Concept Generation and Selection

EML 4551C – Senior Design #1

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Project Introduction

This project is a joint effort between two universities: Florida State University of the United States, and Federal University of Paraná, of Brazil. The project aims to expose students to the challenges and advantages of working on international teams.

In recent years, there has been intensive research on the production and implementation of clean and renewable fuels. Climate-changing pollution and shrinking fossil fuel supply are often cited as the main driving forces in this field of research, as well as a new-found public interest. Among the many new energy alternatives emerged biodiesel.

Biodiesel is a biodegradable fuel derived from renewable sources and can be obtained from several different raw materials. There are many conventional agricultural crops that can be used to produce biofuels, such as corn, soy and Castor beans. However, the growth period of these crops is substantial and they require large quantities of land which could otherwise be used for food production. Biodiesel can also be produced from the fatty acids extracted from microalgae. Research shows that biodiesel production through microalgae is much more efficient both in volume of oil and in cultivation area., as algae is an organism with a great capacity for photosynthesis and an extremely rapid rate of growth. Being a plant, algae also consumes carbon dioxide to propel biomass production.

The search for sources of clean, renewable energy is intimately tied to research in improving the efficiency of existing energy-harnessing systems. Therefor, it is very important to efficiently utilize energy and heat when it is produced. A manifestation of this concept, coined "trigeneration," was developed to do just this. The trigeneration system that was developed at FSU produces electricity, hot water, and a refrigerated space from one small internal combustion engine. A generator is coupled to the drive shaft of the motor to produce electricity. The energy typically wasted by expelling the hot exhaust gases into the atmosphere is "recycled" to heat water and run an absorption refrigerator.

The ultimate goal of this project is to design and build a prototype of a unit that is able to treat and cool (if needed, to be determined) the exhaust gases from a trigeneration system (Figure 1), and to introduce these gases to a photobioreactor (Figure 2) for the cultivation of algae. Introducing the waste gases to the photobioreactor will help accelerate the growth of algae and the algae will in turn remove harmful greenhouse gases from the exhaust stream.

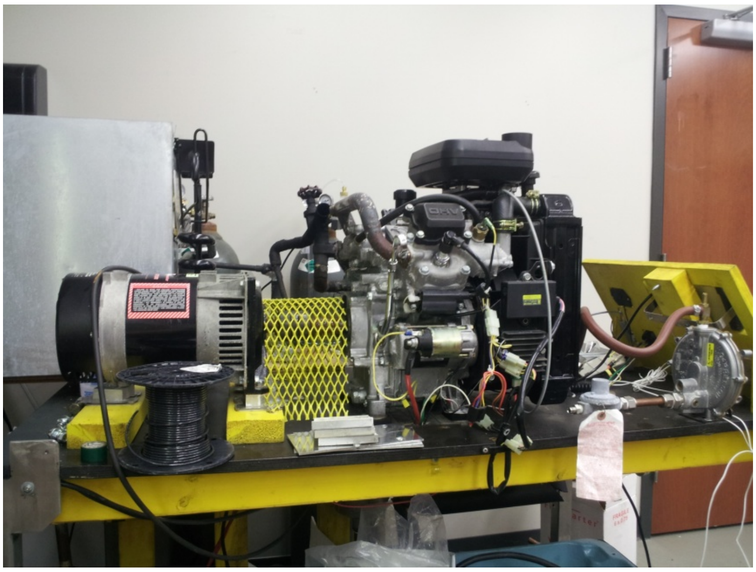

Figure 1 - Trigeneration System

Figure 2 - Photobioreactor

Existing Technology

Attempts to reduce carbon emissions and improve system efficiency by virtue of algae photosynthesis has been attempted in select applications. The Massachusetts Institute of Technology recently implemented a rooftop algae bioreactor system that made use of industrial flue gasses. The system was a great success and was capable of both significantly reducing emissions for its scale and produce a large quantity of algae. However, the system has yet to become commercially viable.

Many bioreactor systems utilize compressed carbon dioxide to accelerate the growth process. There currently several companies attempting to make algae production in bioreactors a commercial viable means of generating biofuels. None have had great commercial success, but all are still in their infancy. Making use of combustion gasses, however, is a very new and exciting means to both reduce emissions and produce useful fuels and products. No modular product yet exists that extracts exhaust gasses from a combustion source for direct application in a bioreactor system.

