HYDROGEN STUDENT DESIGN CONTEST - 2012

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The theme of 2012 Hydrogen Student Design Contest is to design a Combine Heat, Hydrogen and Power (CHHP) system for a university campus, using local resources. This report is the proposal prepared by the team of the students from the University of Bridgeport.

The buildings considered to be facilitated by the Heat and Electricity supply from the CHHP System, consist of a couple of dormitories, a dining hall and a recreation center located on the campus of the University of Bridgeport, Connecticut. To ensure constant fuel supply to the designed CHHP System, a biogas plant is proposed to be built which will generate 58.8 scfm biogas using sewer waste and other organic waste available on campus.

The CHHP System will generate 300kW Electricity along with 808,000 Btu/hr Heat which would be supplied to the campus buildings under design consideration. While the electricity will power the buildings, the heat will be utilized for heating the building space during winter and for heat generated cooling during summer. Moreover, it is also estimated to produce 275 gallons hydrogen per day, which would be utilized to operate university vehicles used for student transportation, security and facility services.

Solar thermal system is designed to replace natural gas dependencies for hot water needs for Wheeler recreation center at campus, which cannot be entirely compensated by the designed CHHP System. Solar thermal system further provides energy for hot water as input to biogas plant in cold weather. Use of Evacuated tubes collector for its known quality for cold climate in state of Connecticut, is proposed which will satisfy 400 gallons of water tank in Recreation center.

It has been realized that reducing cost and improving durability are the most important challenges in order to commercialize Fuel Cell technologies and make them cost effective. It has been concluded that research is needed to be focused to identify and develop new materials that reduce the cost and extend the life time of fuel cell to further improve Return on Investment.

After analyzing the project economically, a budget of US $2,385,000.00 is calculated to install the whole system and the payback period for the same was obtained as 4.61 years. With the installation of CHHP it will be possible to save 1,925,000KWH electricity, 4377x10^3CF natural gas and 80,318 gallons fuel per year. For promoting the benefits of using renewable energies, a strategy of starting from the grass root level, i.e. local schools, colleges and universities, is considered. Moving further in the process of education, it has been decided to target community housing and business complexes. An association called ‘Hello Hydrogen’ to help spreading the awareness of CHHP System to national level is also to be formed.
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1. Resource Assessment:

We have conducted an analysis of the available resources on campus and decided to install a CHHP system, based on the constant supply of Methane gas produced from anaerobic digestion of organic waste.

We intend to use Fuel Cell Energy’s DFC 300 system to generate Heat, Hydrogen and Electricity. The electricity produced from the DFC 300 system will be used to power a couple of dormitories named Cooper Hall and Chaffee Hall along with the Marina Dining Hall and Wheeler Recreation Center, located on campus. Moreover, the heat produced from the system will be used to heat these buildings in winter and operate thermally activated cooling systems in summer. Still, there is an additional requirement of heat for a large swimming pool located in the Wheeler Recreation Center, which would be supplied through a Solar Thermal system designed to compensate the CHHP system. Finally, the Hydrogen gas produced by the system will be used to operate various university vehicles used for transportation, facilities management and security.

To facilitate the anaerobic digestion of the organic waste available on campus a digester of total volume 375 $m^3$ is proposed to be built near the central collection and process station of the organic waste. Given below is the detailed description of the available resources on campus:

1. Human waste and waste water from the sewer system:

On an average day the total population of students and professionals on campus is around 4500, which consists of more than 2500 students living on campus. Hence, the calculation of human waste available for supplying to the anaerobic digester (biogas plant) is as follows;

- Total solid (TS) contained in a certain amount of material is usually used as the material unit to indicate the biogas producing rate of the materials.
- Most favorable TS value is 8 %

Human Body Weight: 50 kg (Assumed Average)

Excrement Discharge per day: 0.5 kg

Urine Discharge per day: 1 kg

Human excrement: Dry matter content – 20%
Water content – 80%

Human Urine: Dry matter content – 0.4%
Water content – 99.6%

TS value of fresh discharge: 20% by weight
Hence, for 2500 Persons of Body Weight 50 Kg each (Population living on campus):

Total Solid Discharge = \((0.5 \text{ kg} \times 2500) + (1 \text{ kg} \times 2500 \times 0.4)\) = 2250 kg / Day

\(\text{TS of fresh discharge} = 2250 \text{ kg} \times 0.20 = 450 \text{ kg}\)

2. Organic waste:
   The organic matter is available in abundance as solid waste on the vast university campus. The Campus Facilities Management has estimated around 200 kg of daily organic waste production from the campus landscaping, leaf and woody material falls. Moreover, the organic waste generated by the cafeterias and Marina dining Hall located on campus is around 150 kg per day. In addition to this the organic waste production from over 30 small kitchens located inside the dormitories on campus is estimated to be over 100 kg per day.
   - Organic Waste:
     
     Dry matter content: 24%
     
     Water content: 76%
     
     \(\text{Total Organic Waste} = 550 \text{ kg} / \text{Day}\)
     
     \(\text{TS of Organic Waste} = 550 \text{ kg} \times 0.24 = 132 \text{ kg}\)

     All these organic wastes are suitable to be fed to the anaerobic digester after proper processing and they make a large portion of our system resources.

Furthermore, as we also plan to incorporate a Solar Thermal System to compensate the additional heat requirement of the university buildings under design consideration, the estimated energy supply from the Solar Thermal System is as following:

On a sunny day there would be availability of approximately 40,000 Btu/Panel at the city of Bridgeport, CT, USA. On cloudy day, it is about 10,000 Btu/Panel.

These resources and the base of our CHHP system design, which will help us to make the above mentioned for key buildings on the university campus totally energy independent. This implies that there will be no requirement of the conventional energy supplies to these four buildings, except as a back-up during occasional system down time.
2. CHHP System Technical Design

2.1 Site Plan:

![Site Map of CHHP System](image)

University of Bridgeport is located in the City of Bridgeport, Connecticut, USA. The location of the buildings considered for the design of CHHP System is as shown in Figure 1.

