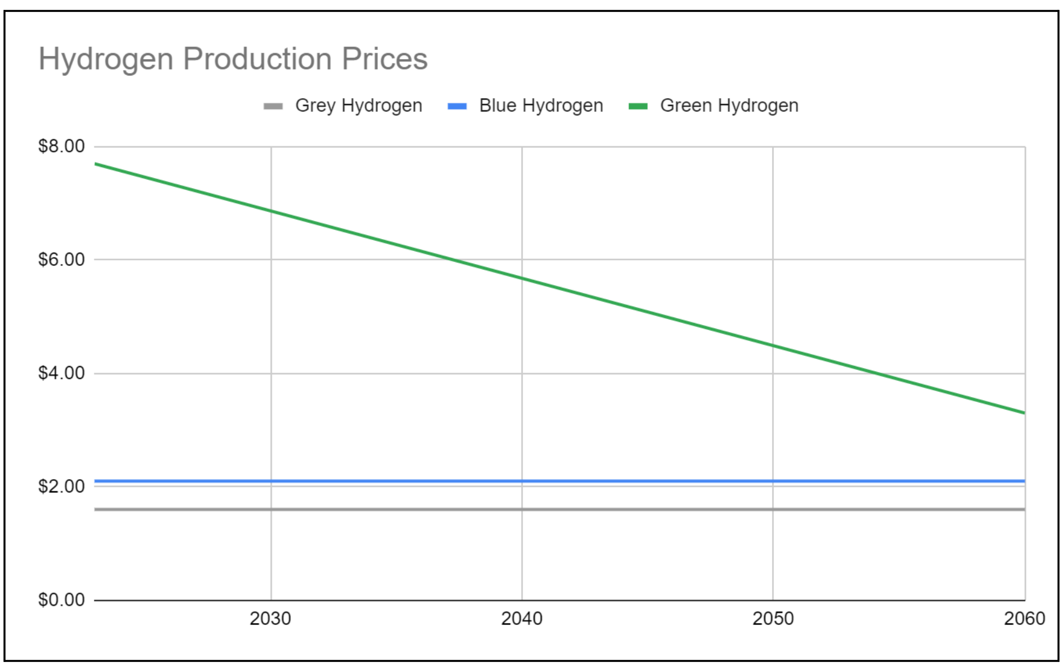

Figure 6-1: Hydrogen Production Price Projections (produced using information from IEA [22])

6.2.2 – Air Products Maintenance

Air Products will be in control of everything housed on the concrete skid (tanks and vaporizer), and will be responsible if anything should go wrong involving those items. That responsibility does not extend past the boundary of the concrete skid. They will also have routine maintenance to be done, which will be a monthly recurring fee.

7 – Discussion

The purpose of this project was to assess the feasibility of introducing a hydrogen blend into the two natural gas combustion turbines at the UC Utility Plant. In the first semester of this project, the two challenges the team focused on were the source of hydrogen and the storage location. The team determined that green hydrogen is not yet feasible, but that Air Products Inc. is a world leader in hydrogen production and are working towards blue and green hydrogen plants in the United States. In terms of storage location, it was important that it be on the Utility Plant site, in close proximity with the turbines. When the alcove location next to Short Vine Street was chosen, the team was unaware of the regulation for hydrogen storage to be located at least 25 ft away from any building. With this in mind, it was clear that the team would need to meet with industry representatives to gain better understanding on hydrogen acquisition and turbine retrofitting in the coming semester.

It was in this second semester that the team met with Air Products representative, Eric Schwartz, to get specifications on hydrogen supply and storage. From him, EEC learned about the 25 ft requirement, tank sizes based on volume of hydrogen, and the concrete skid information. It is from that meeting that the team determined the final design storage location for the hydrogen. Mr. Schwartz also provided the team with approximate prices for gray and blue hydrogen. Any other pricing information regarding equipment and maintenance were unavailable. The team also met with representatives from SolarTurbine, the manufacturer of the University’s combustion turbines. They shared information about their Tier 1 and 2 studies, but could not give access to either due to confidentiality. The team understands that these studies will be available to the University as a customer to SolarTurbine in the future when the project is further along. Again, costs for retrofitting are not able to be disclosed at this time.

Due to the current staggering prices of blue and green hydrogen, this project is not yet economically feasible. Even without considering the additional initial costs for the project like modifying the existing turbine infrastructure or building the gas line from the off-site gas storage to the plant, buying the necessary amount of green hydrogen is enough to affirm the current cost would be too high. So although more input from the leaders in the industry would have been helpful, they gave the team helpful insight as to what should happen with this project in the future. It is for this reason that the team has come up with a set of steps the University should take if they wish to reduce carbon emissions using hydrogen blending in natural gas turbines.

8 – Recommendation

Edge Energy Consultants has come to the conclusion that the implementation of this project is not possible within the team's timeframe. It is for this reason that the team has made a set of recommendations for future implementation, should the University decide to move forward with hydrogen cofiring at the Utility Plant.

