Implementing alternative, renewable energy sources for ground-based airport operations

April 2022

Design Challenge: Airport Environmental Interactions: Implementing alternative, renewable energy sources for ground-based airport operations

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Executive Summary

Decoupling carbon growth from market growth requires the development of cost-competitive and environmentally sustainable aviation fuels (SAFs). The jet fuel that is low-cost, clean-burning, and produces little soot can be made from renewable and wasted carbon. According to new research, aviation fuel could be produced by diluting aromatics with renewable Iso alkanes, then replacing them entirely with high-performance molecules that provide mission value to jet fuel consumers. This will save the billions of gallons of commercial jet fuel produced, and the threat its carbon emission produces to the environment. Iso-alkanes, cycloalkanes, and high-performance molecules are sourced from low-cost sources to make this fuel path work. Additional benefits can be gained by using waste carbon, such as cleaner water or less waste going to landfills when sourcing carbon from municipal solid waste or plastics in municipal recycling. The research will be most successful if it begins with the goal in mind. Jet fuel properties differ from gasoline and diesel.

This report introduces a system that can obtain and convert low-cost degradable wastes into usable fuels for the powering of airport vehicles, the airport environment, and producing gas for the ground running of aircraft. The system incorporates a high-level safety system to ensure the safety of the plant is an ideal airport environment. We interacted with, and surveyed many different industry experts in the aviation sector, including airport planners, former and present pilots, and Human Factors specialists. Others are Assistant Airport Manager at the Valkaria Airport and the Executive Director at Naples Airport Authority.

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Problem Statement and Background

This report aims to demonstrate how anaerobic digestion systems can be implemented sustainably and safely in an ideal airport environment to be used for ground-based operations. Every day, we experience the harmful effects of global warming. The Earth's average surface temperature has risen by about 0.8 degrees Celsius (1.4 degrees Fahrenheit) since the early twentieth century, with about two-thirds of that rise occurring since 1980. The warning from the climate system is unequivocal, and scientists are now more than 90% sure that human activities such as deforestation and the burning of fossil fuels are the primary cause. All major industrialized countries' national science academies have endorsed these findings. Because of the over-dependence on fossil fuels, there is still a long way before biogas focuses on a level playing field. Some of these fossil fuel systems lack sustainability in terms of high costs and environmental impact. Fossil fuel use has increased Earth's average surface and ocean temperatures since the late nineteenth century and is a major environmental problem. Sustainable energy has been introduced, which assists with this problem. The biogas system is the cheapest and safest sustainable energy source in an ideal airport environment. In the biogas system, anaerobic digestion systems are used and must be improved through innovation, optimization, and implementation strategies to become more environmentally friendly.

Over the past 15 years, the global production of biogas has gained considerable momentum, but there is a wide range in the development and number of plants in different countries. Whereas the biogas industry has flourished in countries such as Germany and China over the last decade, it is only now beginning to take off in other countries. In 2017, the world's biogas generation capacity was 16.9 GW, up from 6.7 GW in 2008 (Jerry, 2018). As the by-products of each process are used as the feedstock for the following process, integrated biogas systems are essentially zero-waste systems that make optimal use of nature to produce energy and nutrients. The most important criteria for a sustainable biogas system in a perfect airport environment, including economic, environmental, and social considerations, will be discussed first. For developing countries or countries with an emerging biogas sector, a series of case studies highlighting various integrated solutions implemented around the world will be presented, focusing on countries that are not reliant upon financial support.

Literature Review

Renewable Energy Resources for Airports - Biogas

Every sector is trying to implement environmentally-friendly measures to cope with global warming and habitat loss. Airports account for 2.5 percent of global greenhouse gas emissions (Huq et al. 2021) and have a greater responsibility for improving the airport environment (Wennberg, L., 2019). An enormous amount of aviation fuel is used for operating aircraft. Only 44 airports in the world are certified at the highest level of the Airport Carbon Accreditation (ACA) program (Wennberg, L., 2019). The solid waste produced by the airports is huge as the movement of people around the airport per day is high. Usually, all the waste produced through restaurants, toilets, and aircraft is diverted to sewage lines. Stachowiak et al. (2021) suggested that biomass can play significant energy generation as it is highly potential and renewable, especially lignocellulosic biomass. This biomass degrades biologically quickly under anaerobic conditions.

Tloczynski et al. (2020) surveyed the environmental protection plans at polish airports. The European Union has set a target for the aviation industry to reduce CO2 emissions by 75%, nitrogen oxides by 90%, and noise by 65% by 2050. Though there are many factors influencing pollution levels in airports, the degree of the pollution depends on the quality of equipment being used for airport operations. The measures implemented include solar panels, electric vehicles, sewage treatment plants, waste segregation, etc. Baxter et al. (2018) studied the waste management strategies and systems at Copenhagen Airport for seventeen years. The airport generates 140 tons of waste for one million passengers every year. Each aircraft movement contributed to 0.014 metric tons of waste at the airport. They have examined the types and the change in total waste annually. The airport has used various disposal mechanisms like incineration, landfill, and recycling techniques to deal with the waste produced. The separation of waste is the key factor that helped in managing the waste. The incineration is done on about 76.6 percent of the total annual waste produced at the airport. The total by-products of incineration are used as heat and power sources for the airport. Recyclable waste is used as building and construction material. Hazardous waste is incinerated at high temperatures before disposal. This ACRP project focused on document analysis and suggested a few ways to reduce waste production using reuse methods. The study was limited to ways of mitigating improper waste disposal.

Wennberg, L. (2019) reported Swedavia's long-term sustainability policy. Swedavia is a state-owned airport operator in Sweden. It has developed rules for operations and development to work as a climate-neutral company by adapting continuous environment assessment in its operations. This is achieved by managing environmental risks, using energy-efficient products, etc. It aims to reduce the global carbon dioxide emissions of 2005 to half by 2050. It has replaced heating of airport buildings with oil to biofuel, green electricity, and vehicles, renewable sekundol fuel for fire fighting exercises are major changes adopted by the operator. The key factors of the company are renewable fuel and less energy usage. Two of their ten airports have achieved zero-emission targets by 2019. The researcher also mentioned the advantages of biofuel, the significant being the renewability, identical to the jet A-1 fuel chemical composition. The drawback is that biofuel is being produced on a very small scale despite its benefits. Li et al. (2021) studied biogas fuel combustion and its characteristics. The researchers suggest increasing concern for fossil fuel combustion products all over the world. To implement biogas fuel there is a need to study the combustion characteristics and the effect of the composition of the fuel. The components of the fuel are methane, carbon dioxide, oxygen, and nitrogen. The test was carried out using different fuel composition ratios, at different initial pressure, temperature, and fuel-air equivalence ratio. The main pollutant exhausted by gas turbine engines is carbon monoxide, unburnt carbon-hydrogen, solid particles, and nitrogen oxides. The study suggests methods for reducing nitrogen oxides by shortening the residence time of gas and local high temperatures. The temperature and pressure differences act oppositely for nitrogen and carbon oxides. Achieving a zero pollutant is tricky, and there is a need to look into the effects of the pollutants on the environment.