The buildings considered for design (1,2,3,&4) are located close to each other and they are more suitable for the CHHP System usage. CHHP system will be located on an empty plot marked by (6-10). This empty plot is of approx. 415m² area, which is big enough to install all the components of our designed CHHP System along with the Biogas Plant.
The choice of the location of the CHHP System is based on following factors:

1. It is close to our targeted buildings: Cooper Hall, Marina Dining Hall, Chaffee Hall and Wheeler Recreation Center.
2. It located on current school main sewer collection system for processing, buried underground near the University Avenue.
3. Marina Dining Hall has abundant organic resource to be supplied to biogas plant.
4. High-land areas will comply safety code; and it is located a suitable distance from student resident halls.
5. It is close to a parking lot which can be conveniently used for fueling hydrogen to the vehicles.

Main design components are illustrated in Figure 1, detailed system layout is as following:

![CHHP System Layout Diagram](image-url)
2.2 Design of Biogas Plant:

Design parameters:

1. Favorable Conditions for Fermentation:
   - Temperature: Average Temperature: 20°C
   - Design TS value is 8%
   - Biogas Producing Rates at given Temperature
     - Human Waste: 0.25 – 0.30 m³/Kg of TS
     - Organic Waste: 0.20 - 0.25 m³/Kg of TS
   - pH Value: Neutral pH
     - Acceptable Range: 6.8 – 7.2
   - Carbon-Nitrogen (C/N) Ratio
     - Human Waste: Carbon Content – 2.5%
       - Nitrogen Content – 0.085%
       - C/N Ration – 29:1
     - Organic Waste: Carbon Content – 14%
       - Nitrogen Content – 0.54%
       - C/N Ration – 27:1

2. Hydraulic Retention Time (HRT): 60 Days

Figure 3. Biogas plant scheme

A detailed calculation of the dimensions of the biogas plant is shown in the appendix
Dimensions:

Volume of gas collecting chamber: \( V_c = 18.75 \text{ m}^3 \)
Volume of gas storage chamber: \( V_{gs} = 85 \text{ m}^3 \)
Volume of fermentation chamber: \( V_f = 215 \text{ m}^3 \)
Volume of hydraulic chamber: \( V_H = 85 \text{ m}^3 \)
Volume of sludge layer: \( V_s = 56.25 \text{ m}^3 \)

Total Volume of Digester: \( V = V_c + V_{gs} + V_f + V_s = 375 \text{ m}^3 \)

Hence, suitable fuel cell model for the system is DFC 300.

Calculation of the CHHP System Fuel consumption based on the use of natural Gas (930 Btu/ft\(^3\)), as given by the Fuel Cell Energy brochure.

CHHP System Fuel consumption (MMBtu/Year) =

\[
\text{DFC 300 Fuel Input rate (Btu/hr) } \times \text{Equivalent Full Load Hours (hr/Year)}
\]

\[
= \left[ 930 \text{ (Btu/ft}^3\text{)} \times 39 \text{ (scfm)} \times 60 \text{ (mins.)} \right] \times [18 \text{ (hrs)} \times 365 \text{ (Days)}]
\]

\[
= 14300 \text{ MMBtu/Year}
\]

Calculation of the proposed CHHP System based on Biogas 841 Btu/ft\(^3\);

Available Energy =

\[
\text{Biogas Production rate (scfm) } \times \text{Biogas Energy content Btu/cf} \\
\times \text{Production Time (hr) } \times \text{Fuel Utilization Rate (\%)}
\]

\[
= 58.8 \text{ (scfm)} \times 841 \text{ (Btu/ft}^3\text{)} \times (60 \times 24 \times 315) \times 0.65
\]

\[
= 14500 \text{ MMBtu}
\]

Note: Biogas Plant operation is assumed to be for 315 Days/year
2.3 Design of DFC Fuel Cell and Hydrogen Separation System

Following are the main components of the system:

a. Gas Treatment System and Fuel Storage
b. DFC 300 Fuel Cell
c. Hydrogen Separation

a. Gas Treatment and Fuel Storage System:

The biogas produced as the result of anaerobic digestion is required to be cleaned and process as it is the fuel supplied to the DFC 300 Fuel Cell.

The biogas cleaning process starts with the use of water scrubber, which washes and cools the biogas. The water scrubber will remove fine solids, chlorides and other water soluble from the biogas. Furthermore an acid gas remover is used to clean the gas by removing various sulfur compounds from the gas. Final by using a cyclone separator, very fine solid particles will be removed from the gas. As a result of sulfur compounds from the biogas, the remaining constituents of the gas are Methane CH₄ and Carbon Dioxide CO₂. The Gas is then stored in a storage tank for the continual supply of Biogas to the DFC 300 Fuel cell.

b. DFC 300 Fuel Cell

The DFC 300 Fuel Cell by Fuel Cell Energy is a self-contained power generation system. It internally reforms the Biogas produced by the anaerobic digest into Hydrogen, which powers the fuel cell. The Biogas production rate of the designed anaerobic digester is 58.8 scfm, which will be supplied to the DFC 300 Fuel Cell after proper processing. Moreover, it is necessary to ensure supply of preheated air and water for the fuel cell’s operation.

The internal process of the DFC 300 Fuel cell can be explained as following:

The composition of Biogas is 60% CH₄ and 40% CO₂

Hence, reactions at anode are:
CH₄ + 2H₂O = 4H₂ + CO₂
H₂ + CO₂ = H₂O + CO₂
For 65% fuel utilization rate and 2:1 CO shift ratio to Hydrogen, the products at anode are as following. [8]

- $\text{H}_2\text{O} = 37.10\%$
- $\text{CO}_2 = 45.90\%$
- $\text{CO} = 5.70\%$
- $\text{H}_2 = 11.20\%$

Figure 4. Internal process in DFC 300

Figure 5. Scheme of DFC300 system
As an output of DFC 300 Fuel Cell we will get, 300kW Electricity at 480 V and 60 Hz and 808 Btu/hr Heat at 120 °F. Along with the heat and electricity a mixture of Carbon Dioxide and Hydrogen is also obtained which, will be further supplied to a Hydrogen Separator to separate pure Hydrogen gas.

