2011-2012 Hydrogen Student Design Contest:
Design a Combined Heat, Hydrogen and Power (CHHP) System for a University Campus Using Local Resources
---Florida International University

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Executive Summary

Every day, Modesto A. Madigue (MAM) campus of Florida International University (FIU) will generate large amount of waste, such as wastewater, organic waste, and landfills, which needs funding, space and labors to be processed and disposed. The state that FIU located, Florida—the sunshine state, is famous with abundant solar energy.

In our project, we designed a solar, biogas processing system to transfer the solar energy and waste from MAM campus into biogas by biological treatment, and then generate heat, hydrogen and power by application of fuel cell and photovoltaic tech. We are also planning to build a hydrogen station to charging the fuels cells for automobiles, farms, hospitals and other communities. We are going to save the biomass, landfills that generated by the nearby communities such as Miami-Dade county, the biomass from farms in homestead and everglades. We are going to distribute the product into FPL electricity grid, FIU and Miami Dade heat supply system as well as hydrogen service station.

The combined heat, hydrogen and power system (CHHP) is comprised by feedstock analysis, technical design, economic and business analysis, safety and environmental analysis, as well as educational and marketing plan. Technical support by biology, chemistry, electric engineering, Mechanical engineering, as well as materials science and engineering will be provided through the whole project. Upon the realization of the project, it will not only provide energy for university’s daily use but protect the environment clean from the waste. The fees for waste disposal and transportation will be saved and the energy generated could be utilized to meet the demand for university development.

The marketing and environmental analysis proved this project to be a profitable, high efficiency, environmental friendly and energy saving system which will be a model in Florida. This project is also going to serve as a model for public awareness of environmental protection, “go green” and energy savings.

In sum, we have designed a profitable, high efficiency, environmental friendly and energy saving system which will benefit the FIU and surrounding communities. As well, this model is also going to benefit the public awareness for green energy.
1 Energy Flows and Resource Availability Study

1.1 Energy demand
FIU’s University Park campus occupies 573.4 acres (2.32 square kilometer). It has an annual electrical energy demand of about 21 million kWh which is mainly covered by Florida state power supply services. Fig.1 shows the monthly distribution for energy demands in the fiscal year 2010-11.

Now, the challenge is to feed the electrical supply for FIU using the local resources. These local resources should be easily accessible as well as relatively cheap.

Preliminary calculation based on energy requirement in the year 2010-11 at FIU:
Annual electrical energy demand = 21189004 kWh
Thus, the total capacity of required electrical energy generating unit = 2.45 MW.
DFC3000 should be used for generating this much amount of energy.

However, if we consider month of November the energy demand capacity should not be less than 2.78 MW. Fortunately, this is within the capacity of a single DFC3000.

1.2 Feedstock Analysis
The resources which can be readily available at FIU and its surroundings have been keenly investigated. These preferably include organic wastes (papers, cardboards etc.) and waste water.

In addition, wood chips from land cleaning and urban tree trimming activities (can also be purchased from local areas like West Palm Beach and Fort Lauderdale etc.) should also be considered. Various local sugarcane based industries can provide bagasse which can be useful for biomass-based electrical energy production. Everglades can be one of the biggest providers for forest residues and grasses.

Florida is blessed to be a sunshine state. The sunlight can be a huge resource for the production of solar energy. FIU has been successfully utilizing solar powers for several years. Now, the time has come to enhance its prospect and let it be one of the largest contributors for the energy demands at FIU.

Energy distribution charts On the basis of available resources as well as economics, we have distributed our energy requirements into these three major contributors. Their contributions have been shown in percentage amount of the total requirement.
### Heat Content Ranges for Various Biomass Fuels

<table>
<thead>
<tr>
<th>Fuel type &amp; Source</th>
<th>Higher Heating Value, HHV (MJ/kg)</th>
<th>Lower Heating Value, LHV (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agricultural Residues</td>
<td>17.3-19.4</td>
<td>17.7-17.9</td>
</tr>
<tr>
<td>Sugarcane bagasse</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Herbaceous Crops</td>
<td>18.1-19.6</td>
<td>17.8-18.1</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>18.0-19.1</td>
<td>16.8-18.6</td>
</tr>
<tr>
<td>Switch grass</td>
<td>18.2-18.6</td>
<td>16.9-17.3</td>
</tr>
<tr>
<td>Other grasses</td>
<td>18.6-19.6</td>
<td>17.8-18.1</td>
</tr>
<tr>
<td>Forest residues</td>
<td>18.6-20.7</td>
<td>17.5-20.8</td>
</tr>
<tr>
<td>Hardwood wood</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Softwood wood</td>
<td>18.6-21.1</td>
<td></td>
</tr>
<tr>
<td>Urban Residues</td>
<td>13.1-19.9</td>
<td>12.0-18.6</td>
</tr>
<tr>
<td>MSN</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Newspaper</td>
<td>19.7-22.2</td>
<td>18.4-20.7</td>
</tr>
<tr>
<td>Corrugated paper</td>
<td>17.3-18.5</td>
<td></td>
</tr>
</tbody>
</table>