Huq et al. (2021) studied new conversion technologies that are needed to process waste feedstocks and satisfy carbon reduction and cost requirements as demand for net-zero sustainable aviation fuels (SAF) grows. Waste that has been wet is a low-cost, widely used feedstock that has the potential to produce significant amounts of energy. Over 20% of US jet fuel consumption might be replaced; however, its complexity and high moisture content limit its use to methane. Anaerobic digestion produces energy, methanogenesis can be stopped during fermentation, and C_2 is produced instead. For catalytic upgrading to SAF from C_8 volatile fatty acids (VFA), the key cost drivers of the catalytic process were examined in a techno-economic analysis, and the minimum gasoline selling price was determined because of VFA production costs. According to the analysis, if food waste is redirected from landfills to avoid methane emissions, VFA-SAF might reduce greenhouse gas emissions by up to 165 percent compared to fossil jets.

Implementing biogas as aviation fuel or for powering airports is very rare. This is not an expensive step. Careful study of the structure of the airport, aircraft, and ground vehicles is necessary for planning to build a biogas plant. Biogas plants will be cost-effective and can be implemented in any airport and climate.

Comparisons Between Solar Power and Biogas

Airport terminal buildings consume more energy than other buildings in an airport due to their functional and operational characteristics (Yildiz, 2021). Ventilation, heating, and air conditioning systems have been substantial energy users in terminal buildings, contributing significantly to annual overall energy consumption, particularly in difficult regions. Therefore, the use of renewable energy resources is important. Airport energy consumptions are strongly correlated to the overall passenger number and flows (Xianliang, 2020). The features of airport energy use are stochastic, nonlinear, and dynamic and are influenced by various factors. In recent years, airport management has made significant efforts to align airport operations with environmental sustainability by limiting environmental effects, with one of their cornerstones being energy conservation and efficiency. Due to the numerous aspects and singularities involved, understanding energy usage and consumption behavior are critical in reducing energy consumption at airports (Alba, 2017). Many airports throughout the globe have built solar photovoltaic systems as part of their environmental sustainability goals to minimize their dependency on traditional fossil-based energy sources and alleviate the environmental effect of energy use. The use of solar photovoltaic systems at airports reduces carbon dioxide emissions.

One of the greatest threats to the air transport industry, and, specifically, the airport industry's ability to grow and operate in the future, is climate change (Preston, 2015). Due to this focus, the airport industry is confronting the impact of growing environmental pressure (Graham, 2014). Accordingly, there has been greater attention paid to the impact that airports have on the environment, and airports are working to make themselves more environmentally responsive (Vanker et al. 2013). Using Renewable Energy at Airports 3 To maintain operations and meet the needs of important stakeholders, airports require a consistent supply of power throughout the year. New renewable technologies such as solar and wind power can be used to assist meet the energy demands of airports (Hariprasad et al. 2017). The use of renewable energy resources has several advantages for airports. First, these systems tend to be low impact, and second, they provide an alternative source of power to operate the airport (Kramer, 2010). Renewable energy sources produce very little waste (Yerel and Yayli, 2016). Airports are extremely energy-consuming areas (Akyüz et al. 2017; Baxter et al. 2018; Ortega Alba and Manana, 2017). This is because of the large buildings that are equipped with heating and air-conditioning systems, the high-power demand for lighting and electric equipment, and the energy requirements from the many facilities located within the airport precinct (Cardona et al. 2006). Approximately 70% of the energy that is consumed in airport terminal buildings is utilized for air conditioning, cooling, and heat purposes. This rate can be higher in countries that have cold climates (Akyüz et al. 2017). To be able to undertake an airport's landside and airside activities, a certain amount of energy is required. The two key energy sources are electricity and fuel, such as diesel, natural gas, and propane (Ortega Alba and Manana, 2016). Electrical energy is typically sourced from various sources and is supplied directly to the airport through dedicated sub-stations (Janić, 2011).

Usually, airport electricity supplies are sourced from the commercial grid and are supplied by a power company (Ortega Alba and Manana, 2016, p. 349). With technological advancements, market maturity, and public-sector investment in renewable energy systems, renewable energy has become a more cost-effective commercial choice for airports (Barrett, 2015). Using Renewable Energy at Airports The quantity of power a solar PV system can generate at an airport is determined by the accessible area (Sukumaran and Sudhakar, 2017a), as well as the type of system, the system's orientation, and the available solar resource, or the amount of sunlight reaching the earth's surface (Kandt and Romero, 2014). One of the critical issues that need to be addressed in developing large-scale PV systems is an appropriate location: flat, secured from possible vandalism and thieves, and located near existing power lines (Wybo, 2013). Airports typically feature many open areas that might be used for the construction and operation of a PV system (Baek et al. 2016; Curran, 2016). The use of biogas can be another source of renewable energy for the airport. Unlike the solar-powered system, the biogas plant does not require enormous land. Biomethane gas can be produced in this plant from the organic waste from the airport and flights. Various other organic waste which can be used in this plant are wastes from the kitchen and possibly sewage. A good and high amount of electricity can be produced from these biogas plants, which would reduce the consumption of fossil fuels. Due to glare reflection, the usage of solar photovoltaic (PV) systems near airports can affect pilots, air traffic controllers, aircraft, and air navigation systems (Mostafa et al. 2016). The possible effects of a solar system's PV module reflectivity include glint and glare, as well as both. This could cause a momentary loss of vision, which could be dangerous for aircraft pilots (Anurag et al. 2017). As a result, glare caused by sunlight reflecting off the metal portions of a solar PV panel could pose a risk to flight safety (Mostafa et al. 2016).

There are several concerns about the impact of solar PV systems on wildlife, including whether the solar PV system structures and any associated human activity will disturb local wildlife to the point where Using Renewable Energy at Airports will avoid the area, and whether this will have a negative impact on the wildlife in the area (Baxter, 2021). The mirrored surfaces of the mirrors and solar panels may look to a flying bird as a body of water, according to the US Fish and Wildlife Service (2018). Insects, birds, and bats fly through the sunbeams generated by the solar PV system. According to Miller (2018) Insects, birds, and bats that fly between the solar beams generated by the solar PV system are ignited in mid-air, creating a plume of smoke or streamer, according to Miller (2018). These creatures may also perish because of the heat, the force of falling to the ground, or a predator lurking nearby (Miller, 2018). Furthermore, bird deaths and injuries caused by collisions with solar PV system mirrors and panels should be addressed while establishing a solar PV system (United States Fish and Wildlife Service, 2018). Currently, the biogas market is valued at around $24 billion and is estimated to reach $37.2 billion by 2028 (Fortune, 2021). Comparatively, the production of energy from a biogas plant is much easier, it does not require abundant land. These gas plants do not impact any wildlife.