2.4 Design of Hydrogen System:

Hydrogen gas has good energy density by weight, but poor energy density by volume versus hydrocarbons, hence it is very important to find a proper way to compress, store and deliver hydrogen energy.

The complete Hydrogen system layout is as Figure 6 shown. System can be controlled both automatically and manually. Pressure monitor and fire alarm control system have been included in this system for safety concern; details for the safety issue will be discussed in the safety analysis section.

Figure 6. Hydrogen system layout

2.4.1 Hydrogen Compression

A hydrogen compressor is a device that increases the pressure of hydrogen by reducing its volume. Compression of hydrogen gas naturally increases its temperature, due to Charles' Law. Compressed hydrogen in hydrogen tanks at 350 bar (5,000 psi) and 700 bar (10,000
psi) is used for in hydrogen vehicles. In our design, to find out a perfect compressor, following factors should be considered:

a) The pressure range we need  
b) The production rate of hydrogen  
c) Temperature rise of a gas as it is compressed  
d) Power needed to run an air compressor

To accomplish above goal, we realize all hydrogen resource are come from DFC 300 plant and outlet hydrogen pressure really low(12scfm@1psi), which means a low-inlet to high-outlet gas pressure compressor with small capacity will be used into our design. After exploring all available products, a multi-stage high pressure hydrogen compressor by HYDRO-PAC INC is the one totally meets our needs (see Figure 7). All the products from this company are designed to meet the Japanese High-Pressure Gas Safety Law (HPGSL) as well as American standard.

Figure 7. Multi-stage high pressure hydrogen compressor scheme

According to our consideration, model No. C06-40-70/140LX will be used into our design. This compressor module will properly solve the huge pressure difference between DFC 300 outlet and hydrogen tank by using multi-stage compress process.

2.4.2 Hydrogen Storage

A Hydrogen tank (other names- cartridge or canister) is used for hydrogen storage. Safety of hydrogen tank is the primarily considered. Currently, there are two type of hydrogen tank can stand hydrogen pressure higher than 5000psi, one type is tank made from composite material, the other type is Composite tank such as carbon fiber with a polymer liner. Furthermore, the volume of hydrogen tank should be also counted. Since the hydrogen production rate from DFC 300 is 275 pound/day, we need a hydrogen tank with the volume at least is $5 \text{ m}^3$. In view of the safety issue and the needs of our design, a hydrogen tank developed by Nissan is a perfect choice. This hydrogen tank with the maximum filling
pressure of 70MPa is layered with an aluminum liner and C-FRP (Carbon-Fiber Reinforced Plastics). The hydrogen storage volume of the tank is 30% larger compared to the conventional tank with the same capacity. The volume issue will be a serious problem once we use it on the hydrogen vehicle but it is not a problem when we use it store energy on the ground. Also this tank was designed to be used on the hybrid car; therefore it will accomplish all safety code as a part of hydrogen storage system.

2.4.3 Hydrogen Dispensing System

Dispensing system located nearby hydrogen tank which is not only save the hydrogen delivery process but also can share the safety secure system with other component. A pressure regulator will be used to control the pressure of the hydrogen stream entering the single-hose dispenser. FTI's hydrogen dispensers are currently providing safe hydrogen refueling in seven different countries, therefore we are decided to use this product than design a new one. The dispensing unit allows hydrogen inlet pressures up to 447bar (6500psi) for flow rates up to 20 kg/min. This flow rate cans no doubt to save the refueling time. Since it has been wild using lots of region into the world, safety issue has already been solved by the rich experience and outstanding R&D people.

2.5 Design of Solar Thermal System:

Solar Thermal Systems use heat energy from incoming solar radiation to meet hot water needs both for domestic and commercial applications. It does so by transferring it to water circulating through the system. ST is very common to use for hot water systems at homes.

There are several technologies in the today’s market. We propose Evacuated Tubes Collector type for the following reasons.

1. Our campus is located in state of Connecticut, located in North America where climate is relatively cool.
2. Evacuated Tubes are specially designed to work in cold and cloudy environment.
3. ET Collectors easily attain the higher temp needed, even on cloudy day due to their superior Incidence Angle Modifier.
4. They collect solar energy evenly throughout the day that results in a lower buffer or thermal storage requirement thus reduces the system cost.
5. ET works throughout the day as compared to flat plates that generally work form 11am – 2pm.
6. Easy installation and no maintenance are needed.
7. Last longer life as compared to other technologies
8. They passively by designed are able to track the sun all day.
9. More efficiently in transferring heat (up to 160%).
10. Durable, but if tubes are damaged or broken, can easily be replaced.
11. Requires less roof areas as compared to flat plate
12. Less corrosion problem.
13. By design, it reduces conductive and convective heat loss from the interior of the tube.

2.5.1 System Description

Normally we have 40,000 BTU/Day/Panel on sunny day. On cloudy day, it is about 10,000 BTUs. Each panel has about 30 tubes mounted on stainless steel rack.

Weight is about 210-230 lbs/rack and Price is about $1900 – $2200 / Panel. Each panel would generally take about (10 × 4) 40 ft².

2.5.2 Wheeler Recreation System Analysis

This center has water tank size about 400 Gallons. Their desired temperature is about 160 °F. City water is supplied at around 45 °F. Therefore, we need to spec out our ST system for (160 – 45) = 115 °F. Based on size of our tank, amount of energy required to raise the temp of 115 Degrees (115 × 400 Gallons x 8.3 BTU/Gallons) = 383180 BTUs. This is to raise the temperature inside the storage tank to heat it up to 160 degrees.