#### 1.2.1 Organic wastes
This includes papers and cardboards. The annual production (2008) of papers and cardboards at FIU was about 1000 tons. About 81% corresponded to that of papers.

#### 1.2.2 Waste water
The most common waste water is from sewage and drainage. The Facilities Management Department at FIU has upgraded the sanitary system. This led to a decrease in emission by 22% in recent years from wastewater. Waste water should be dark fermented and thus can be utilized for energy generation.

Needed amount of Feedstock and their contribution:

#### 1.2.3 Biomass based fuels without waste water
Efficiency of DFC =45% and efficiency of biomass converter.

Thus total heat content of fuels need to be processed per day = 180/ (.45*.4) =1000 GJ

Note: assumption has been made that 180 GJ of energy will be given by biomass and the rest will be delivered by solar power and waste water. Waste water will be retrofitted with biomass set up and run only in the night. However, solar power will be a totally isolated unit set up at different locations of FIU.

<table>
<thead>
<tr>
<th>Fuel type &amp; Source</th>
<th>Ton Per day</th>
<th>Energy content LHV( GJ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic wastes (Papers and cardboards)</td>
<td>10</td>
<td>190</td>
</tr>
<tr>
<td>Sugarcane bagasse</td>
<td>25</td>
<td>450</td>
</tr>
<tr>
<td>Forest residues</td>
<td>10</td>
<td>190</td>
</tr>
<tr>
<td>Grasses</td>
<td>10</td>
<td>170</td>
</tr>
</tbody>
</table>
Thus, the total energy content of the above feedstock is 1000 GJ/day. Fig.2 shows the pictorial representation of these distributions.

### 1.2.4 Waste water
The idea is to use dark fermentation process to generate electricity by the use of waste water at FIU and its surroundings. The needed amount of electricity should be around 10-12 GJ/day.

### 1.2.5 Solar Energy
The most efficient PV cells have an energy capacity of 120J/m². Our need is to achieve 20 GJ/day of solar energy that requires an approximate area of about $1.7\times10^5$ m² i.e. 7.33% of whole FIU campus area. We will locate the positions at university campus which will be most suitable to set up these solar panels.

This chart shows the average hrs of sun in Miami during different months of a year.

Approx. 8 hrs of sun is available throughout a year in Miami.

All of this sewage goes to a central county operated system (Miami-Dade Water and Sewer Department). Now, what kind of treatment they use once this wastewater is in their processing plant I am not sure. Within FIU we do not have any kind of treatment process. Again, all of our wastewater flow into the county system and it is collected by their central plant.
2 Combined Heat, Hydrogen and Power Facility Technical Design

2.1 Site Plan
Fig 2.1 shows the location of DFC 3000 and Hydrogen gas station. The DFC 3000 is designed to be constructed along the SW 8th Street in the FIU Main campus, based on the consideration of feed stock transportation as well as the conjunction between the Fuel Cell and gas station.

From the feed stock analysis, the wastewater and landfills are mainly come from outside campus. So the construct site for DFC 3000 along SW 8st, which is the main road in the Sweetwater area, will give convenience for the transportation of the energy source from outside FIU.

As we know the hydrogen storage and hydrogen transportation will be a big problem if we cannot use onsite hydrogen generation. So constructing the hydrogen station nearby the DFC3000, the hydrogen generation source, will solve the problem and save the cost that are to be generated by the transportation and storage of hydrogen.

For the hydrogen station of FIU, we are going to choose PG5 as a target for service. The general storage tech is going to be high pressure tank. The hydrogen could be generated from methane and transported from nearby DFC 3000. So construct DFC 3000 near the station will lower the total cost, considering transportation. However, safety analysis is required since the site is of high population density.
The location for the Hydrogen station is also considering the traffic flow all the year. From the Fig 2.2, we can find the gas station distribution in the Sweetwater area. The SW 8st has the highest gas station density which indicates the highest traffic density. This evidence shows a very good marketing opportunity for the newly built hydrogen distribution station for the renewable energy, based on the fact that hydrogen station will not share the market with other traditional gas station which leading the marketing shrink.