Cost-Effectiveness of Sustainable Fuels

In Perspectives for Sustainable Aviation Biofuels in Brazil, Cortez et al. (2015) suggests that the aviation sector has set lofty targets for reducing carbon emissions in the coming decades. They also pushed for a plan that includes the use of sustainable biofuels to achieve environmental, social, and economic benefits. Brazilian conditions are excellent in their context, with developed agroindustry that produces automobile biofuel regularly, which is widely used by Brazilian road cars, and air transportation has been increasing at a rapid pace, with modern aviation business in place. Their review summarized the key findings and recommendations based on a comprehensive examination of the technological, economic, and sustainability obstacles and opportunities involved with the development of drop-in aviation biofuels in Brazil. Cortez et al. (2015) prepared eight workshops with the active participation of more than 30 stakeholders encompassing the private sector, government institutions, NGOs, and academia. Cortez et al.’s main outcome was a set of guidelines for establishing a new biofuels industry, including recommendations for

(a) “Filling the identified research and development knowledge gaps in the production of sustainable feedstock”. Cortez et al. (2015)

(b) “Overcoming the barriers in conversion technology, including scaling-up issues”. Cortez et al. (2015)

(c) “Promoting greater involvement and interaction between private and government stakeholders, and

(d) Creating a national strategy to promote the development of aviation biofuels”. Cortez et al. (2015)

The study also suggest that only Brasilia International Airport (6%) relies on tanker trucks from a refinery 700 kilometers distant for its jet fuel, unlike the other 12 major airports in Brazil (which account for 85% of the country's jet fuel usage). As a result, a terminal near the appropriate airport and suppliers is the best solution for completing the biofuel, producing the blend, and issuing a quality certificate for each batch of jet biofuel. Contrarily, however, an airport like Brasilia, which uses about 0.5 million cubic meters of jet fuel annually, is far from any refineries but nearby production facilities for raw materials for jet fuel and could benefit economically if the “drop-in” point was nearby. The gasification and gas cleaning processes, which are not optimized for the Brazilian biomass, are the major development gaps in this path.

In estimating cost savings for aviation fuel and CO_2 emission reduction strategies, (Johnson & Gonzalez, 2013) argued achieving reductions in aviation greenhouse gas emissions while growing the aviation industry is both a national and a global challenge. Their paper discusses and summarizes the suggestions for reducing emissions and the short-term and long-term emissions goals for three aviation industry groups, the European Union, United States aviation regulatory agencies, and the United Nations specialized agency for civil aviation. They implied that reducing fuel consumption affects an air carrier's bottom line by reducing fuel costs and carbon emissions. Investments may be required in aircraft or procedural changes to reduce demand for fuel by reducing consumption while still providing the same level of air service. They claimed in their study that investing in reducing fuel consumption is important to comply with any emission trading scheme and will also become a major factor for survival in the present competitive air transportation market. The researchers used a general method to estimate cost savings that presents a comparison method independent of the specific type of fuel reduction method. Their method used the percentage of fuel reduced to analyze cost savings using a range of fuel prices and a non-discounted payback period. They claimed analysts use this method for calculating the savings specific methods of reducing fuel consumption. Fuel consumption reduction percentages of 3 percent, 4 percent, and 5 percent were used to illustrate this strategy for the sake of convenience. Changes in fuel consumption or decreased percentages were made to this procedure to meet the objectives of specific investment analysis. In addition to not accounting for non-capital expenses like equipment changes, ground costs for adding a stop, and any adverse maintenance events, this method failed to account for the time value of money, tax, or other financing considerations. It also failed to account for future fuel and carbon costs, nor does it identify capital expenditures like aircraft modifications or fleet changes.

Johnson and Gonzalez (2013) suggest that when gasoline prices are high, it is more cost-effective to make investments to minimize usage. Fuel savings account for a larger portion of the savings than the cost of emissions at current pricing. Carbon credits will have a greater impact on reducing the payback period if the price of carbon credits skyrockets. Based on their calculations, the price of fuel per gallon is added to the price of carbon credits per gallon, which is determined by how much fuel is used. The cost of fuel is substantially larger than the cost of carbon credit, so the percentage of fuel saved has a significant impact on the return. Unfortunately, their technique does not consider the cost of capital, depreciation, or the tax benefits of investments; therefore, these can be either capital investments or operational expenses. They also stated that cutting back on gas consumption is an excellent way to cut emissions because the EU ETS factors in fuel consumption when estimating carbon emissions. Their study observed that it's a win-win situation for both the bottom line and the environment because reducing fuel consumption lowers fuel costs and reduces carbon emissions, hence, the need for biogas exploitation.

In a review of the methanol economy, Liso et al. (2020) showed promise in the fight against global warming for the use of methanol as a renewable energy source. There was a special focus on fuel cells as a means of obtaining and using methanol inefficient energy systems for a net zero-emission carbon cycle. Methanol and a fuel cell perspective on the carbon cycle were examined by the researchers, and according to their research, there has been significant progress in methanol's renewable production and utilization technology in the last few years. The research discovered, that although it is still in its infancy, it is an excellent liquid electro fuel for the transition to a sustainable economy. Furthermore, Liso et al. (2020) found that by converting CO_2 into liquid fuels, the harmful effects of CO_2 emissions from existing industries that still rely on fossil fuels are reduced. Hence, methanol can be used both in the energy sector and the chemical industry and become an all-around substitute for petroleum. The scope of their review was to put together the different aspects of methanol as an energy carrier of the future, with a particular focus on its renewable production and its use in high-temperature polymer electrolyte fuel cells (HT-PEMFCs) via methanol steam reforming.

Some see the cost not based on money but on fossil fuel's impact on the environment. In Sustainable Aviation—Hydrogen Is the Future, Yusaf et al. (2022) discovered that renewable fuels and hydrogen are emerging as potential saviors for environmentally polluting industries like aviation as the global search for new methods of combating global warming and climate change continues, of which the aviation industry's current goal is sustainable aviation. Their study observed that there is increasing interest in achieving carbon-neutral flight to combat global warming. According to their research, hydrogen has proven to be a suitable alternative fuel. Yusaf et al. (2022) saw the importance of hydrogen as a more economically sustainable fuel because it is abundant, clean, and produces no carbon emissions, but only water after use, which has the potential to cool the environment. Their paper traces the historical growth and future of the aviation and aerospace industry.

Yusaf et al. (2022) examined how hydrogen can be used in the air and on the ground to lower the aviation industry's impact on the environment. In addition, while aircraft are an essential part of the aviation industry, other support services add to the overall impact on the environment. Hydrogen can be used to fuel the energy needs of these services. However, for hydrogen technology to be accepted and implemented, other issues such as government policy, education, and employability must be addressed. Improvement in the performance and emissions of hydrogen as an alternative source of energy and fuel has grown in the last decade. Hydrogen, on the other hand, faces several challenges that must be overcome before it can be widely used. Renewable energy and hydrogen roadmaps from the international community can serve as a long-term blueprint for the development of alternative energy. This information will be shared so the private and public sectors can adjust their plans accordingly.

While other researchers looked closely at biofuels, Rixhon et al. (2021) researched wind and solar energies which presents a time and space disparity that generally leads to a mismatch between the demand and the supply. In their study, one of the main challenges is the storage and transport of these energies to harvest their maximum potential. Based on their research, this challenge can be tackled by electro fuels, such as hydrogen, methane, and methanol. According to Rixhon et al. (2021), they offer three main advantages, which include compatibility with existing distribution networks or technologies of conversion, economical storage solution for high capacity, and the ability to couple sectors (i.e., electricity to transport, to heat, or industry). However, the level of contribution of electric-energy carriers is unknown. To assess their role in the future, we used whole-energy system modeling to study the case of Belgium in 2050 (Rixhon et al. 2021).