Concept Generation

To simplify the concept generation process, we decided that all concepts could be lumped into two broad methods: direct and indirect gas capture. Exhaust gases are brought directly from exhaust line to the bioreactor with the direct method. They are sequestered in a storage medium before being injected with the indirect case. Once these methods were defined, it became easier to generate plausible concepts. A diagram was drawn to help the brainstorming process. (Figure 3, Figure 4). Three direct and two indirect concepts were generated.

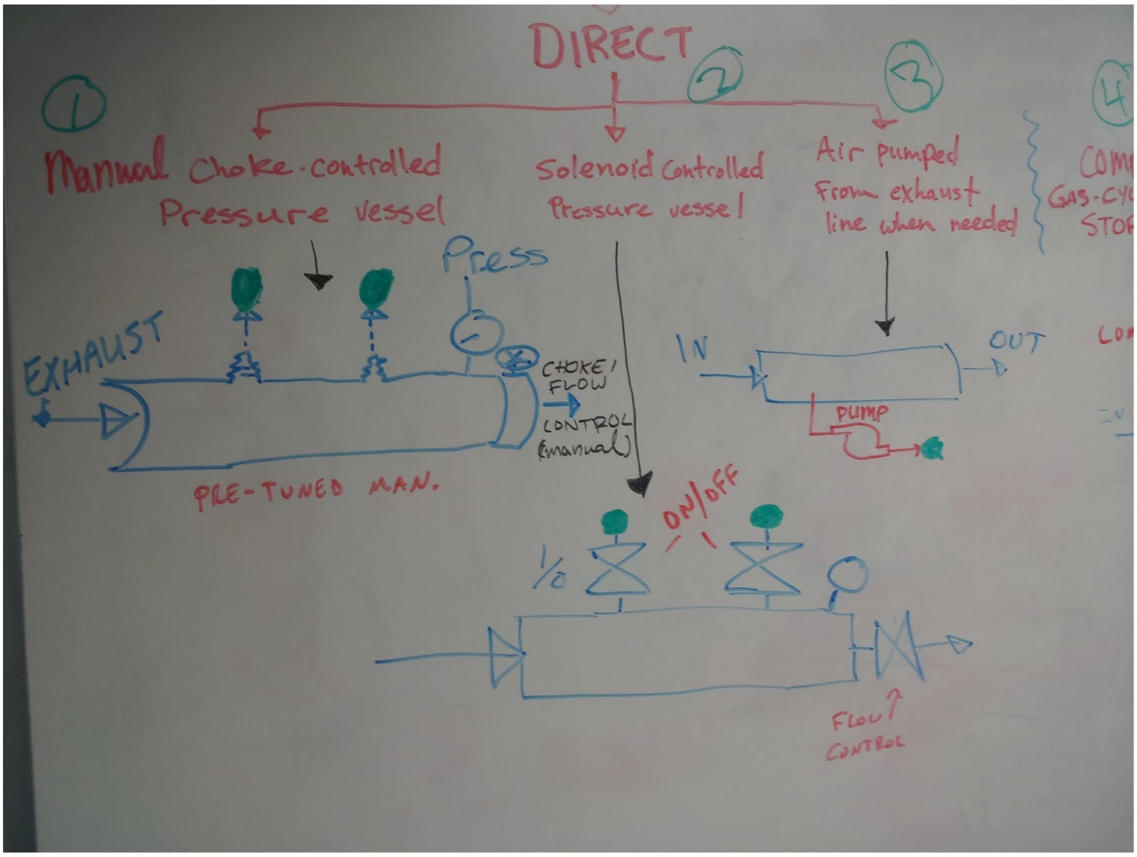

Figure 3 - Concept Generation Chart, Direct Methods

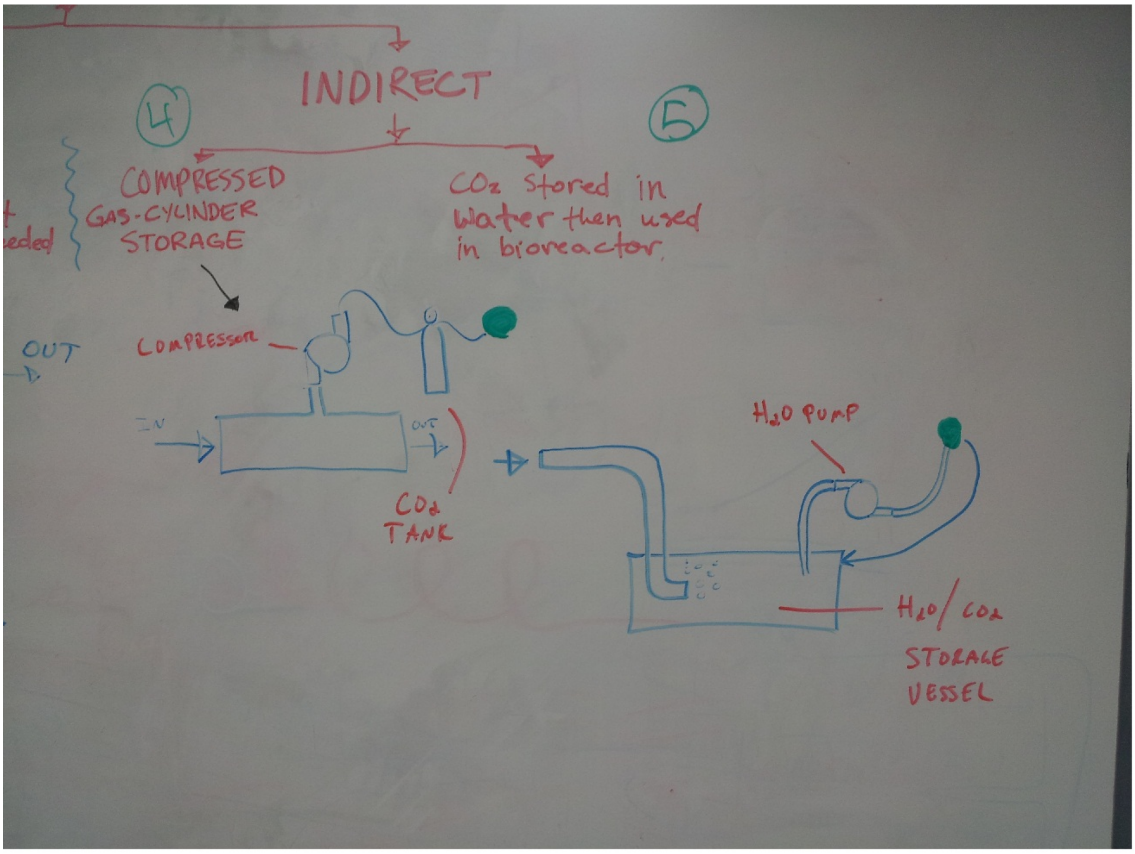

Figure 4 - Concept Generation Chart, Indirect Methods

Concept 1: Direct Manual Pressure Vessel

Our first concept is a manually operated pressure vessel. This is a direct method. First, the exhaust stream will be directed into a corrosion resistant pressure vessel, which is adjusted with a manual choke valve at the exit. Two barbed tube fittings (Figure 6) allow a constant gas stream to be delivered to different photobioreactor chambers. Each connection barb will have its own independent control valve. The amount of gas delivered to the photobioreactors can be controlled with the position of the choke valve (Figure 7). Pressure from the engine will drive this process, which means some back-pressure toward the engine will be generated by this device. Back-pressure will decrease the efficiency of the engine, which is not desired. However, we believe that the pressure needed to force gas into the photobioreactors will be sufficiently small to keep the efficiency within an acceptable range.