So we take average as 25,000 BTUs/Panel/Day for our design. We need (383180 BTUs / 25000 BTUs/Panel) = 15 Panels to meet our demand.

Our Cost would be (15 Panels × $2000 / Panel) = $30,000. We need space about (15 × 40) 600 ft².
CHHP plants can provide three important products: electricity to power the campus, thermal energy for heating/cooling purposes and hydrogen for transportation, back-up power or other needs.

The fuel used in CHHP system is Biogas produced by the anaerobic digestion of solid waste, collected in a central collection tank and supplied to the Biogas plant.

The Energy content of the Biogas $= 841 \text{ Btu/ft}^3 = 31335 \text{ kJ/m}^3$ \[1\]

Equivalent Full Load Hours $= 24 \times 300 = 7200 \text{ hr/year}$

Note: We have considered the number of days, when the campus buildings require power to be 300. This consideration is due to very low power demand on campus during summer holidays.

Based on the fact that the University buildings operated by the CHHP system are a couple of dormitories, a cafeteria and a recreation system; which would require the CHHP system to operate in Full Load condition unless during the summer break.

3.1 CHHP System Thermal Output

Useful thermal output of the CHHP system (MMBtu/year)

$$= (\text{Rated output of DFC 300 system at } 120^\circ\text{F (MMBtu/Hr)} \times \text{Equivalent Full Load Hours (hr/year)})$$

$$= (0.808 \times 0.62) \times 7200$$

Useful thermal output of the CHHP system $= 3600 \text{ MMBtu/Year}$

Avoided Fuel Thermal (MMBtu/year)

$$= \frac{\text{(Useful Thermal Output of CHHP System (MMBtu/year))}}{\text{Displaced Boiler Efficiency (\%)}}$$

$$= 3600 / 0.8^{[6]} = 4500 \text{ MMBtu/year}$$

In our design, heat comes from two sources, one is DFC300 Fuel Cell and the other one is solar thermal panel placed on the roof of wheeler recreation center. All this heat resources will be used, combined with current boiler heating system. Heat load in our design consisted of 4 buildings: Wheeler Recreation Center which has independent boiler, Cooper Hall; Chaffee Hall, and Marina Dining Hall which has a common boiler located into Cooper Hall. Details for the heat end use system can be illustrated by Figure 8:
3.2 CHHP System Electricity Output

Net Electrical Output (kWh) = Gross Electrical Output (kWh) – Parasitic Loads (kWh)

= 275 kW – 25 kW

Net Electrical Output (kWh) = 250 kW

Avoided Central Station Electricity (kWh) =

Net Electrical Output Exported (kWh) + (Net Electrical Output Onsite (kWh) / (1 - T&D Loss factor)) = 0 + (250/(1-0.0647))

Avoided Central Station Electricity = 267.29 x 7200 = 1,925 MWh / Year

The electricity produced by the DFC 300 Fuel Cell is sufficient to power all four buildings under design consideration. Hence, the power output in the form of electricity will be enough to make the buildings independent from the central grid. However, proper arrangements will be done for providing backup power to the building from the grid, in case of CHHP System down time.
3.3 CHHP System Hydrogen Output

Amount of Hydrogen produced by the CHHP system (kg/year) = Hydrogen production rate (kg/hr) × Equivalent Full Load Hours (hr/year)

Amount of Hydrogen produced by the CHHP system = \((275 \times 0.4536) / 24 \times 7200\)

Amount of Hydrogen produced by the CHHP system = 34,422 kg/year

# As per the project fact sheet on Electrochemical Hydrogen Separator by Fuel Cell Energy, 275 pounds of hydrogen is produced per day by the DFC 300 system.

The produced Hydrogen will displace Gasoline use in the university vehicles, used for transportsations and facility managements.

Avoided Fuel Hydrogen (MMBtu/year) = \((\text{CHHP System Hydrogen Output (kg/year)} \times \text{Hydrogen Consumption Rate (Miles/kg)}) / (\text{Displaced Gasoline Consumption Rate (miles/gallon)} \times \text{Gasoline Heat Content (MMBtu/gallon)})\)

Avoided Fuel Hydrogen = \((34422 \times 35) / (15 \times 125)\) MMBtu/year

Avoided Fuel Hydrogen = 438.42 MMBtu/year

# The fuel efficiency of the university vehicles is assumed 35 miles/kg of Hydrogen Gas.

Total Fuel Savings (MMBtu/year) = \((\text{Avoided Fuel Central Station (MMBtu/year)} + \text{Avoided Fuel Thermal (MMBtu/year)} + \text{Avoided Fuel Hydrogen (MMBtu/year)}) - \text{CHHP Fuel Consumption (MMBtu/year)}\)

Total Fuel Savings = 6498.53 MMBtu/year

Our CHHP system will produce 275 pounds (124kg) Hydrogen per day; this is a valued resource for the hydrogen consumer. In our design, school transportation was deemed to be potential Hydrogen consumer. Assume all the school transportsations were refit into Hydrogen vehicle, thus to find out the Hydrogen demands for current school transportation system, we have following calculation:

Through analyzing the parameters of current gasoline-based school transportation system, we understand the amount of all school vehicles’ daily mileage is 3180 miles (see Table 1). Since fuel mileage of hydrogen-based vehicle is 35 miles/kg, it is easy to calculate that daily hydrogen demand of school transportation system is at least 91kg. This result shows that our hydrogen production rate is sufficient to fuel current school transportation system.
<table>
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<th>Daily mileage</th>
<th>Amount</th>
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<tr>
<td>Facility Services Vehicles and Vans</td>
<td>10</td>
<td>30 mile/day</td>
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</tr>
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</table>

Table 1. Calculation for school transportations

Besides hydrogen used for school transportation, we also have another hydrogen consumer on campus, that is, a PEM fuel cell which located into UB Renewable Energy Lab. By using this appliance, student can not only study the hydrogen characteristic through series of experiments but also connects it to “Micro Grid System” to deliver electricity to the grid. Details for PEM fuel cell and Micro Grid System see Appendix B.