It was observed in their report that they have a multi-energy and multi-sectoral approach, which reduces the overall system's costs and emissions by optimizing its design. To represent the future energy system as accurately as possible, such a model relies on numerous parameters (e.g., natural gas price, heat pump efficiency, etc.). On the other hand, these variables can be extremely unreliable, especially when used for long-term strategy. Consequently, their study employs the polynomial chaos expansion method to incorporate a global sensitivity analysis to highlight the influence of the parameters on the total cost of the system. Compared to the deterministic cost-optimum situation, the system cost, accounting for uncertainties (up to 17 percent higher and twice more uncertain at carbon neutrality), electro fuels are a major contributor to the uncertainty (up to 53% in the variation of costs) because of their importance in the energy system and their high uncertainties, their higher price, and uncertainty.

Problem Solving Approach and System Design

We are concentrating on developing an alternate energy source for fossil fuel usage in ground operations. Various renewable and clean energy sources exist, such as solar, wind, and hydro. These have many restrictions regarding the climatic and geographical conditions required for their operation. Our motive is to find a source that can be implemented in most climatic and geographical conditions; the best fit is the biogas plants. A biogas plant can be constructed underground quickly with reasonable costs. Gas is one of the cleanest fuels and can be used to generate electricity. This electricity can be continuously generated as the raw material used to produce the biogas will be the food waste from the airport. After properly treating them, these can be obtained from terminals, flight kitchens, and administrative offices.

Task Analysis

The task flow of the biogas electric generator we are proposing is quite simple and also has alternative usage and storage. The food waste will be collected from the airports and segregated to remove non-biodegradable waste such as plastic and foam by boiling in water to 30-40 degrees celsius. The biodegradable waste is transferred to the digester tank for digestion by the bacteria anaerobically. The anaerobic digestion releases methane gas that can be used under high pressure for generating electricity or as fuel for cooking or running small appliances. The excess gas can also be stored in storage tanks for later usage. The digestion process leaves a solid waste residue that can be used as a cheaper and better alternative as a fertilizer for plants.

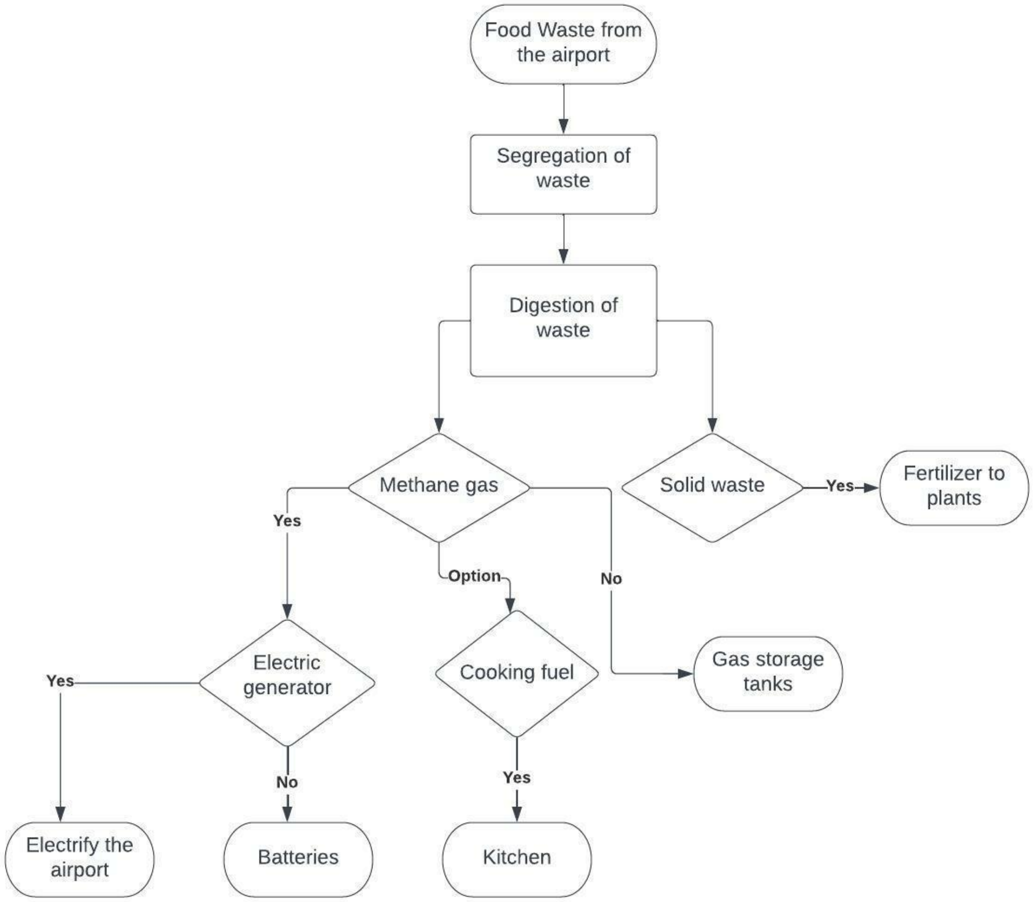

Figure 1: *Task Analysis of Biogas Digester*

Error Analysis

Every process is subject to errors. We have identified risks and errors that might arise during the process flow designed for our project and came up with the solutions to mitigate the errors in Table 1.

Table 1

Error Analysis of Biogas Digester

Process flow step	Potential errors	Potential effects	Recommendations for process changes
1. Collection of	The tendency to	There would be a	Proper planning of the

wastes from approved sewage lines	obtain wastes from unapproved sources.	mixture of necessary and unnecessary wastes, which could make the plant unable to function to its full capacity.	construction of the sewage lines directed towards the inlet of the biogas plant and segregation of waste.
2. Segregation of wastes into biodegradable and non-biodegradable	Difficulty in identifying biodegradable versus non-biodegradable wastes.	This will harm the airport environment since non-biodegradable wastes cannot be easily broken down.	1. There should be a mechanism to segregate wastes 2. Safety culture must be built to separate wastes from the point of collection so that the workload associated with the segregation of biodegradable versus non-biodegradable is reduced to the nearest minimum.
4. Digestion process	Air may enter through with the waste and hinder the digestion process	Hazard of explosion when the air reaches 10-30% in the tank.	High-quality air seals should be used to build the digester tanks. Maintain and inspect the seals regularly
5.2 Biogas energy derived is used to run the turbines of electric generators	There could be a possibility of gas leakages in the gas pipes that will transfer the energy derived from the plant.	If there are gas pipe leakages, Biogas, in combination with air, can form an explosive gas mixture that can result in an explosion in a confined space near an ignition source.	1. The biogas plant should be done with high-pressure materials. This is to reduce the potential of leakage. 2. Further to 1, the compartment that houses the pipe must be airproof, to prevent air-gas interaction which can lead to an explosion. 3. Periodic scheduled maintenance should be carried out on the plant to check for wear and tear of components.
5.2.1 The generated electricity is sent to the power station	Poor siting and insulation of electrical cables.	Underground cables are normally used to transfer electric power generated from the plant. Hence, there could be a risk of electrocution.	1. High-quality insulating devices should be used and inspected at regular intervals. 2. Armored cables should be routed in such a manner that will not pose a hazard to the airport environment. 3. These cables should be

			routed away from fuel lines. 4. The cables should be routed away from water lines to avoid water contamination and possible electrocution.
5.2.2 The electricity is modified to the required voltage and amps	The hazard of voltage surge and fluctuations.	The Equipment and vehicles using the electricity will be damaged.	1. Implementing standard procedures in power conversions. 2. Standard calibrated instruments to monitor the power output.