The first step will be to set up a site survey with Air Products in order to determine the optimal storage location for the hydrogen storage tanks. This should include plans for exactly where the concrete skid should be located, which houses the tanks and vaporizer. Planning should begin for gas lines, which will transport hydrogen from the tanks to the Utility Plant. Based on the team's design plan, a blending station should be located in the alcove on the east side of the Utility Plant building. UC representatives should be maintaining open communication with representatives from SolarTurbine, especially when referring to the blending station, to ensure blending is being done according to their standards.

SolarTurbine mentioned in the previous meeting that they have conducted a Tier 1 Study, which included introducing 4% of hydrogen into the turbines. This study concluded that little to no operational adjustments were necessary due to the dilution of the hydrogen. SolarTurbines representatives informed the team that this study could be shared with their customers at no cost. Therefore, the next step would be working with SolarTurbines in order to test the hydrogen blending in accordance with the Tier 1 study. Testing can be done on one of the two combustion turbines. This should be done before construction of the hydrogen storage tanks and gas lines. Air Products should be contacted to provide a small volume of hydrogen via mobile truck for the test. For this small batch test, a large amount of volume is not necessary, and for that reason, the hydrogen should be delivered in a gaseous state. This means that a vaporizer will not be necessary, but a blending station should still be included in the test. It is important to note that during testing, initial firing should begin without hydrogen and hydrogen should subsequently be introduced at a low percentage and slowly increased to the full 4% blend.

When SolarTurbine deems the test successful, or multiple tests if necessary, construction should begin for a long term hydrogen storage location, along with gas lines and the blending station. The same operational adjustments made for the first turbine in the testing period should be made to the second combustion turbine. Upon completion of these items, UC Utilities should begin regularly using the 4% hydrogen fuel.

The next step will be to increase the percentage of hydrogen being blended with the natural gas. This will require information from SolarTurbine's Tier 2 study, which evaluates introducing between 4% and 20% hydrogen. Access to this study will require an additional fee. Introducing hydrogen above 4% will require the turbines to undergo a significant amount of retrofitting, including the replacement of steel hardware with aluminum. These adjustments should be done to one of the turbines for subsequent testing with an increased amount of hydrogen. Upon completion of successful tests for up to 20% hydrogen, the second turbine should undergo the same retrofitting, and the Utility Plant may begin regularly running both turbines on the increased hydrogen fuel blend. If issues should occur with the hydrogen at any point, the hydrogen supply can be shut off and the turbines can continue running on only natural gas.

It is the team's understanding that SolarTurbine will be going forward with more studies like those of the Tier 1 and 2 Studies, where they will continue to evaluate the integrity of their turbines with increasing amounts of hydrogen. It is recommended that UC Utilities maintain communication on this topic, so that testing and implementation of increased hydrogen ratios can be done at the UC facility.

9 – Conclusion

The Edge Energy Consultants team was tasked with doing research on the introduction of hydrogen blended natural gas for fuel in the two combustion turbines at the University of

Cincinnati Utility Plant. Given the time period allotted to the team, the main topics of interest included the availability and feasibility of clean hydrogen and the storage location of the hydrogen. The team chose Air Products, Inc. as the best alternative for supplying the hydrogen for this project. The team has agreed that hydrogen will be transported in liquid form to the proposed storage location. The liquified hydrogen will be vaporized at the Vine St. and Goodman Dr. storage location before being transported to the carve-out location at the utility plant. A blending skid will be installed to quantify the amount of both natural gas and hydrogen gas before introducing the mixture to the turbines. The turbines located on site will require retrofitting actions which can be found in the Tier 1 and Tier 2 studies. The Tier 1 and 2 studies are studies conducted by the turbines' manufacturing company, SolarTurbines Inc., to modify all the required parts of the turbines so that they are compatible with the new fuel and the cofiring process.

The Edge Energy Consultants team has established an environmental analysis of the effects of introducing hydrogen into natural gas. The combustion of natural gas emits several pollutants such as carbon dioxide, nitrogen oxides, and other pollutants that play a key role in impacting both humans and the surrounding environment. The team studied the environmental analysis of carbon dioxide and concluded that utilizing more hydrogen on the cofiring process will reduce carbon dioxide emissions. On the other hand, NO_x emissions are one of the major pollutants that result from the hydrogen co-firing process. The team expects the values of NO_x emissions to increase due to the high temperature in the combustion process. The rest of the pollutants will be reduced as more hydrogen enters the combustion process. For this reason, NO_x control measures should be taken to reduce these emissions. Solar Turbines is able to provide NO_x control technology.

The team has also conducted economic analyses and these analyses include all the areas affected by the implementation of this project. Analyses were performed to study the storage location and the required modification for the site. Other analyses were also performed on the construction of the new gas line that is going to deliver the vaporized hydrogen to the blending skid. For the turbines, all retrofitting costs can be provided through Tier 1 & 2 studies where they cover the modifications on the turbines along with the modifications on the other equipment located on the site. Since the price of green hydrogen is still significantly high, other types of hydrogen can be used in the co-firing process at a reduced cost. The project will utilize both gray and blue hydrogen until the prices of green hydrogen are feasible to the Utility Plant Administration.