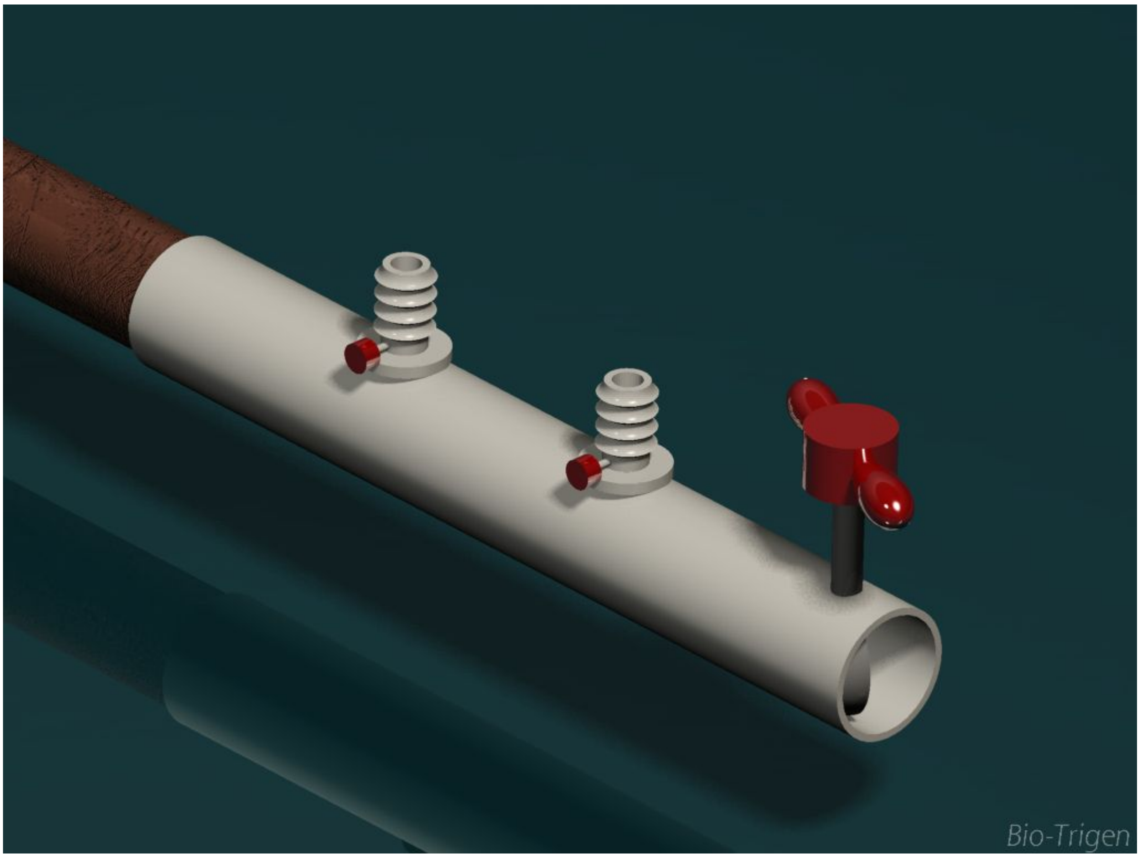

Figure 5 - Concept 1

Pros

1. Simple construction and maintenance
2. Very modular, adaptable and scalable
3. Easily operated and adjusted
4. Corrosion resistant and easily replaceable
5. Requires no electricity, only hand operation
6. Cost-effective

Cons

1. Causes back-pressure to the engine, decreasing efficiency
2. Requires manual monitoring and operation
3. Not resistant to higher temperatures