Heuristic Evaluation

The design being proposed is evaluated heuristically to improve efficiency and productivity and is represented in the following table 2:

Table 2

Heuristic Evaluation of Biogas Digester

6 usability categories	Category criteria/ content	Comments
Design Efficiency	Does it work efficiently? Does it produce biogas as expected? Is it possible to continuously convert and generate the electricity to the required amount and standard power output?	● Operates without faults and leaks ● The amount of output is significant enough to generate electricity. ● The amount and the pressure of the gas transferred to the generator is efficient in generating electricity.

Supportability	Can we perform maintenance of the product without causing hazards to personnel and the environment? Are there any automatic shut-off valves and switches in case of emergencies?	• Enough space and equipment for the maintenance and operating personnel are available. • Automatic shut-off at required locations such as digester inlet and outlet valves when near to full capacity, generator failure, auto switch off the generator when storage batteries are full.
Engaging	What social, environmental, and economic impacts do this implementation have on the surrounding areas? How does the community affect the operations of this implementation?	• Does Social: airport gain a "green" reputation? Env: methane has a strong odor and is a greenhouse gas Economic: the initial cost of production is offset by long-term savings • Community can either agree/support because of the change to biogas but can oppose it due to the smell and negative effects of methane
Accuracy	Do it feed a sufficient amount of electricity to the airport?	• It reduces the electricity bills and fossil fuel usage for ground operations.

Prototype

We have conducted an experiment to explain the process of biogas generation shown in Figure 2. The experiment is a representative model to explain the process. All safety precautions have been taken while performing it. The kitchen waste is taken and left to anaerobically (without oxygen) decompose in an air-sealed container for 72 hours. When it decomposes the bacteria releases the biogas composed mostly of methane and carbon dioxide. Biogas methane is a clean fuel and produces a blue flame. This property of combustibility is tested during the experiment. This gas can be used by internal combustion engines to convert the mechanical energy from the engine into electrical energy. The plant will be modeled according to FAA AC_150_5070-6B and NEPA considerations with the airport planners.

Figure 2: *Prototype* - Kitchen waste is transferred to an air-tight container and decomposed to collect the methane gas, and the gas burns to produce a blue flame.

Figure 3 illustrates an example of a biogas plant we are proposing to generate. Biogas electricity generation can be possible with fuel cells, but that process would be costly as it requires high-quality fuel cells and cleaner gas. With a common electric generator, the costs can be reduced to a significant level when used at high compression rates.

1. The food waste is collected and transferred to the digester through the inlet.

2. The digester is air-tight and the anaerobic bacteria such as methanobactin present in the food waste decompose the waste and release methane biogas and carbon dioxide.
3. The outlet is connected to a machine to remove sulfides from the biogas.
4. The biogas is then transferred to the high compression engine to convert it to mechanical energy to drive the electric generator to generate electricity.
5. The electricity is rectified to standard measures and fed to the electric lines or to the batteries for storage. The excess biogas is stored in the storage tanks as a buffer for two days.
6. 0.4 m^3 (400 liters) of gas is produced per kilogram of biodegradable material. In an hour, gas lights use around 0.1m^3 (100 liters) of gas.
7. The gas can also be utilized to cook food in the airport kitchen or in the room and water heaters.
8. The remaining solid waste can be sold to farms and nurseries as a fertilizer at lower costs than the expensive commercial fertilizers.

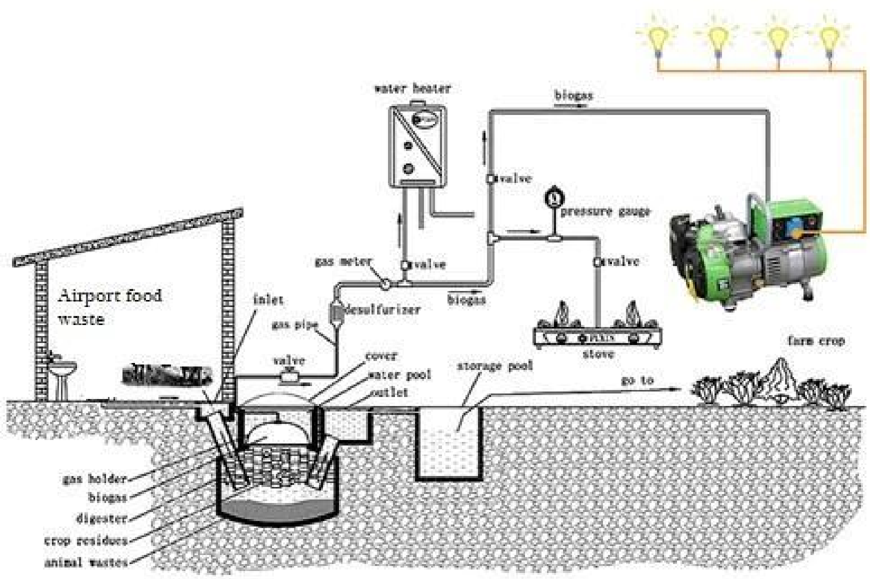

Figure 3: *Illustration of energy generation by a biogas plant (Energypedia, 2022)*

To evaluate the project on a practical level, we have decided to implement the plant in the Orlando Melbourne International Airport initially. Figure 4 shows the layout of the airport. The red stars indicate the possible locations for constructing the biogas plant. The considerations for selecting a location are taken from the risk assessment made. The location will be in an isolated place in the airport, but easy to transport the waste and electricity between the plant and the main operating area of the airport without hindering the main operations of the airport.