10 – References

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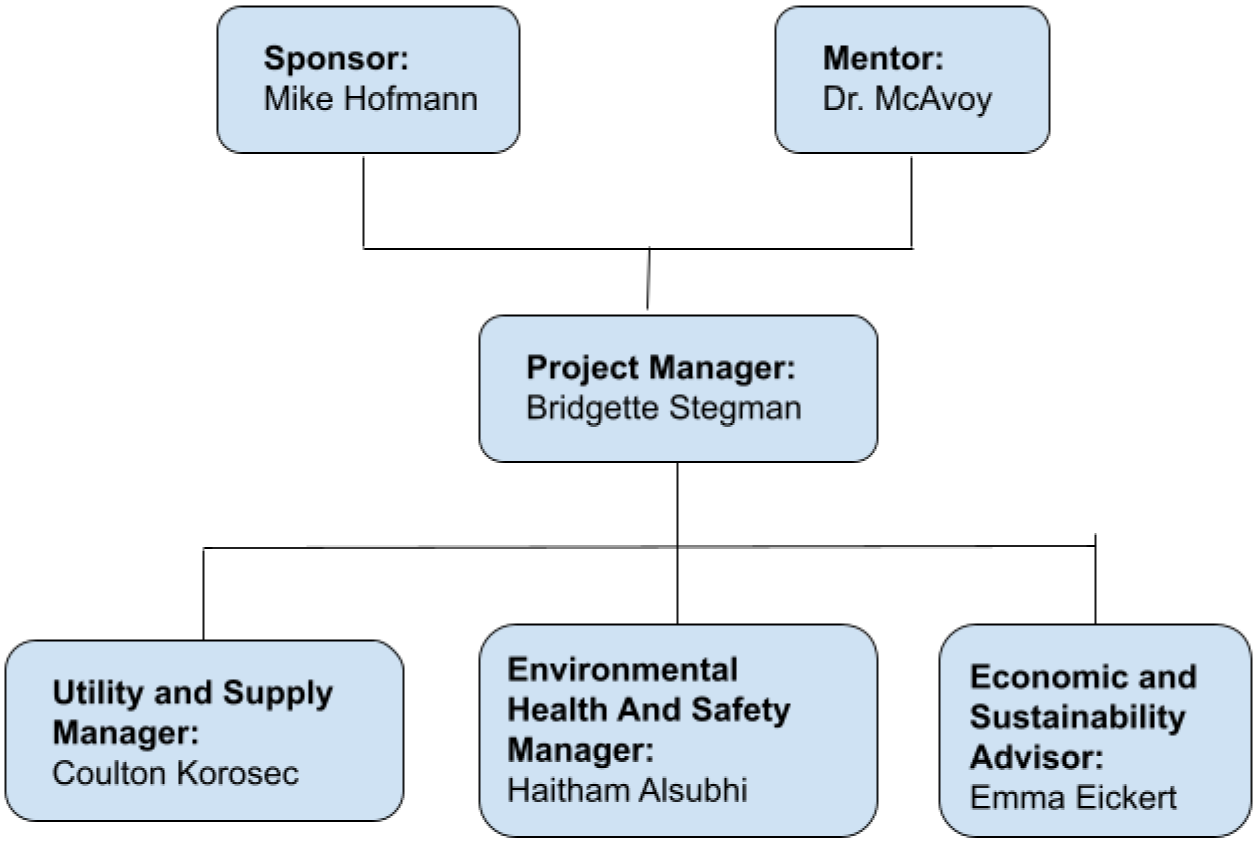
11 – Appendices

11.1 Appendix 1 - About Edge Energy Consultants

11.1.1 – Organizational Chart



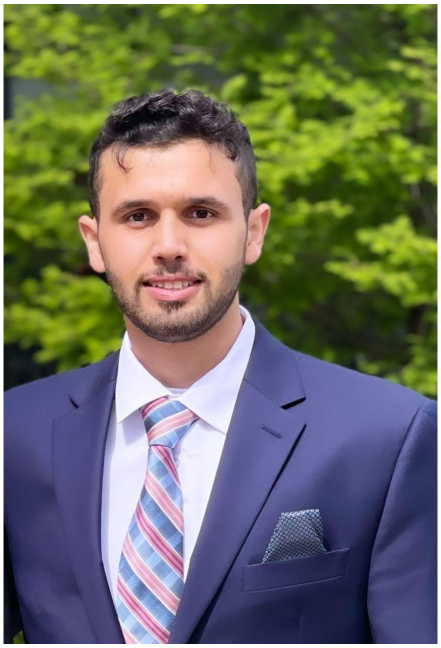
11.1.2 – Vision Statement

Edge Energy Consultants provides cutting-edge energy solutions for our clients to secure a safe and sustainable future.