Fig. 2.3 shows the design of hydrogen service station. The hydrogen comes from fuel cell plant (DFC 3000) with pressure of ~50psi. The highest pressure of the Hydrogen tank is about 11600 Psi for compressed gas or liquid hydrogen (6000 Psi practically limited by the compressor). The hydrogen tank is built underground 5 to 15 meters deep for safety concern. The tank is designed to conserve the hydrogen amount that DFC 3000 generated for 30 days. This station is also...
designed with a convenient store and parking lot for the automobiles coming from SW 8th Street, Miami, Florida.

The Fig2.4 shows the feedstock storage (biomass & Landfills, waste water pond), conversion systems(FICFB Reactor), fuel cell power plant(DFC3000), power distribution(DC to AC reactor for FPL), heat distribution system (hot water generator and pipelines), hydrogen production equipment (Hydrogen clean and recovery system), dispenser(Hydrogen pipeline to Hydrogen Station). We build the hydrogen tanks in Hydrogen station underground for safety concern (in Fig. 2.3). We are going to build one waste water pond to storage the waste water. The waste water comes from the pipeline connected to the whole campus or even Sweetwater sewer system.

2.2 Technical Design

2.2.1. Feedstock Delivery System and Storage
According to our calculation 55 tons of biomass is needed per day in order to produce 1000GJ energy. This alone requires about 4 to 5 truck delivering the feedstock every day. To Store this amount of biomass it will requires a storage container of at least 3200 m³. To process to the gasification the biomass fuel will be bring to the reactor, and then the gases produced will be process until separation of hydrogen and methane. The residue produce from the operation will be transported out of campus by trucks through the Miami Dade waste system by trucks.

2.2.2 Gasification Reactor
Various technologies have been introduced for the gasification of solid fuels. The basic classification of these processes is (a) fluid bed systems; (b) Fluidized bed systems; and (c)
entrained flow systems. These processes can be run at ambient or increased pressure and serve the purpose of thermo chemical conversion of solid biomass into a secondary fuel in a gaseous state. Fluidized-bed reactors contain a fluidized mix of bed material and biomass. The gasification medium flows in through the nozzle bottom and fluidizes the bed material. This can be inert, as for example quartz sand or also catalytically active with regard to the conversion of organic contaminants in the crude gas through possible after-reactions in the gas phases. The fuel, which is shredded and has a maximal edge length of 50 mm (to 100 mm) is fed into the fluidized or circulating bed. Depending on the degree of fluidization, i.e. inflow speed of the fluidization/gasification medium, one differentiates between a bubbling and circulating fluidized bed. In the case of the circulating type, the bed material removed from the combustion chamber must be precipitated out of the gas stream by a cyclone and then re-circulated into the reaction chamber.

The process concept lies in the idea that first the fuel is normally fed using conveyor belt into the gasification reactor via an air-tight closure. Hence, the fuel is converted into producer gas in the gasification reactor. The other processes of drying, pyrolysis, oxidation and reduction takes place in the gasification or auxiliaries reactors.

Here, we have selected the fast internal circulating fluidized bed (FICFB) gasification design, which is realized in a demonstration plant of 8 MW\textsubscript{fuel} in Gussing (Austria) since 2002. The process consists of two fluidized bed, one for gasification with steam (left) and one for the combustion of a part of the fuel for heating up the bed material, which is internally circulated between combustion and gasification zone [figure 1]. This creates a major advantage because it allows the gasification and heat generating combustion reactions to be separated and occur in two different reactors. This is an example of an allothermal gasifier. The result is producer gas can be generated with a heating value three times higher than conventional gasifiers because very little nitrogen is allowed to enter the gasification reactor where the producer gas is generated. Hence the producer gas can have a calorific value of 13-15 MJ/Nm\textsuperscript{3} compared to the usual 4-6 MJ/Nm\textsuperscript{3}. Depending on the gasification principles (reactor geometry, used gasification agents – air, steam, oxygen) different qualities of the producer gas relating gas composition, tar content, dust content in the raw gas before gas cleaning can be achieved.