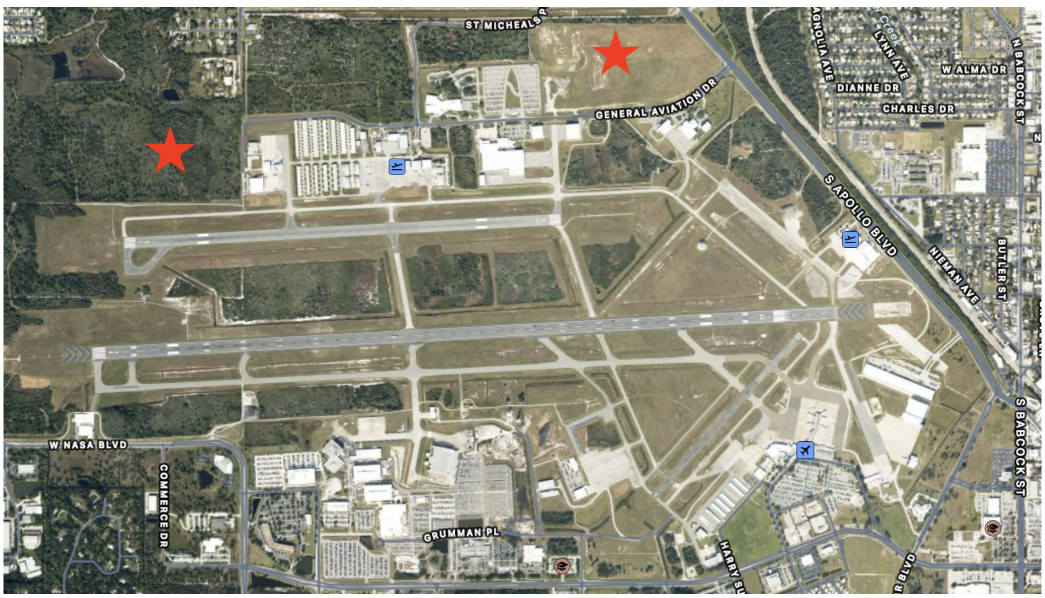

Figure 4: *MLB Airport Layout,* Stars indicate optimal locations for biogas plant implementation

Storyboard

The storyboard, Figure 5, describes the event of the building of a biogas plant and how that would reduce the costs and benefits of the airport.

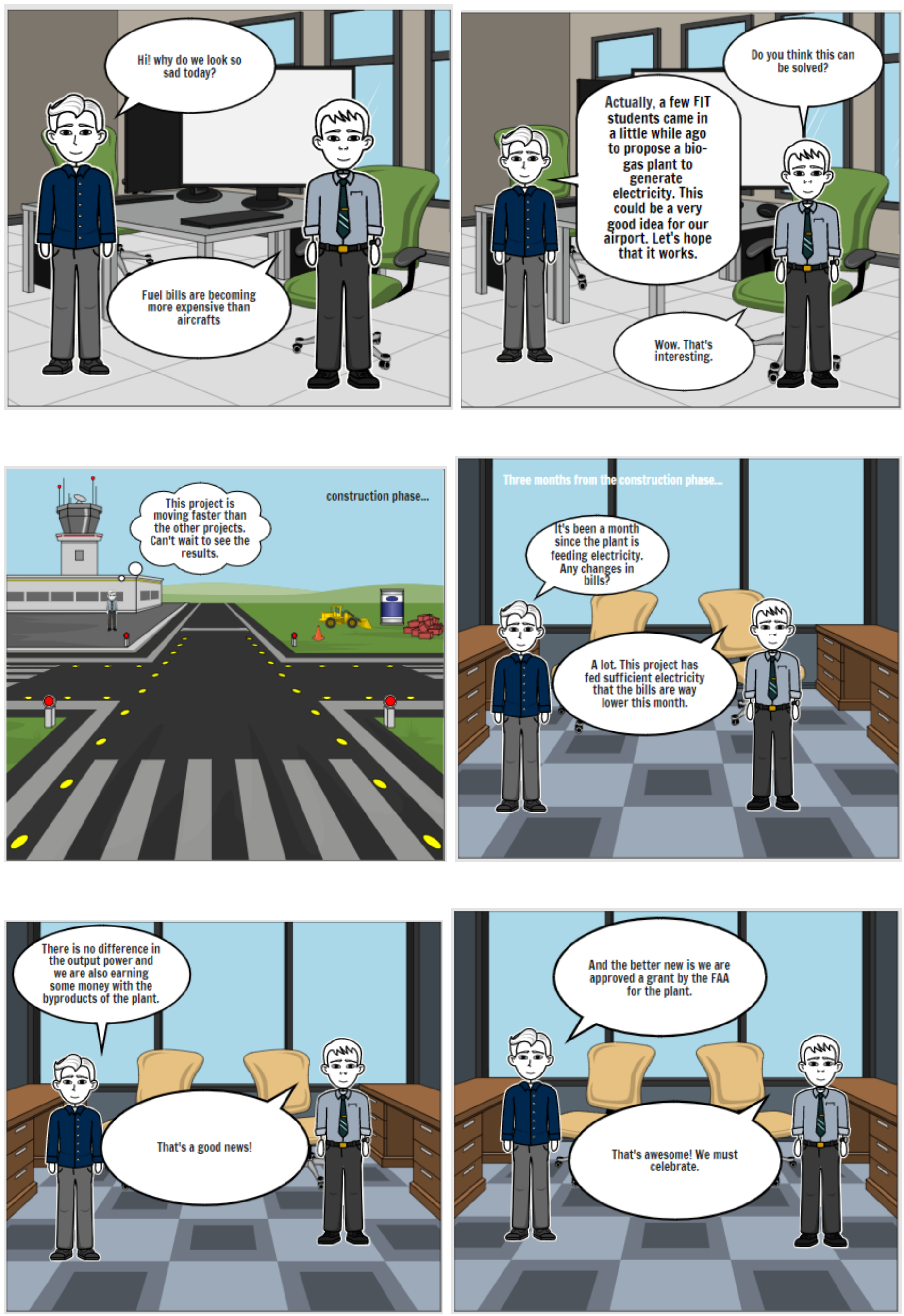

Figure 5: *Storyboard*

Safety Risk Assessment

Safety is inevitable, and no strategy can completely ensure safety. On the other hand, safety culture plays a vital role in ensuring the implementation of safety management systems in an organization. ICAO has created four elements for the safety management system: safety policies and objectives, safety risk management, safety promotion, and safety assurance.

For implementing our project, a few changes in the policies should be made to accommodate a new project. Safety risk management includes risk identification, assessment, and mitigation strategies. There should be continuous monitoring and improvement in the risk mitigation strategies as risks are dynamic. This can be achieved easily by following the FAA guidelines, and the potential risks that should be managed to reduce hazards are discussed in the following paragraphs.

According to the article, industrial food waste consists of 68% methane, 26% carbon dioxide, 6% H_2O, and about 290ppm of hydrogen sulfide. The biogas produced through this matter will have methane (50-75%), carbon dioxide (25-50%), water (H2O), hydrogen sulfide (H2S), nitrogen (N2), oxygen (O2), ammonia (NH3), and organo-halogenated, siloxanes (biogas world). These are a few risks directly associated with the product. The risk levels are indicated in Table 3.

High risk
Medium risk
Low risk

Table 3

Safety Risk Assessment

Type of Risk	Assessing Risk	Mitigation method
Fire and explosion	Gas leak, creation of an explosive zone, welding, clogged or frozen pipes, or others.	the isolated location, plant underground, and high-quality sealants and equipment.
Electric Short circuit	Fire hazard	High-quality insulation, routing away from flammable materials and water lines.
Corrosion	The water, CO_2, and H_2S make the biogas corrosive. The corrosion reduces productivity and can become hazardous in the long run.	Corrosion-resistant materials and coating, timely maintenance, and replacing of the equipment.
Confined space	Hazard to personnel working.	Ventilation and oxygen masks in emergencies.
Gas leaks and poisoning	Hazard to personnel and environment	Isolated location, masks for personnel, high-quality sealants, and their proper maintenance.