11.1.3 – Biographies

Emma Eickert is a fifth-year Environmental Engineering student at the University of Cincinnati. She has completed three co-op rotations at Rumpke Waste and Recycling where she worked on landfill construction projects, water and air permitting, and internal environmental audits for a variety of Rumpke locations. She also spent two co-op rotations at Contech Engineered Solutions where she worked as a Stormwater Design Engineer Intern. There she sized and designed underground detention systems and hydrodynamic separators.

Bridgette Stegman is in her fifth year at the University of Cincinnati working towards a B.S. in Environmental Engineering. She has worked for Clear Consulting, Inc. for two full co-op rotations as well as working part-time during the school semesters. There, she worked primarily in wastewater consulting, involving data analysis, procedure writing, and programming. She then spent two semesters abroad working for Allianz SE in Munich, Germany where she worked in ESG as a research assistant. There, she spent much of her time working on climate models, and contributed to several published papers.



Haitham Alsubhi is a fifth-year Environmental Engineering student at the University of Cincinnati. He is from Oman and his first co-op was there as an environmental specialist at the Ministry of Environment and Climate Affairs. He was responsible for performing several analyses on the impacts of governmental projects towards the environment. Haitham worked for the Metropolitan Sewer District of Greater Cincinnati as an environmental compliance co-op. His primary responsibilities were stormwater, air, and discharge permitting. He also helped in providing CAD drawings for wastewater treatment plants and high rate treatment facilities.

Coulton Korosec is a fifth-year Environmental Engineering student at the University of Cincinnati. Born and raised in Cincinnati, OH, his first co-op was spent as a sustainability intern at historic Findlay Market. There, he launched a residential compost program along with expanded recyclable collection in conjunction with the Cincinnati Recycling & Reuse Hub. He spent his next two rotations as a solar project engineer for Moss and Associates Construction. After remediating and demobilizing a solar site near Tampa, FL, he worked on a new build from scratch, in Gainesville, FL. Here he did takeoffs, material delivery coordination, quality control, blueprint analysis comparing design specs vs what is realistically needed, and subsequent submittals.

11.1.4 – Resumes

BRIDGETTE STEGMAN

B.S. Environmental Engineering

Address: 131 Parker St. Cincinnati, Ohio 45219
Email: bridgettestegman@gmail.com
Birth Date: September 22, 1999
Phone: +1 (859) 468-4030

TRAINING/EDUCATION

- **University of Cincinnati** | Cincinnati, OH, USA — **AUG 2018-MAY 2023**
  Bachelor of Science in Environmental Engineering — **GPA: 3.769 / 4.00 (max)**
  Alpha Lambda Delta Honor Society

PROFESSIONAL EXPERIENCE

- **Hydrogen Cofiring Capstone - Project Manager** | University of Cincinnati | OH — **SEPT 2022 – PRESENT**
  - Planned and created initial design of a project retrofitting a natural gas turbine to cofire with hydrogen to reduce emissions at the University of Cincinnati Central Utility Plant.
  - Coordinated with turbine manufacturer, hydrogen suppliers, and other industry experts to make initial design.
  - Performed economic and environmental analysis of the lifecycle of the project.
- **ESG Research Assistant** | Allianz SE, Economic Research Dept. | Munich, Germany — **FEB 2022 – JUL 2022**
  - Wrote and published a paper on the rise of energy poverty in the European Union. Researched this topic, gathered data, and created a model to predict energy poverty levels in the EU due to rising oil and gas prices caused by the energy crisis.
  - Assisted the senior ESG economist in daily tasks, including gathering emissions and energy mix data for EU states and preparing models.
- **Engineering Intern** | Clear Consulting Inc. | Cincinnati, OH, USA — **APRIL 2020-PRESENT**
  - Consulted for companies within the wastewater industry. Worked as a contractor primarily for Metropolitan Sewer District of Greater Cincinnati with side projects for companies such as Dayton Water Reclamation Facility.
  - Improved efficiency in the data analysis sector by leading a team of 3 to create a program that would update visualizations for record processing productivity in a selected week.
  - Wrote detailed procedures on how to perform workplace tasks, often involving data analysis and technical skills.
  - Created a program robot to mass update records in MSD's work management app. Wrote a procedure to then update these records manually. Trained Level 1 interns on how to do this work.
  - Analyzed flow data post-installation to check for expected patterns and trends.
- **Sustainability Advocate** | UC Office of Sustainability | Cincinnati, OH, USA — **SEP 2019-PRESENT**
  - Promoted sustainability within the University of Cincinnati campus community by hosting university events to foster learning and engagement in students about sustainability topics.
- **Engineers Without Borders** | Cincinnati, OH and Nyambogo, Tanzania — **AUG 2018-DEC 2020**
  - Traveled to Tanzania to implement a latrine design in August 2019. Collaborated with team members during construction and used problem solving and engineering skills to refine the design.