Since PEM fuel cell is an experimental based appliance, the hydrogen consumption is not huge and easy to be controlled, therefore the main usage of hydrogen stored in the tank is still school hydrogen transportation.
3.4 Exceptions

Although our design is reliable, there are lot of extreme conditions may impact our system even destroy it. The most effective way to prevent our system from such condition is to take preventive measures. Hence, we have considered all the potential conditions to be prevented.

1. Lack of resources:
   a. Long term vacation: The decreased campus residents’ amount will dramatically reduce amount of organic waste and reduce the hydrogen and electricity production as well.
   b. Consecutive cloudy days will lead to the low efficiency of solar thermal system and then impact on the heat cycle system.

   **Solutions:** Along with operating hydrogen vehicle, we recommend reserving few gasoline-based school transportations in case of extremely condition; even though our CHHP design can meet most of the heat requirements, we still leave original boiler in our design to be an optional heat source; electricity will never be a problem when all load still connected to the grid.

2. Excess production:
   a. Hydrogen production rate increases compare to its consumption rate which could be caused by interruption of the use of hydrogen-based school transportation.
   b. Burning hot summer day will generate abundant heat resource while heat requirement drops in the meantime.

   **Solutions:** The hydrogen tank in our design has a volume will contain almost 2 day’s hydrogen production from CHHP system. Also some of the hydrogen can be stored into portable tanks for PEM fuel cell usage. If hydrogen-based vehicles out of service for a long time, the system should be turned off in case of hydrogen tank safety issue; excess of heat resource could be delivered to the swimming pool which has a huge demand of heat. Boilers can also be considered to stop under specific condition.

3. Extreme weather

Since University of Bridgeport located at the seaside, some extreme weather issues also need to be considered such as: hurricane/tornado, tsunami/flood. Those issues have big impact on the normal operation of CHHP system. Sometimes, system could be destroyed by those unusual extreme weather.

   **Solutions:** First of all, our system located at a high altitude area compare with other campus region, normally wind and flood will not affect CHHP system. Once weather is really bad, the whole system will be shut down and valves operated manually will be closed. If the situation is critical and system faces to the danger of destroying, apart from shutting down system, hydrogen should also be discharged. This effectively prevent hydrogen tank explosion.
4. Safety Analysis:

4.1 CHHP System Safety

The CHHP System is producing a large amount of Heat, Hydrogen and Electricity which could result into a potential hazard if proper safety precautions are not taken. These precautions could be taken by the implementation of established safety codes for the installation and operation of such systems.

The Heat produced by the system is used to heat water which will eventually be transmitted to all the buildings for the purpose space heating. Hence, established safety codes for the Heating, Ventilation and Air-conditioning of spaces occupied by large number of people are applied to the design.

For the installation of a supplementary Solar Thermal system used for providing additional heat following safety consideration are made;

Evacuated tubes can operate even on cloudier days. They use somewhat fragile glass — think of an insulated vacuum-sealed bottle. However, they may have some problems where snow or ice may accumulate and need to be removed. There can also be problems if breakage or damage destroys the all-important vacuum or from heat buildup if there is not an adequate draw on the system.

a. Installer need special training and license to be able to safely install system on roof with zero injury to themselves and zero damage to land and/or roof structure.

b. Home owners/building manager need to be educated to take cautions should they need to go on roof while system has been installed already.

c. Water pipes need to be properly insulated to minimize heat loss and minimize human injury due to hazard of extremely hot water temperatures.

Moreover, the electricity produced by the CHHP system is to be supplied to the building in the design consideration. The distribution system of the electricity should comply with the safety code established by the authorities.

We are challenged to plan and design the basic elements of residential hydrogen fueling system and installation. Therefore the safety of the residents who lives in the selected building is the big issue, we must consider. Since, Hydrogen is flammable over a wide range of concentrations and its ignition energy is very low, therefore any little problem will lead to disaster. The safety issue in our design can be divided into two phase: unpredictable safety hazards and predictable safety hazards.
We have done a failure mode and effect analysis of the system, for this the effects are scaled on the base of their severity have a scale from 1 to 10 where, 1 is the least severe effect while 10 is the most severe effect. The likelihood of a cause is also scaled from 1 to 10 where, 1 is least likely and 10 the most likely cause. The severity (S) is then multiplied by the likelihood (O) of the event’s occurrence in order to obtain a critical number (CRIT).

The Primary Failure mode and Effect analysis is as following:

<table>
<thead>
<tr>
<th>Function</th>
<th>Potential Failure Mode</th>
<th>Potential Failure Effects</th>
<th>S</th>
<th>Potential Cause of Failure</th>
<th>O</th>
<th>CRIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic Digestion</td>
<td>Stopped Biogas Production</td>
<td>No fuel Supply to DFC System</td>
<td>1</td>
<td>System Shutdown</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Reduced Biogas Production</td>
<td>Low Fuel Supply to DFC System</td>
<td>1</td>
<td>System Operation Errors</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Biogas Leakage</td>
<td>Suffocation, Fire, Explosion</td>
<td>10</td>
<td>Failure of the Collection Valve</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Digester Material Leakage</td>
<td>Litter Buildup, Suffocation</td>
<td>5</td>
<td>Failure of the Waste Removal System</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Compressor</td>
<td>Overpressure</td>
<td>explosion; leak; fire</td>
<td>10</td>
<td>failure of downstream valve; failure to remove a downstream blind; leakage on suction side; increase of surrounding temperature</td>
<td>3</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>High temperature</td>
<td>explosion; leak; fire</td>
<td>10</td>
<td>failure of lubrication system; failure of cooling system</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>Reverse Flow</td>
<td>explosion; fire</td>
<td>10</td>
<td>high discharge side pressure; operator falsely turned off valve when leak</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Artificial damage</td>
<td>leak; implosion; fire</td>
<td>10</td>
<td>seriously damage from external; falsely operating when emergency</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Electricity spark</td>
<td>explosion; fire</td>
<td>10</td>
<td>failure of lubrication system; mechanical failure</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Water invade</td>
<td>shot circuit; fire; implosion</td>
<td>10</td>
<td>Flood</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Overpressure</td>
<td>explosion; fire; suffocation</td>
<td>10</td>
<td>excessive fill rate; ignition; external fire; obstructed vent;</td>
<td>3</td>
<td>30</td>
</tr>
</tbody>
</table>
Table 2. Primary failure mode and effect analysis

Hence, based on our analysis the Dispensing of the Hydrogen gas proves to be the most critically hazards process.