Industry Interactions

In an interview with an FAA safety specialist at the Florida Institute of Technology, he stated the feasibility of the project and its importance to an ideal airport environment. Furthermore, he mentioned its cost-effectiveness and how it reduces the danger of carbon monoxide emissions in an ideal airport environment. Also, he stated the need for more safety considerations because the biogas plant stores compressed flammable gasses, which can be explosive in nature, and when it interacts with oxygen, there could be a risk of fire. He also stated that there could be human exposure to biohazards, and biogas plants emit a bad odor. He did not leave us without solutions to these problems. He advised of the use of underground reservoirs and wiring and an ideal fire prevention system at the plant site. Finally, he came up with ideas of checklists on what to do in the event of pump failures and pipe leaks.

We interacted with the Airport Director at Naples Airport on Zoom conferencing. He agreed that this is a feasible idea in an ideal airport. He said because it is being implemented in India and the UK, then it is very feasible in the United States, but based on the regulations and policies in the United States regarding waste, there have to be some processes to be followed and gaps to be filled before it can be implemented.

We further sent a detailed questionnaire to an Airport Planner at Syracuse Regional Airport Authority & Syracuse Hancock International Airport. Elected Working Group Member - American Association of Airport Executives. Ground Service Equipment is known to be one of the airport's biggest emitters, which entirely depends on the facility you propose. This could be compact or require a lot of space. He told us we could scale our project from one airport to the central facility for multiple airports in the area, which proposes that the plant be placed as far as it can be from the terminal and any manned areas on the airport. He told us that crops can be used as part of the waste and can be grown in the airport environment, but it depends on the height the crops grow to. He also said that the biogas plant should not be a problem. Airports are currently big emitters of emissions, he said, and airports have now taken important steps to be environmentally sustainable by reducing emissions - of which one key path is the project we are undertaking. This offers Sustainable Aviation Fuel, and more environmentally de-icing programs, reducing airport emissions. He said that biogas plants are safe to operate at airports as long as the plant does not infringe on the Part 77 surfaces. On the need for this plant at the airports, he told us that there is no existing infrastructure at most airports for the manufacturing of renewable energy hence, we would essentially have to do this as a part of the Design, Planning, and Engineering of the project because most airports currently do not have one. Lastly, he said we would have to propose a roadmap to attract potential customers with no impending problems and hurdles that pertain to this project, which would be to get a FONSI from the FAA's ADO as regards Part 77 Obstruction Analysis, Building Restriction Line, Environmental Analysis.

Projected Impact and Conclusions

The implementation of a biogas digester has many impacts. Overall, this system shows an advancement of the airport in numerous ways. From directly mitigating negative on the environment to utilizing a renewable source of energy, the outcomes of using a system like this are endless and provide benefits in the long term.

Airports all over the world can learn from this and implement their own biogas or other renewable power sources at their location. Larger airports have the opportunity to utilize more waste and produce larger amounts of fuel for power. This advances the aviation industry in many ways and establishes a basis of green operations, which other airports and similar industries can grow from and further advance themselves. The changes in safety culture are minimal and require the proper use, training, and maintenance to uphold.

Cost and Benefit Analysis

A cost and benefit analysis is necessary when implementing any sort of project investment. The implementation of a biogas digester at any airport would require a cost and benefit analysis to determine the ultimate worth and effect of such a project. As important factors include finances, environmental and operational impacts, and reputational changes, it is crucial to weigh all costs and benefits involved in the project.

Cost Assessment

Stage 1: Alpha Phase

The Alpha stage of this project involves the research and development of the design. This stage took about four months and was completed by our team. It includes the cost of labor for both the students and faculty involved, which totals $4,250 given in table 4.

Table 4

Initial Stage Costs - Research and Development

Alpha Phase: Initial Stage Costs				
ITEM	RATE	QUANTITY	SUBTOTAL	REMARKS
LABOR: Research and Idea Development for ACRP University Design Competition				
Student	$20/hr	200 hrs	$4,000	4 Graduate Research Students - 50hrs each
Faculty	$75/hr	30 hrs	$2,250	Faculty Advisor
Subtotal			$6,250	

Stage 2: Beta Phase

The Beta phase includes the actual development and the testing of the project. This stage is planned to take about six months and incorporates all products, materials, and labor that are involved throughout the development of the project, as well as all on-site planning and construction up until the system is ready to be used by the airport given in table 5.

Table 5

Stage 2 Costs - Development and Testing

Beta Phase: Stage 2 Costs				
ITEM	RATE	QUANTITY	SUBTOTAL	REMARKS
LABOR: Design Development and Testing				
Student	$20/hr	200 hrs	$4,000	4 Graduate Research Students - 50 hrs each
Faculty	$50/hr	15 hrs	$750	Faculty Advisor
Civil Engineer	$30/hr	200 hrs	$4,500	4 Civil Engineers - 50 hrs each
Airport Planner	$30/hr	50 hrs	$1,500	2 Airport Planners - 25 hrs each
MATERIALS				
Biowaste Storage Building	$30,000	1	$30,000	14' Drum Hazmat Storage Building
Biogas Storage Container	$30,000	1	$30,000	5,000 Gal. ASTM Double Wall Tank
Anaerobic Digestion Tank	$500,000	1	$500,000	All digestion processes will take place within this tank
Subtotal			$570,750	

Stage 3: Product Implementation

Table 6 describes the final stage involved in this design product implementation. This includes physically integrating the biogas system into airport operations, specifically Melbourne Orlando International Airport for this case. This process is planned to take about three months and will incorporate all training, onboarding, and integration of the new process into the airports' previous way of operations.

Table 6

Cost Analysis of Implementation and Onboarding

Cost Analysis of System Implementation and Onboarding				
ITEM	RATE	QUANTITY	SUBTOTAL	REMARKS
LABOR: Implementation and Onboarding				
Student	$30/hr	60	$1,500	4 Graduate Research Students - 15 hrs each
Faculty	$50/hr	10	$500	Faculty Advisor
Trainer	$50/hr	20	$1,000	Proper Operations Training for New/Former Employees
Civil Engineer	$30/hr	50	$1,500	4 Civil Engineers - 15 hrs each
Airport Planner	$30/hr	20	$600	2 Airport Planners - 10 hrs each
Subtotal			$5,100	

Benefit Analysis

There are many benefits to implementing a biogas digester at an airport. From environmental to social, the integration of such a system at an airport can impact all areas of operations and change how the airport is perceived from many perspectives. Shown in table 7 are a number of potential environmental, operational, social, and economic benefits that can arise from the implementation of a biogas digester.

Table 7

Benefit Analysis

Benefit Analysis	
Benefit	**Description**
Environmental Benefits	1) Biogas is a renewable source of energy. 2) Removing the abundance of biowaste from the environment prevents nitrogen pollution and runoff into water. 3) Helps to mitigate methane emissions that would have entered the atmosphere through landfills and other waste-disposal properties.
Operational Benefits	1) Creates a cycle where airport waste can consistently be used to power operations. 2) Contributes to a constantly advancing industry. 3) Creates jobs for necessary personnel.
Social Benefits	1) Establishes a "green" reputation for the airport. 2) Can draw attention, increasing overall operations.
Economic Benefits	1) Long-term savings outweighs initial cost of product implementation.