SKILLS

-Microsoft Office (Excel, Word, PowerPoint)	-MATLAB	-Python
-Visual Basic for Applications	-LabVIEW	-GIS
-German (beginner)	-Spanish (conversational)	

PUBLICATIONS

- **Averting 'Gasmageddon' and securing a just transition** | Allianz SE | Munich, Germany — September 1, 2022
- **Back on the (climate) track** | Allianz SE | Munich, Germany — July 13, 2022
- **The great green renovation** | Allianz SE | Munich, Germany — June 2, 2022

Emma B. Eickert

2411 Moerlein Ave. Apt. 2, Cincinnati, OH 45219
(567) 201-3394 | eickereb@mail.uc.edu

EDUCATION

University of Cincinnati, Cincinnati, OH — **Class of 2023**
GPA 3.5/4.0

- BS Environmental Engineering
- Cincinnatus Scholarship

EXPERIENCE

Stormwater Design Engineering Co-op, Contech Engineered Solutions — **01/22 – 08/22**

- Responsible for Indiana as the Stormwater Design Engineer and point of contact for design purposes
- Designed and sized underground detention systems and hydrodynamic separators according to state and local regulations
- Utilized AutoCAD to create accurate system drawings to present to customers
- Value engineered alternative detention systems to bid against competing designs
- Trained new engineers on the process design of 3 Contech products
- Extracted relevant sanitary system information from various contractor site plans
- Reviewed drawings of full-time engineers sent to contractors for quality assurance

Engineering Intern, Rumpke Waste and Recycling — **01/20 – 07/21**

- Utilized AutoCAD Civil 3D to generate accrual for Pike Landfill future construction projects
- Managed all federal and state permit requirements for Pike Landfill
- Standardized Stormwater Pollution Prevention Plans for 30 Rumpke facilities
- Utilized Geographic Information Systems to stake locations for landfill gas wells
- Ensured compliance with groundwater, surface water, solid waste, air permits, and environmental best management practices for 25 facilities
- Coordinated landfill cell construction communications with contractors
- Performed internal environmental audits for 25 facilities for annual review
- Wrote reports for review by CEO, general counsel, area presidents, and site management

ACTIVITIES

College Mentors for Kids — **09/19 – Present**

- Form relationship with local elementary student to provide guidance
- Meet with the same student for two hours every week to build relationship and serve as role model

University of Cincinnati Sailing Club — **09/19 – Present**

- *Founder:* Collaborated with students, faculty and community; created constitution and bylaws; established professional website
- *Vice Commodore:* Coordinate recruitment, communicate with members, contact point for Cowan Lake Sailing Association

College of Engineering and Applied Science (CEAS) Ambassador — **04/19 – 05/20**

- Represents CEAS to prospective students by conducting tours

SKILLS

- Microsoft Excel
- AutoCAD Civil 3D
- Technical Writing
- GIS
- Laboratory Skills

Available for Full Time Position Fall 2023

HAITHAM ALSUBHI

134 William Howard Taft Road, APT5, Cincinnati, Ohio, 45219

alsubhha@mail.uc.edu | (513) 885 – 9297

Available for work May 2023

EDUCATION

University of Cincinnati, Cincinnati, Ohio — Class of 2023
Bachelor of Science, Environmental Engineering — GPA: 3.3/4.00

Abi Said Alkidamy High School, Alhamra, Oman — July 2017
High School Diploma — GPA: 3.8/4.00

WORK EXPERINCE

Co-Op, Metropolitan Sewer District of Greater Cincinnati, Cincinnati, United States
January 2022- August 2022

- Visited eight wastewater treatment plants to identify new pathways for stormwater pollution.
- Renewed Spill Prevention Control and Countermeasure plans for four treatment plants.
- Utilized CAD to model pollutant spills through sewer network to create NPDES, SPCC, and SWPPP permits.
- Collaborated with plant supervisors and reviewed NPDES permits for three treatment plants.
- Managed analysis of emissions for wastewater treatment plants and emergency generators.

Co-Op, Ministry of Environment and Climate Change, Muscat, Oman
January 2020 – April 2020

- Analyzed studies on seawater, groundwater, and other environmental projects to ensure compliance with government standards.
- Followed the government protocol and studied the impacts of the projects on the environment.
- Involved in daily meetings for over 100 environmental projects.
- Utilized Excel to compare air and water quality parameters to ensure compliance.
- Visited mines, factories, and oil companies and evaluated the compliance criteria.