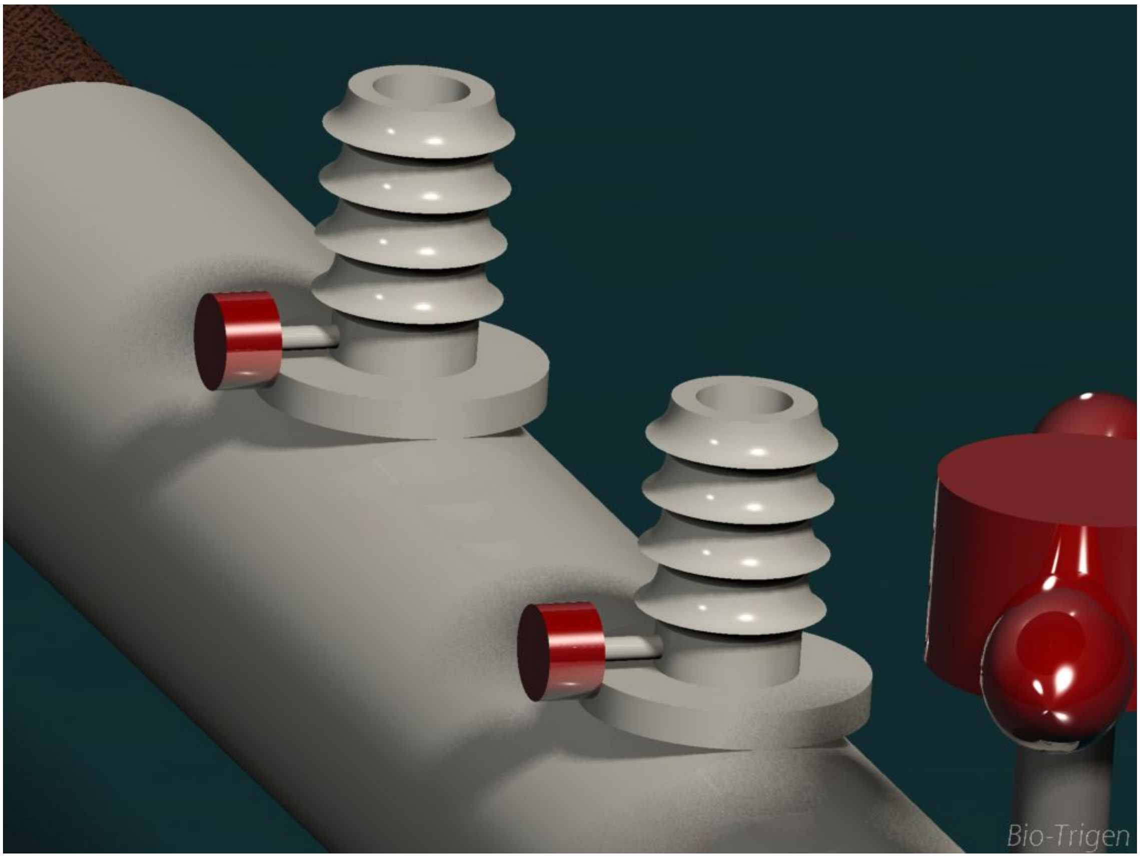

Figure 6 - Concept 1, Detail View 1

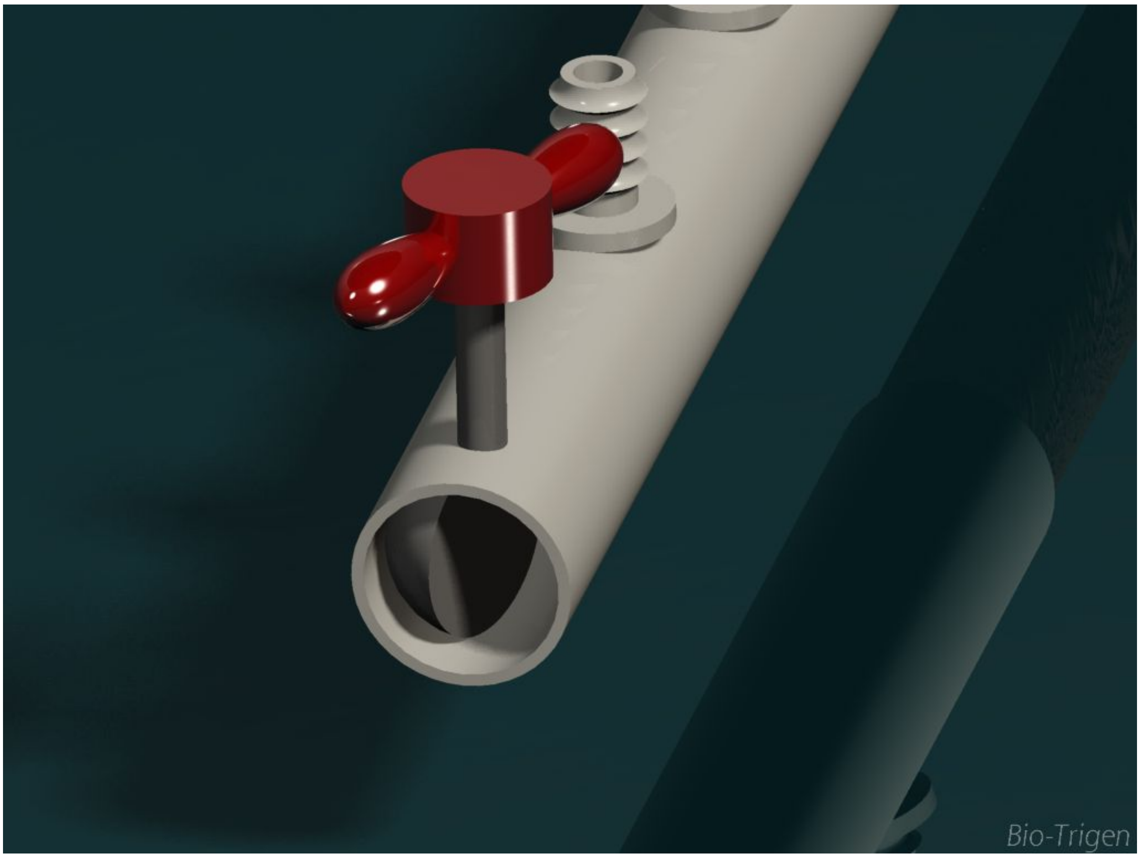

Figure 7 - Concept 1, Detail View 2

Concept 2: Direct Automated Pressure Vessel

The second direct concept follows a similar design to the first. The same pressure vessel will collect the exhaust stream, again with a choke valve at the exit. They differ in how the choke and two barb connections are controlled. These three valves will be solenoid or servo controlled. A micro-controller will open, close, or adjust the valves depending on pH, temperature or pressure readings. This system could be programmed to manage optimal algal growth conditions automatically.