Conclusion and Future Developments

Overall, there are many things to consider when implementing a biogas plant. After conducting research, weighing out the costs and benefits, and establishing a design plan, it is easy to see the purpose and benefits of converting non-renewable sources of energy to sustainable sources. As this proposal is specific to Melbourne Orlando International Airport, other airports will most likely require a different size, location, and cost/benefit analysis for their specific operational needs.

Appendices

Appendix A: List of Complete Contact Information

Team Member	Permanent Address	Email	Fax Number (if applicable)	Phone Number
Team Member- Navya Nikhita Agasam	Florida Institute of Technology College of Aeronautics 150 West University Blvd. Melbourne, FL 32901	nagasam2021@my.fit.edu	-	
Team Member- Alfa Ekele	Florida Institute of Technology College of Aeronautics 150 West University Blvd. Melbourne, FL 32901	aekele2020@my.fit.edu	-	
Team Member- Hope Ann Erlwein	Florida Institute of Technology College of Aeronautics	herlwein2018@my.fit.edu	-	

	150 West University Blvd. Melbourne, FL 32901			
Team Member- Tejas Krsn Rachur	Florida Institute of Technology College of Aeronautics 150 West University Blvd. Melbourne, FL 32901	trachur2021@my.fit.edu	-	
Advisor Name – Dr. Debbie Carstens	Florida Institute of Technology College of Aeronautics 150 West University Blvd. Melbourne, FL 32901	carstens@fit.edu		

Appendix B: Description of the University

With our focus on student success, Florida Institute of Technology's mission is to provide high-quality educational experiences to a culturally diverse student body in order to prepare them for entering the global workforce, seeking higher-education opportunities and serving within their communities. The university also seeks to further knowledge through basic and applied research and to serve the diverse economic, cultural, and societal needs of our local, state, national and international constituencies. In support of this mission, we are committed to:

-Fostering and sustaining a productive institutional culture of assessment leading to the continuous improvement of academic and administrative programs in order to promote student development;

-Developing an organizational culture that values and encourages intellectual curiosity, a sense of belonging and shared purpose among faculty, students and staff, and pursuit of excellence in all endeavors;

-Recruiting and developing faculty who are internationally recognized as educators, scholars and researchers;

-Achieving recognition as an effective, innovative, technology-focused educational and research institution;

-Recruiting and retaining an excellent, highly selective and culturally diverse student body;

-Continually improving the quality of campus life for members of the university community;

-Providing personal and career growth opportunities for both traditional and nontraditional students and members of the faculty and staff, including those who avail themselves of Florida Tech University Online;

-Securing and maintaining professional accreditation for all appropriate programs.

The mission statement of the College of Aeronautics is:

The College of Aeronautics' mission is to prepare students for success and advancement in the aviation professions; advance aviation knowledge through faculty and student research, scholarly activity, and projects; and encourage and enable student and faculty service to the university, community and aviation professions.

Appendix C: Description of Non-University Partners

Non - University Partners	**Address**	**Email**	**Phone Number**
Dr. Gregory Fox	Florida Institute of Technology College of Aeronautics	gfox@fit.edu	
Mr. Adam Heid	Airport Operations Superintendent Valkaria Airport Terminal	adam.heid@brevardfl.gov	
Mr. Chris Rozansky	Executive Director Naples Airport Authority	rozansky@flynaples.com	
Mr. Arjun Nair, MSA	Airport Planner Syracuse Regional Airport Authority	naira@syrairport.org	

Appendix E: Evaluation of Educational Experience

Students

1. Did the Airport Cooperative Research Program (ACRP) University Design Competition for Addressing Airports Needs provide a meaningful learning experience for you? Why or why not?

Answer: The ACRP provided a meaningful experience for us because it afforded the opportunity to carry out a real-time research proposal for the possibility of being able to actualize it. We saw ourselves going beyond my limits to achieve success. Apart from the competition, it was a great learning experience and interaction with the officials.

2. What challenges did you and/or your team encounter in undertaking the competition? How did you overcome them?

Answer: We got discouraged a lot of times by people. The discouragement was that our project was not applicable to the US. But we picked courage when our contacts told us that they have not seen such and would love to see it materialize. We had to sometimes tell ourselves not to look at the competitive aspect but look at its feasibility and its benefits to the environment. The other challenge was as it is new to the industry, we had tried to bridge the gaps and answer the possible questions.

3. Describe the process your team used for developing your hypothesis.

Answer: Hypothesis testing is used to assess the plausibility of a hypothesis by using sample data. Such data may come from a larger population, or from a data-generating process. The word "population" will be used for both of these cases in the following descriptions. The formation of our hypothesis was based on the following:

a) We collected as many observations about a topic or problem as we could
b) We evaluated these observations and look for possible causes of the problem.
c) We created a list of possible explanations that you might want to explore.

4. Was participation by industry in the project appropriate, meaningful, and useful? Why or why not?

Answer: Participation in the industry was very meaningful and useful because we got more than the information we needed and we were welcomed warmly. The industry experts were willing to share ideas and information and gave all the wealth of knowledge they could offer. Also, 3 industry experts are enough because we got turned down by people who did not want to share information with us because of the sensitivity of their appointment. The project is multi-disciplinary, so we need to contact people outside the aviation industry to get a better picture. We hope the competition will in the future consider the outside aviation industry experts as part of the interactions as their expertise may be critical for some projects.

5. What did you learn? Did this project help you with the skills and knowledge you need to be successful for entry into the workforce or to pursue further study? Why or why not?

Answer: We got a chance to explore other areas and their depths of them. We went out of the box and comfort zone to learn new things. We have understood the sources of regulatory and industry policies to be considered while designing a project. We have learned new skills in approaching and presenting a project

Faculty

l. Describe the value of the educational experience for your student(s) participating in this competition submission.

Answer: The Airport Cooperative Research Program University Design Competition for addressing airport needs provided students with the ability to apply learned research and product development methodologies to a real-world problem and design solution opportunity. Learning is far too often theoretical for students, so this project allows students to apply learned classroom concepts to the real world.

2. Was the learning experience appropriate to the course level or context in which the competition was undertaken?

Answer: A graduate Human Performance 1 course in the College of Aeronautics was the environment for the learning experience. The course level and context are appropriate.

3. What challenges did the students face and overcome?

Answer: The dynamic student team embraced the project components and encountered very limited challenges. Specifically, the only challenge faced was initially obtaining access to airport personnel. However, students were able to identify contact with appropriate airport personnel.

4. Would you use this competition as an educational vehicle in the future? Why or why not?

Answer: I will have students continue to submit to this competition for all future graduate Human Performance 1 courses.

5. Are there changes to the competition that you would suggest for future years?

Answer: I appreciate the video on “Guidance for Preparing Benefit/Cost Analyses.” This was extremely helpful, especially for teams with tangible costs and benefits. The only additional challenge for some team submissions is in identifying costs and benefits for intangible items such as people’s time and increased efficiency. It would be helpful if the competition website can also recommend resources for how to quantify intangible costs and benefits.

Appendix F

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