EEP, University of Cincinnati, Cincinnati, United States
Fall 2020

- Worked on different types of programs. (AutoCAD, Revit, MATLAB, Excel)
- Enhanced communication skills through virtual meetings and programming competitions

SKILLS

Language: Fluent in Arabic

Software: C++, Python, MATLAB, LabView, VBA, Revit, AutoCAD, Advanced Excel, ArcGIS, EPANET, SWMM

AWARDS

- OSHA 10-hours class license — Fall 2022
- Dean's List, University of Cincinnati — Summer 2020 & Spring 2019

COULTON THOMAS KOROSEC

korosect@mail.uc.edu , (513)-213-7834, 9995 Jackson St. Camp Dennison, OH 45111
https://www.linkedin.com/in/coulton-korosec-470ab3194/

EDUCATION

University of Cincinnati, Cincinnati, OH — Expected: August 2023
Bachelor of Science: Environmental Engineering — GPA: 3.0 / 4.0
Dean's List Honoree: Spring 2020 through Spring 2021 — 3rd Year GPA: 3.7 / 4.0

EXPERIENCE

Project Engineer Intern, Moss & Associates, Tampa Bay, FL — January 2022 – August 2022
- Executed the rehabilitation and finalization of a 74.5 Mega Watt solar farm before starting up another.
- Orchestrated essential deliveries for site function including equipment maintenance, fuel, water, etc.
- Established a tracking software to measure and illustrate daily build progress on all levels.
- Centralized all site activity to one document, advancing the report to owners and head engineers.

Sustainability Intern, Findlay Market Corporation, Cincinnati, OH — May 2021 – August 2021
- Launched and streamlined composting program, doubling yield of the largest regional operation.
- Managed mass recycling drop-off in coordination with the Cincinnati Recycle and Re Use Hub.
- Planned out and laid groundwork for a solar array to offset a fraction of energy used by the kitchen.
- Devised subterranean aquifer allowing compost dirt to be utilized, saving costs on multiple fronts.

Upskill Experiential Program (EEP), University of Cincinnati — August 2020 – December 2020
- Researched extensively sustainability and ways to impact conservation on every level.
- Motivated to take advantage of lost co-op opportunity by pursuing online learning opportunities.
- Enrolled in courses to extend knowledge of skills pertinent to making a better-rounded engineer.

Engineers Without Borders, University of Cincinnati — February 2020 – Present
- Led tasks such as alternative analysis, troubleshooting spec performance, and analyzing topographic maps with GIS for water towers ensuring Roche, Tanzania can reliably pump clean water.
- Promoted self-sustainability by enabling an up-and-coming village to embrace available technology.

COMMUNITY INVOLVEMENT

UC Mountaineering Club, University of Cincinnati — February 2020– Present
- Transported up to three peers to club trips, responsible for safe timely pick up, arrival, and return.
- Orchestrated and executed weekend excursions open to any UC mountaineer interested.

Intermural Sports, University of Cincinnati — August 2018 – Present
- Coordinated team competitions and practices involving nine comrades plus opposition.

United Methodist Church, Cincinnati, OH — Lifetime Member
- Volunteered at shelter house, made kids passing through enjoy themselves and feel at home.
- Distributed meals to those in need during hard times alleviating holiday season stress.
- Organized weekly scheduled recreational basketball between fourteen members and non-members.

SKILLS

- Software Languages: GIS, AutoCAD, Python, MATLAB, Revit, R, Civil3D, Bluebeam.
- Proficient with engineering statistics and advanced Excel functions. Read/Write/Speak Spanish.

AVAILABLE SUMMER 2023

11.2 – Appendix 2 - Acknowledgements

The team of Edge Energy Consultants would like to thank the following individuals for their involvement in this project:

- Dr. Drew McAvoy, UC CEAS professor and the instructor for this capstone class, who provided us with support and guidance.
- Mike Hofmann, Head of University of Cincinnati Utility Plant and sponsor of this project, who supplied us with technical support, guidance in research, and industry contact information

11.3 – Appendix 3 - Request for Proposal

University of Cincinnati Environmental Engineering Senior Capstone RFP

Campus Hydrogen Utilization

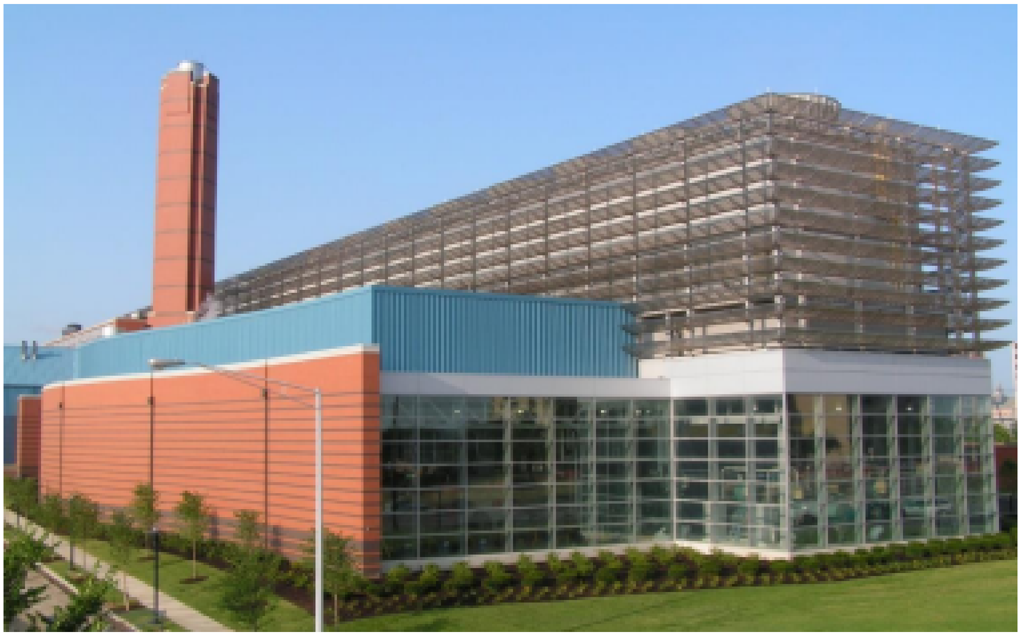
Sponsor: University of Cincinnati Utilities