4.2 Code and Standards

All the equipment we chose and parameters of our design meet with the codes and standard given below. As hydrogen and fuel cell technology are getting improved, new safety challenges are expected to be discovered and should be addressed by some updated code and standard.

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Code &amp; standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>All equipment</td>
<td>AIAA G-095, ISO TR 15916, CGA Publication H4</td>
</tr>
<tr>
<td>Piping system</td>
<td>NFPA 55, EIGA Doc 120/04, HPGSL</td>
</tr>
<tr>
<td>Storage</td>
<td>CGA Publication H6, NFPA 55, CGA Publication PS17</td>
</tr>
<tr>
<td>Dispenser</td>
<td>SAE J2799 - TIR, 20083235-T-469, 20083233-T-469</td>
</tr>
<tr>
<td>Detector</td>
<td>ISA 12.13.01, ISO 26142</td>
</tr>
</tbody>
</table>

Table 3. Code and standard
In today’s tough economy, almost every country in the world is going through financial hard times. With the continuous growth in the demand for energy, the quantity of fossil fuel is diminishing day by day. This is leading to the unstoppable rise in the cost for getting energy in the form of hiked electricity bills and gasoline prices. Many educational institutions in United States are facing budget cuts and hence, they are trying to reduce their operating expenses through whatever means they can. But the strong competition and the desire to grow more make them use energy even more. So there should be means by which they can reduce their expenses on energies somehow.

The same financial concern is being faced by University of Bridgeport as well. To keep electricity, heat and transportation prices affordable in the future, we have to use energy more efficiently and devote more research to the development of renewable sources. With the use of CHHP, the utility expenses can be brought down to a great extent. After doing some calculations, it is evident that the initial cost for installing this plant is quite high, but in the long run it can be cost effective method.

Cost Calculations and Return on Investment:

Our plant will support four university buildings:

- Cooper Hall (University Housing)
- Chaffee Hall (University Housing)
- Wheeler Recreation Center
- Marina Dining Hall

Along with supporting these buildings plant will also produce Hydrogen fuel for running university vehicles replacing conventional gasoline. The installed CHHP will take care of 25% of complete utilities expense on Bridgeport campus of University of Bridgeport.

Capital Cost: Capital cost includes the total expenditure which University of Bridgeport needs to install CHHP Plant (including each component and installation). This is one time expenditure.
<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>DFC 300</td>
<td>$1,050,000.00</td>
</tr>
<tr>
<td>Solar Thermal</td>
<td>$35,000.00</td>
</tr>
<tr>
<td>Hydrogen Tank</td>
<td>$400,000.00</td>
</tr>
<tr>
<td>Hydrogen Fueling System and Safety Equipment</td>
<td>$300,000.00</td>
</tr>
<tr>
<td>Biogas Plant</td>
<td>$50,000.00</td>
</tr>
<tr>
<td>Replacement Cost of 22 vehicles* @ $25,000.00</td>
<td>$550,000.00</td>
</tr>
</tbody>
</table>

**TOTAL CAP COST**  
$2,385,000.00

Table 4. Total Estimated Expenditure on DFC, Bio Gas Plant and Solar Thermal

*Currently, school vehicles run on gasoline so we either need to install Hydrogen Kits in the existing vehicles or completely replace the old vehicles with the new one. After analyzing the costs involved, we have decided to buy the new vehicles. $25,000 is the average price for buying one new vehicle less selling price for old one.

Maintenance and Operation Cost:

This cost includes expense which has to be borne every year for running CHHP system.

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maintenance Hydrogen System</td>
<td>$12,000.00</td>
</tr>
<tr>
<td>Maintenance DFC</td>
<td>$11,475.00</td>
</tr>
<tr>
<td>Salary for Employees*</td>
<td>$216,000.00</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$239,475.00</strong></td>
</tr>
</tbody>
</table>

Table 5. Maintenance and Operation Cost (Per Annum)

* Cost for hiring 2 additional employees we require for operating the system.

Return on Investment (ROI): This is the number of years required to recover the cost from any investment. We have calculated ROI by analyzing the money which we will be saving each year after installing CHHP.
<table>
<thead>
<tr>
<th>UNIT COST</th>
<th>UNIT</th>
<th>Avoided Fuel</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity</td>
<td>0.2*</td>
<td>KWH</td>
<td>1925000</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>11.5*</td>
<td>cf</td>
<td>$4377 \times 10^3$</td>
</tr>
<tr>
<td>Gasoline</td>
<td>4**</td>
<td>Gallon</td>
<td>80318</td>
</tr>
</tbody>
</table>

| Maintenance PA |  |  | ($239,475.00) |
| Savings PA |  |  | $517,132.50 |

Table 6. Savings Per Annum

* Average unit cost for Electricity and Natural Gas (commercial use) 2011
** Approximate gasoline price

Return on Investment (in years) = \frac{\text{Total Capital Cost}}{\text{Savings PA}}
= \frac{$2,385,000.00}{\$517,132.50}
= 4.61 Years

This shows after 4.61 years we will able to get the breakeven point for our investment and after that we will start saving money every year for approximately 8 years (life of CHHP).
In this society, the environment becomes the important issue for any country. Especially the gasoline, it is the most reason to destroyed the world rapidly, because the gasoline will produce the carbon dioxide (CO$_2$). It will make the average annual temperature increase, and make our living environment becomes worst. Now there are many scientists around the world want to find the solutions to solve it, and the hydrogen based automobile will dramatically drop the gasoline usage. Hydrogen and fuel cell system is effective method can reduce the carbon dioxide (CO2) from the gasoline.