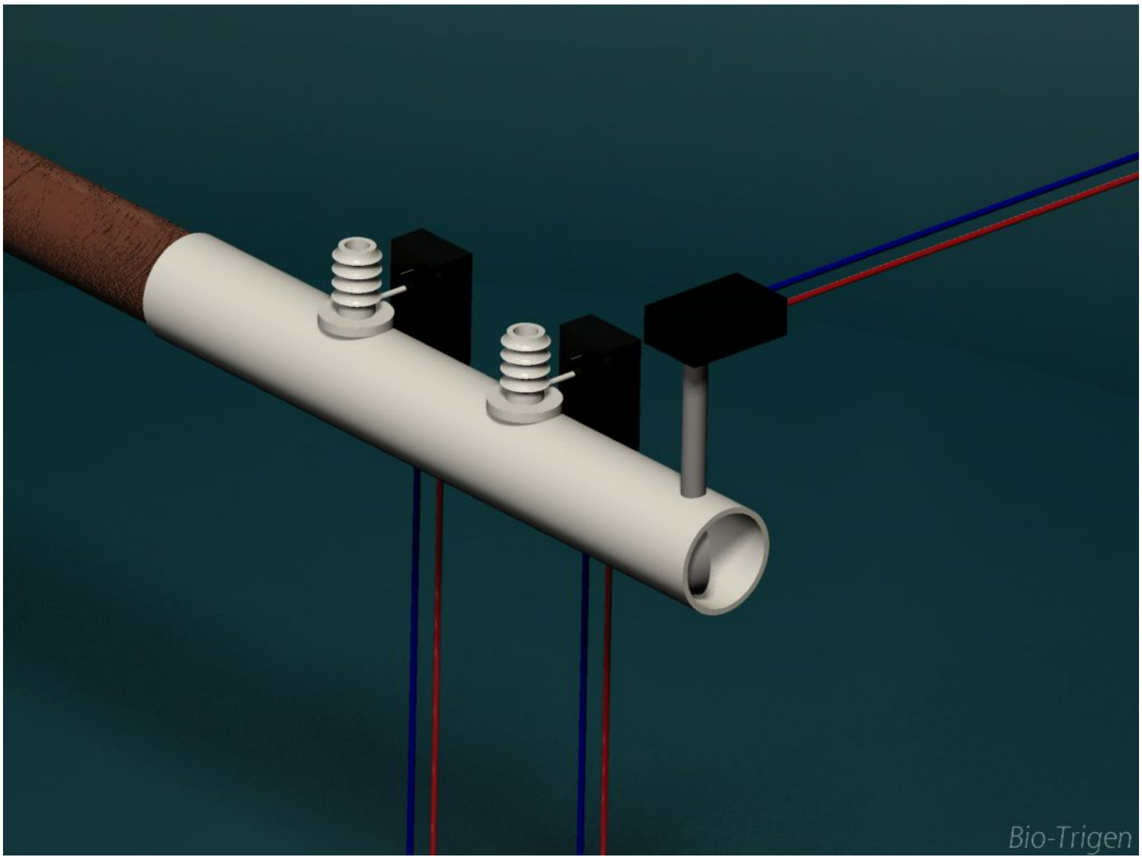

Figure 8 - Concept 2

Pros

1. Fully automated
2. Prevents pH, temperature and pressure runaways
3. Modular and easily adjusted
4. Can be programmed to manage algae growth conditions
5. Shell is corrosion resistant and easily replaceable

Cons

1. Micro-controllers and servos add complication to the design, build and maintenance schedule
2. Electrical components draw power, reducing the total efficiency
3. Causes back-pressure to the engine, decreasing efficiency
4. Not resistant to higher temperatures

Concept 3: Direct Air Pump

Concept 3 utilizes an air pump to draw a specific flow rate out of the exhaust stream. The air pump will couple to the exhaust line at a T-joint. One end of the joint will remain open to release excess exhaust. This simple design will reduce any extra back-pressure seen by the engine due to the gas coupling system.

Figure 9 - Concept 3

Pros

1. Causes no extra back-pressure to the engine
2. Minimal construction
3. Simple maintenance
4. Consistent air delivery
5. Very modular and scalable
6. Cost-effective

Cons

1. Pump draws some power, reducing the total efficiency
2. Not easily adjustable air flow
3. Pump will need maintenance and may see a corrosion problem

Concept 4: Indirect Pump to Pressure Vessel

This concept utilizes a compressor to draw the exhaust gasses from the exit pipe to a pressurized vessel. It has the advantage of producing little back-pressure to the engine, as well as conveniently storing the gas for use when the engine is not running. This system is significantly more complicated then some of the direct capture systems, and will be much more expensive to produce.