Introduction

The University of Cincinnati is embarking on a journey to, over the course of time, reduce its carbon footprint, improve campus resiliency, and provide for more sustainable utilization of energy in all aspects of our community. The utilization of hydrogen blended with natural gas supply to utility plant production equipment will further reduce the dependency on fossil fuels on campus and promote renewable energy use in the surrounding area.

The Utilities Department at UC is responsible for reliable and economic supply of electricity and steam to all main campus buildings, including several hospitals that are located on uptown campus. Peak power demand on main campus currently exceeds fifty-five megawatts, with an average demand of over thirty megawatts. Steam peak demand exceeds 400,000 lbs/hour.

Approximately thirty percent of the power used on campus is obtained from the electric commodity market. The current expansion of University Hospital facilities coupled with the advent of electric vehicle utilization, and the projected increase in electric demand throughout campus coupled with a corresponding increase in steam demand will result in the need for additional renewable supply resources. This project would support expected future electric and steam demands on campus supplied by clean energy.



Project Description

As governments, countries, and companies establish their charters for achieving carbon reduction goals, they will all struggle with the “Energy Trilemma”: the need to balance affordable energy, maintain reliable power supply, and improve sustainability. Each will prioritize the elements of the trilemma differently, but the most effective way is a mix of generation resources that complement one another. The University of Cincinnati is no different.

The strategic deployment of renewables and natural gas power will enable UC’s campus to accelerate its near-term trajectory for addressing climate change while providing substantive reductions in greenhouse gas (GHG) emissions, while in parallel continuing to advance the technologies supporting reduced carbon steam and power production.

Hydrogen (H_2) is the most abundant substance in the known universe. It has been studied intensely and used industrially for decades. It’s the smallest, lightest element in the periodic table, and has both one of the highest gravimetric energy densities and lowest volumetric energy densities of gaseous fuels. Hydrogen is, scientifically, a well-understood element.

Despite this history and the interest in hydrogen as a method to help decarbonize the power generation sector, the use of hydrogen as an electric power generation fuel source remains in its infancy. The motivation to use hydrogen is clear because the combustion of H_2 results in zero emissions of carbon dioxide (CO_2). There are, however, environmental considerations associated with hydrogen combustion for power generation that necessitate further exploration. Hydrogen, as a carbon-neutral fuel, is a pre-combustion way to “decarbonize” a gas turbine.

Use of hydrogen as a gas turbine fuel has been demonstrated, but there are potentially significant variations between hydrogen and natural gas that must be identified and addressed before hydrogen can be used in a gas turbine correctly and safely.

Utilities at the University of Cincinnati employs two Solar Titan 130 Combustion Turbines to produce electricity to power campus, steam to heat campus, and to drive a twenty-two megawatt steam turbine. This equipment produces over 50% of the electricity used and 40% of the steam used on campus annually. In addition, through the combustion of natural gas, this equipment accounts for 85% of the Carbon footprint of UC's main campus.

The purpose of this project is to determine the feasibility of using hydrogen gas to displace, in part, the use of natural gas as a fuel source in the Solar Titan combustion turbines employed on campus. The application proposed must be economically justified on a long-term basis, as well as safely stored, transported, and utilized, while proving to be a feasible source of reliable energy to the University.

The design provided will have the potential to provide significant strategic opportunities to the University. These include:

- ➢ Reducing UC's carbon footprint by decreasing the environmental impact of the University's carbon emissions, making for a greener and more eco-friendly campus. Eco-friendly universities often see increased enrollment and greater interest levels across the student base.
- ➢ Identify and address environmental permitting and monitoring requirements.
- ➢ Providing greater exposure of renewable energy to students, faculty, and visitors, as well as neighboring communities.
- ➢ Seeking grants and tax incentives that may be available to help reduce the cost. For example, there are government programs available to schools that choose to install solar arrays.

Services Required

The project team will need to determine the efficacy of using hydrogen gas blended with natural gas to power the Solar Titan 130 Combustion Turbines in the Central Utility Plant on UC's main campus. The system must be: (1) economically feasible on a long-term basis, (2) meet environmental and permitting requirements, (3) safely stored, moved, and combusted, and (4) prove to be a reliable energy source to the University. An economical evaluation and a projected payback period are also required.

Fall Semester

Specific tasks include, but are not limited to, the following:

1. Conduct research on available green hydrogen supplies. This should include volumes

required and costs.