CO2 emissions associated with the CHHP system fuel consumption:

\[
\text{CHHP CO2 Emissions (tons/year)} = \frac{(\text{Fuel Consumption (MMBtu/year)} \times \text{Net CO2 Emissions Rate (lb/MMBtu)})}{2000 \text{ lb/ton}}
\]

\[
\text{CHHP CO2 Emissions (tons/year)} = 0
\]

All biomass CO2 are assigned a net CO2 emissions value of zero because these organic materials would otherwise release CO2 (or other greenhouse gases) through decomposition. [3]

### 6.1 Avoided Central Station Fuel and Emissions

Avoided CO2 Emissions Central Station (tons/year) =

\[
\text{Avoided CO2 Emissions Central Station (tons/year)} = \frac{(\text{Avoided Central Station Electricity (kWh) / 1000)} \times \text{Average Fossil CO2 Emission Rate (lb/MWh) / 2000 lb/ton}}{2000 \text{ lb/ton}}
\]

\[
= (1,925,000/1000) \times (1236.1/2000)^{[5]}
\]

Avoided CO2 Emissions Central Station = 1189.75 tons/year

### 6.2 Avoided Thermal Fuel and Emissions

Avoided CO2 Emissions Thermal (tons/year) =

\[
\text{Avoided CO2 Emissions Thermal (tons/year)} = \frac{(\text{Avoided Fuel Thermal (MMBtu/year)} \times \text{Net CO2 Emissions Rate (lb/MMBtu)})}{2000 \text{ (lb/ton)}}
\]

\[
= 4500 \times (116.8^{[1]}/2000)
\]

Avoided CO2 Emissions Thermal = 262.8 tons/year
6.3 Avoided Gasoline Fuel and Emissions

Avoided CO2 Emissions Hydrogen (tons/year) =
\[(\text{Avoided Fuel Hydrogen (MMBtu/year)} \times \text{Net CO2 Emissions Rate (lb/MMBtu)}) / 2000 (lb/ton)\]

\[= (642.544 \times 154.8) / 2000\]

Avoided CO2 Emissions Hydrogen = 49.73tons/year

**Total CO2 Savings (tons/year)** =
\[(\text{Avoided CO2 Central Station (ton/years)} + \text{Avoided CO2 Thermal (ton/years)} + \text{Avoided CO2 Hydrogen (ton/years)}) – \text{CHHP System CO2 Emissions (tons/year)}\]

\[= 1189.75 + 262.8 + 49.73 – 0\]

**Total CO2 Savings = 1502.28 tons/year**

This shows a significant reduction of the Greenhouse gas addition in the environment through the replacement of conventional systems by CHHP System. It moreover emphasize the use of waste (sewer and organic) which would otherwise prove to be pollutants to the environment, even after being processed to discharge.
The objective of marketing is to make people aware of the environmental, social and economic benefits of using renewable energies. There are many forms of renewable energies which people can use in their daily lives by replacing the conventional sources like grid electricity, gasoline etc. It can be used for different purposes like heating homes, generating electricity etc. Over dependence on energy from fossil fuels are having serious repercussions on the world environment. We must realize that non-renewable sources of energy like coal and petrol will get exhausted in the future. In order to delay the inevitable and to slowly make a transition from non-renewable sources of energy to renewable energy options, we should use the natural resources of earth like wind, water, solar. We are emitting roughly 2 billion tons more CO2 than our earth can naturally absorb. Hence, if renewable sources of energy are used, we would be able to reduce these emissions to zero.

There are major benefits of using renewable sources of energy. They are environment friendly, available in a much larger quantities as compared to non-renewable sources of energy. Also, if we are able to utilize 100% of these resources we would create a much cleaner world and find more useful ways of using fossil fuels. Windmills are being used in industries to generate electricity and solar powered equipment is getting more and more popular. But, the initial cost of installing such devices is very high and one of the deterrents for its widespread use. We can gauge the importance of using renewable sources of energy from the fact that a single bolt of lightning is enough to provide electricity to 50,000 households. However, we still have not developed the infrastructure and technology to make use of the wonderful renewable sources of energy.

There are other socio-economic benefits of using renewable sources of energy. According to one estimate, it would create 2.8 million jobs in this sector. In the current economic scenario, this would boost the global economy. Also, there would be less in-fighting between nations of the world for non-renewable sources of energy like oil.

So it is most important to change the mindset of people by motivating them to use renewable energies. The best way to achieve this is to start from the root level which is Educational Institutes. Along with marketing this also serves as the purpose of educating students.

In the First Phase of marketing we will be targeting the schools, community colleges and universities which are in the vicinity of University of Bridgeport. The institutions which we will be targeting are, Fairfield University, Sacred Heart University, University of New Haven, Frank Scott Bunnell High School, Christian Heritage School and Kolbe Cathedral High School. Strategies which we will be following:

1. Seminars: We will seek permission from the respective institutions to arrange seminars, where will talk about benefits of renewable energies and show them how this can be utilized in the practical manner.
2. Technical Visits: We will invite the faculty and students of these institutions to visit the campus of University of Bridgeport to see how we have installed and making use of CHHP.

3. Canopy: We will setup canopy in the lobby of Wahlstrom Library where visitors can get information about CHHP installed on campus. Visitors of the library usually are parents of the students or personnel related to educational field.