Figure 10 - Concept 4

Pros

1. Gas can be stored until needed
2. Engine does not need to operate for a supply of gasses
3. Causes no back-pressure to engine
4. Flow of compressed gasses can be precisely controlled during application
5. Fewer issues with hot exhaust streams

Cons

1. Draws substantial electrical power
2. Limited gas storage capacity
3. Least cost effective
4. Limited scalability
5. Requires substantial maintenance
6. Water vapor in exhaust stream may cause mechanical issues
7. More expensive mechanical parts will exasperate corrosion issues

Concept 5: Indirect Water Storage

This concept makes use of the solubility of carbon dioxide gas in water. Although not particularly soluble in water, a significant amount of carbon dioxide may be captured in water of sufficient volume, and water is a very inexpensive solvent. This method of gas sequestration involves diffusing the gas stream beneath a volume of water in a storage tank. The carbon dioxide rich water may then be pumped directly to the bioreactors using inexpensive, low flow rate water pumps when needed. Also, extra nutrients may be added to the storage tank to enhance the growth of the algae.

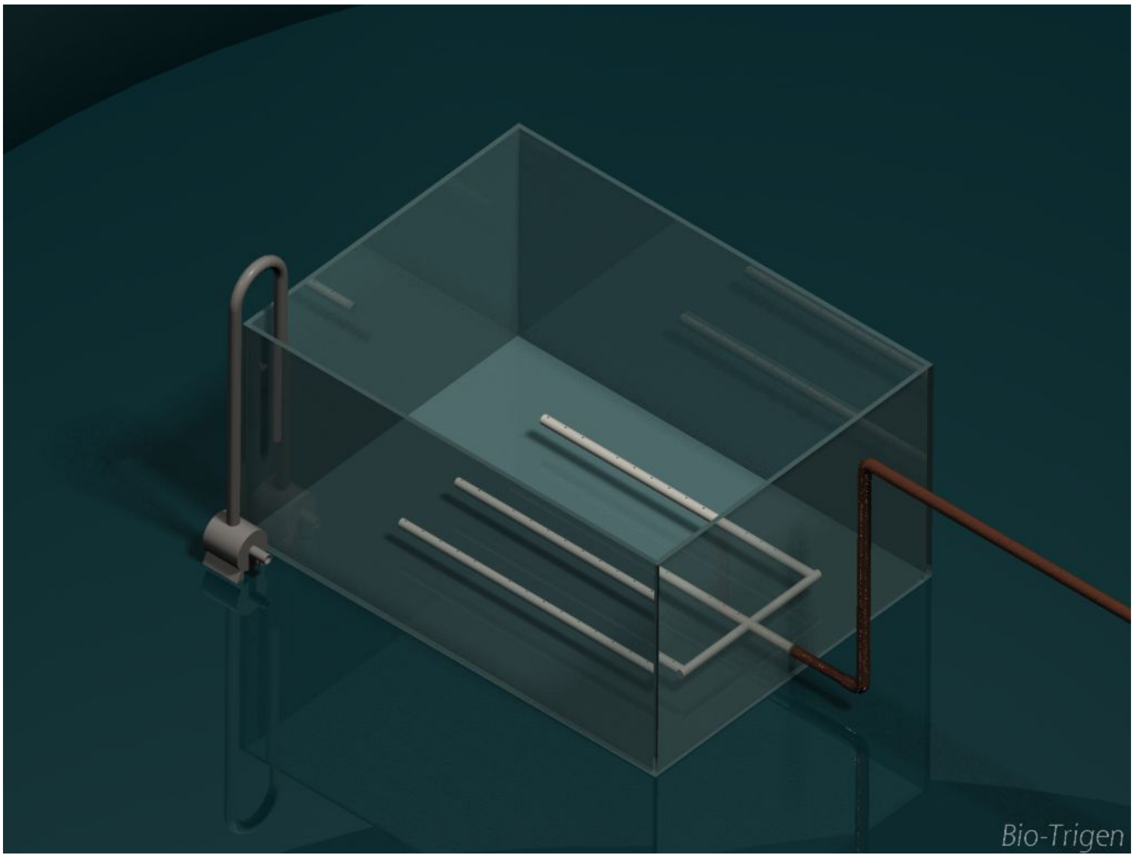

Figure 11 - Concept 5

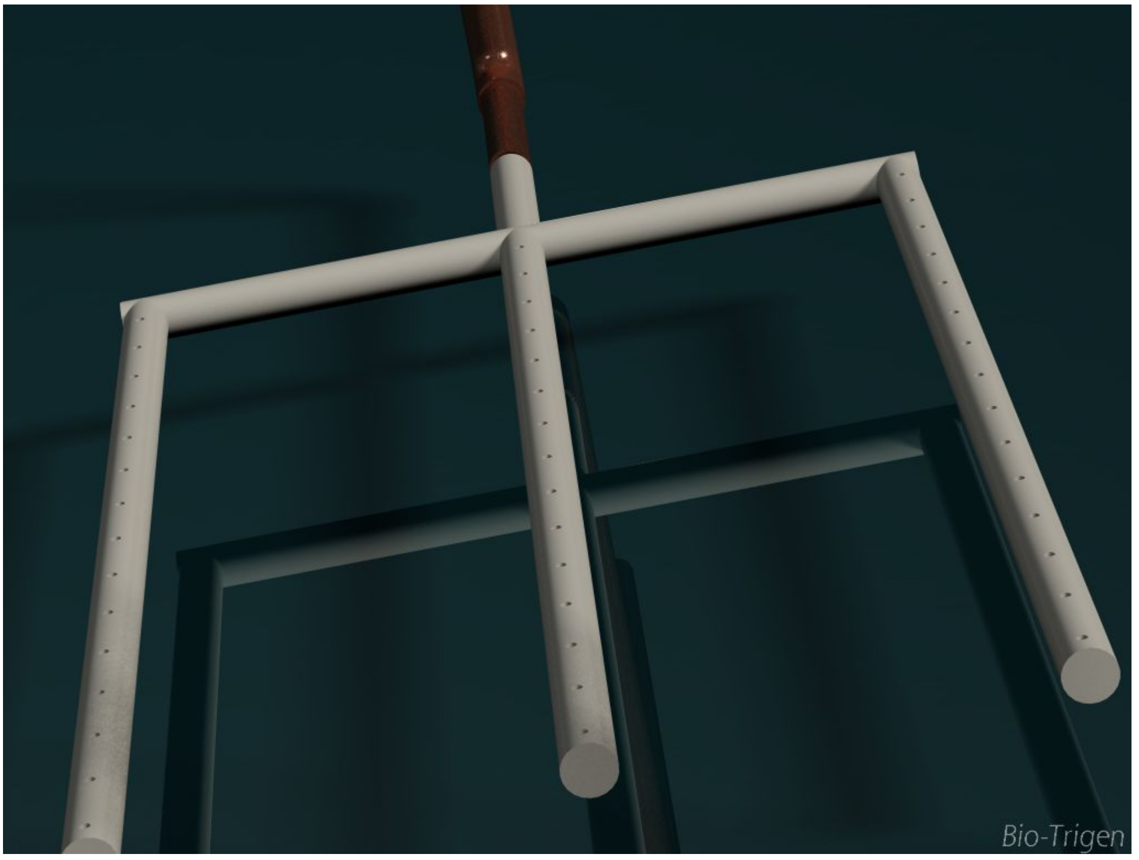

Figure 12 - Concept 5 - Detail View

Pros

1. Gas can be stored until needed
2. Engine does not need to operate for a supply of gas products
3. Flow of gas products can be precisely controlled during application
4. Fewer issues with hot exhaust streams
5. Modular and scalable
6. Little monitoring necessary
7. Minimal corrosion issues
8. Inexpensive and easily manufactured
9. Water may be recycled in a closed system if necessary

Cons

1. Limited gas storage capacity
2. Requires electrical power to operate pump
3. Causes back-pressure to the engine, decreasing efficiency
4. Potential risk of flooding exhaust piping (water trap may be necessary)

Selection Criteria

Concept selection will be the next phase in the project development plan. The following selection criteria represent the most important aspects of the final product. These criteria will be weighted and arranged into a decision matrix. Each concept will be given a score in each category, and a total score for each will be evaluated. The highest scoring concept will be selected and the design process will move into the next phase. If more than one concept scores highly, the lower scoring concepts will be discarded and a refined grading criteria will be invoked.

Adaptabilty - The system should be modular in design for robust application and ease of manufacture.

Scalability - The product should exhibit features of scalability for implementation in a wide range of systems.

Ease of Use - The product should be easy to install, uninstall and operate.

Durability - The product should have a long operating life.

Reliability - The system's behavior should be consistent.

Cost Effectiveness - The budget should be efficiently utilized.

Controllability - Precision control of nutrient administration is ideal.

Exhaust Capture Effectiveness - The system should be able to capture a large portion of exhaust gases to reduce overall emissions.

Power Efficiency - The system should accomplish its goal while drawing as little power as possible.

References

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