2. Conduct research on the most applicable and safe structure for hydrogen storage. This should include type of materials and a cost estimate.
3. Work with combustion turbine OEM (Solar Turbine) on the required physical and operational adjustments needed to burn a mixture of hydrogen and natural gas.
4. Investigate potential governmental incentives for installing safe hydrogen storage on campus.
5. Prepare a proposal report on key findings and the recommended options. 6. Provide a presentation to the Sponsor that covers the key findings and recommendations of the most appropriate option(s).

Spring Semester

Specific tasks include, but are not limited to, the following:

1. Develop design specifications for the recommended system.
2. Identify permitting requirements (environmental, regulatory, electrical, local/city building, etc.)
3. Conduct an environmental impact and economic cost analysis of the final system. This analysis should include a reduction in greenhouse gas emissions, as well as a determination of a payback period. The economic analysis should also include any pertinent governmental incentives.
4. Prepare a final report that includes the design specifications, an economic analysis, and an environmental impact analysis.
5. Provide an oral presentation on key findings at the end of the semester.

11.4 – Appendix 4 - Sample Calculations:

11.4.1 – Monthly Volume of Hydrogen Needed at the UC Central Utility Plant

The initial calculations needed for this project were the actual volume (or weight) of hydrogen needed for this project. The team decided to calculate the amount required on a monthly basis. From the article, "Environmental and Permitting Considerations for Decarbonizing with Hydrogen," from Power Magazine, "at 25% of the volumetric fuel blend, the hydrogen only contributes to about 10% of the fuel blend heating value [16]." Therefore, an increase in fuel volume is needed when hydrogen is blended in order to maintain the same heating value and produce the same amount of energy. Hydrogen has 40% of the heating capacity of natural gas, so this value was used as a basis for the volume calculations. Based on the data given to EEC by Mr. Mike Hofmann, the peak power demand in 2021 was about 9 million pounds of natural gas in one month. Using Equation 11.4.1, this correlates to a volume of just under 5×10^9 L of natural gas per month. Based on a 40% heating capacity of hydrogen compared to natural gas, it is determined that **3.57×10^9 L of hydrogen would be needed every month to achieve a 50% volumetric mix**. This is 3,570,000 cubic meters. Additionally, 3.57×10^9 L of natural gas would also be consumed.

Equation 11.4.1: Vol. total gas in SCF = (lbs natural gas)*(379.3 SCF/lb-mole)÷(MW of gas in lbs/lb-mole)

SCF = standard cubic feet

MW = molecular weight

Source: Cimarron Energy [17]

11.4.2 – Carbon Dioxide Emissions at Different Hydrogen Percentages

This section will include calculation of carbon dioxide. The equation that will be used to calculate all carbon dioxide emissions is:

CO2 Emissions (ton/year) = Amount of NG (lb of NG/month)
x Emission Factor (lb CO2 /MMBtu of NG)
x Rate of Combustion (MMBtu/ lb NG)
x Conversions

The corresponding values of the amount of NG gas that will be consumed are obtained from Table 2-2. Additionally, sample calculation of the amount of NG can be found in section 11.4.1 in this report.

The emission factor is provided on the U.S EPA website in the section of stationary gas turbines [15]. The emissions factor of CO_2 associated in the process of NG combustion is **(110 lb CO_2/ MMBtu NG)**

The rate of combustion values are provided by The Utility Plant Administration the monthly average rate for both turbines is **(92,000 MMBtu NG/ lb NG)**

The conversions associated with these calculations are **(12 months/year) * (ton / 2000 lb)**

For 0 % Hydrogen:

CO_2 Emissions = 9325542.6 x 110 x 92000 x 12 /2000

= 5.62 E+11 tons of CO_2/year

For 20 % Hydrogen:

CO_2 Emissions = 8465740.8 x 110 x 92000 x 12 /2000

= 5.10 E+11 tons of CO_2/year

For 50 % Hydrogen:

CO_2 Emissions = 6657952.4 x 110 x 92000 x 12 /2000

= 4.01 E+11 tons of CO_2/year

11.4.3 – Gray and Blue Hydrogen Monthly Cost Estimations

Approximate costs for gray and blue hydrogen were given by Air Products, those being $25 and $50 per 1,000 SCF (standard cubic feet) respectively. Since the volume calculations were already complete, calculating total monthly cost simply involved converting liters to SCF. The volumes at 20% and 50% were 1.13 billion and 3.57 billion L respectively. This translates to approximately 40 million and 126 million cubic feet. Therefore, the cost of blue and gray hydrogen were calculated by multiplying these volumes by the price given per SCF.

$$\$25 \times 39{,}900 \text{ thousand SCF} = \$998{,}000$$

$$\$25 \times 126{,}000 \text{ thousand SCF} = \$3{,}150{,}000$$

$$\$50 \times 39{,}900 \text{ thousand SCF} = \$2{,}000{,}000$$

$$\$50 \times 126{,}000 \text{ thousand SCF} = \$6{,}300{,}000$$