Second Phase of marketing will target the community housing and business complexes. Again, we will target the complexes which are nearby University of Bridgeport. The targeted complexes include City Trust Apartments (Downtown), Cypress Apartments, Rowe Apartments New Haven, Avalon Gates Norwalk, Hotel Holiday Inn Downtown, and various other complexes. We will be contacting the general secretaries (care takers) of these complexes and convince them to install CHHP in the complexes by explaining them the benefits of these in long run.

Apart from this the other strategies which we will be following for promotion are:

**Hello Hydrogen** Association: After targeting local institutes, communities, complexes, etc we will form an association and ask the leaders of these organizations to become members of this organization. The purpose of forming the association is to generate funds through sponsorships. With the availability of funding, we will be able to expand the domain of our campaign to State level and later on to national level.

Social Media: Social media is the latest buzz in the world and many people get inspired through this in today’s world. So this would be one of the best media to promote the Hello Hydrogen Campaign. We will create a page on Facebook, a Twitter Profile and a YouTube Page in which we will upload the videos and presentations on Hello Hydrogen Campaign.

**Hello Hydrogen** Website: For any campaign to be successful, it is most important to have the web presence. We will design a website which will include all the information about CHHP like its benefits, installation guide, operating information and various other FAQs.

Our objective is to make most people aware of the benefits of renewable energy so that we can make this world an environmental healthy place to live. We are doing this for ourselves and for the future generation as well.
Hydrogen student design contest 2012

End to End concept

Wow! -- We just saved environment by reducing Carbon footprints

H₂

Yesss! Bye-Bye fossil fuel

It's cool to take shower from free energy.

solar thermal
APPENDIX A: Geometrical Dimensions of Cylindrical Shaped Biogas Digester Body

Figure a. Dimension of biogas digester body

Assumptions

For Volume:

- \( V_c \leq 5\% \ V \)
- \( V_t \leq 15\% \ V \)
- \( V_{gs} + V_{f} = 80\% \ V \)
- \( V_{gs} = V_{H} \)
- \( V_{gs} = 0.5 \ (V_{gs} + V_{f} + V_{s}) \ K \)
  
  Where \( K = \) Gas production rate per m\(^3\) digester volume per day

For Geometrical Dimensions:

- \( D = 1.3078 \times V^{(1/3)} \)
\[ V_3 = 0.3142 \, D^3 \]
\[ R_1 = 0.725 \, D \]
\[ R_2 = 1.0625 \, D \]
\[ F_1 = D/5 \]
\[ F_2 = D/8 \]
\[ S_1 = 0.911 \, D^2 \]
\[ S_2 = 0.8345 \, D^2 \]

Volume Calculation of Digester Chamber:

2500 Persons of Body Weight 50 Kg each (Daily Average Year Around)

Temperature = 20\(^\circ\)C
HRT = 60 Days

Total Solid Discharge = (0.5 Kg \times 2500) + (1 Kg \times 2500 \times 0.4) = 2250 Kg / Day

TS of fresh discharge = 2250 Kg \times 0.20 = 450 Kg

Amount of influent to be added to make 8\% concentration of TS (Favorable Condition)
Total influent required = 100 \times (450/8) = 5625 Kg

Amount of water required = 5625 – 2500 = 3125 Kg

Working Volume of Digester = \( V_{gs} + V_f \)

\[ = (2250 + 3125) \times \text{HRT} \]
\[ = 5375 \, \text{Kg/Day} \times 60 \, \text{Days} \]
\[ = 322500 \, \text{Kg} / 1075 \, \text{Kg/m}^3 \, (\text{Density of mixture}) \]
\[ = 300 \, \text{m}^3 \]

From geometrical assumptions:

\[ V_{gs} + V_f = 0.8 \, V \]

Hence, \[ V = (V_{gs} + V_f) / 0.8 \]

\[ = 375 \, \text{m}^3 \]

\[ D = 1.3078 \times V^{(1/3)} = 9.5 \, \text{m} \]
\[ V_3 = \left(\frac{\pi}{4}\right) \times D^2 \times H \]

\[ H = \frac{(4 \times 0.3142 \times 11)}{3.14} = 3.75 \text{ m} \]

Now from assumptions;

\[
\begin{align*}
R_1 &= 0.725 \times D = 6.9 \text{ m} \\
R_2 &= 1.0625 \times D = 10 \text{ m} \\
F_1 &= \frac{D}{5} = 1.9 \text{ m} \\
F_2 &= \frac{D}{8} = 1.1875 \text{ m} \\
V_c &= 0.05 \times V = 18.75 \text{ m}^3 \\
V_s &= 0.15 \times V = 56.25 \text{ m}^3
\end{align*}
\]

Volume Calculation of Hydraulic Chamber:

\[ V_c = 0.05 \times V = 18.75 \text{ m}^3 \]

\[ V_{gs} = 0.5 \times (V_{gs} + V_f + V_s) \times K = 0.5 \times 356.25 \times 0.478 = 85 \text{ m}^3 \]

\[ V_H = V_{gs} = 85 \text{ m}^3 \]

\[ V_f = 300 - 85 = 215 \text{ m}^3 \]
APPENDIX B: PEM-fuel cell and Micro grid system

PEM Fuel Cell

PEM fuel cell is a prime candidate for vehicle and other mobile applications of all sizes down to mobile phones.

The fundamental of fuel cell stack as figure showed. Fuel cell stack is the proper connection of some individual fuel cell in series. It is a device that converts the chemical energy from a fuel into electricity through a chemical reaction with oxygen. The fundamental of this reaction is oxidation-reduction reaction.

Figure c. PEM fuel cell internal process and external shap
Micro grid system

In this system, three kind of renewable energy were used to transmit electricity to specific load or the grid: Fuel cell, Wind turbine and solar panel.

In this system, an integrated control system which is located at Renewable energy lab of University of Bridgeport will be used to monitor both wind turbine and solar panel. In the meantime, electricity which generated by this system can be used either in the battery bank or directly transmits to the grid by using a grid-tie. This combined fuel cell-wind turbine-solar panel system does not only save energy but also is a great sample to educate students.
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