**Gas Cooling**

Gas cooling is to be employed in such a way that an appreciable temperature of producer gas can be attained and thus can be able to fulfill all the requirements. In demonstration facilities the reactor discharge (500-800°C) is cooled down to a level of about 100-500 °C, e.g. to be able to carry out dry particle filtration with ceramic filters or fabric filters respectively. To do so, suitable
coolers and chillers need to be installed, which allows to decrease the producer gas temperature on a certain stable level as well as which allows to fall below the dew point of the producer gas. The gas cooling therefore requires well founded design of the various heat exchangers according to the application requirements of wood gas.

**Gas Cleaning**
Gas cleaning serves the purpose of providing constant gas qualities. Gas cleaning has the task of de-dusting the producer gas as well as ensuring suitable purity regarding tar load. The two possible ways are

(i) combined gas de-dusting and gas cleaning by means of suitable scrubber columns
(ii) Separate gas de-dusting and gas cleaning by means of a preliminary hot/warm filtration for particle separation with subsequent gas cleaning of tarry compounds, whereby attention must be paid to the subsequently required costs for separation of mixtures and for processing and disposal, e.g. waste water treatment.

**Design parameters for FICFB**
Air is injected into the base of the combustion reactor to fluidize the bed material in the bottom of the combustion column and provide some air for combustion of the char. Additional air injection is supplied through the primary air jets to entrain the bed material against gravity up the combustion column. This extra air also oxidizes char and any additional fuel that is introduced. The amount of fluidizing air must be controlled to limit the flow of air up the chute into the gasification zone. Too much air, too lower down, means unacceptable amounts of air track up the chute into the gasification column (Loffler et al., 2003). Some combustion columns have a diffuser section in, above the primary air jets to keep the gas velocity in the desired range. A diffuser strongly enhances particle reflux by increasing the thickness of the wall layer of the downflowing solids (annulus) (Loffler et al., 2003). The vertical positioning of the diffuser is important in relation to the fluidization regime.

Many factors affect the solids circulation rate throughout the FICFB gasifier. This is important because the circulation rate determines the amount of thermal energy which is conveyed form the combustion column to the gasification column. This affects the temperature of the gasification reactions which is a significant parameter influencing the producer gas composition and the tar levels in the gas. Speeding up the circulation rate will reduce the temperature difference between the exothermic combustion reactions and the endothermic gasification reactions. Optimizing the gasification temperatures is an important parameter to drive the equilibrium gasification reactions in the most favorable directions. It is also important that the residence times are long enough in the different stages of the processes occurring within the gasifier so that optimal performance occurs.

Increasing the particle diameter or the particle density decreases the solids circulation rate and the
solids preferentially remain in the lower parts of the fluidized bed. The solids circulation rate can be increased by increasing the total pressure differential across the bed by having a greater bed material loading in the gasifier. At high gas velocities in the combustion column, the solids circulation rate is limited by the bed height in the BFB. The lower the bed height in the BFB, the lower the head of sand developed to push bed material through the chute and into the combustion column.

Gas volume flow rate is the most significant factor effecting circulation rate. However, solids circulation rate is also strongly increased if the entraining gases are introduced lower down in the combustion column. Thus, the bottom air flow has the most pronounced effect on the solids circulation rate. Increasing the height of the primary air jets significantly decreases entrainment and the solids circulation rate.

An important criterion for operating a dual fluidized bed system is the stability of solids circulation with variations in the outlet pressures of the two reactors (flue gas and producer gas outlets). These variations can be caused during normal operation by downstream fabric filters and power plants malfunctions.

M. Bolhär-Nordenkampf in his work made an effort to scale-up by a factor of 80 from the 100kWth pilot plant to the 8MWth demonstration a fundamental study in terms of fluid dynamic had to be carried out. To optimize the two-phase fluid dynamic in the FICFB-reactor a cold flow model made of Plexiglas was set up. The experimental simulation was designed according to the model theory of Glicksman, keeping the parameters Fr, Re, rp/rf and L/dp constant. But we need to have only 2.363 MW of energy from the biomass. Thus, the figure to be considered must lie in between these two values and precise figure can only be obtained when simulation will be designed for this requirement.

| Table 2.1: Technical data used in the demonstration plant and the cold flow model |
|-----------------------------------------------|-----------------|-----------------|
| Parameter                      | Symbol | Demonstration plant | Cold flow model Dimension |
| Bed material                  | quartz  | sand bronze         |
| Particle density              | ρP     | 2500               | 8750 kg/m³ |
| Bulk density                  | ρS     | 1440               | 5380 kg/m³ |
| Average particle Diameter     | dP     | 440-600            | 110-150 μm |
| Shape factor                  | ψ      | 0.9 – 0.95         | 1 |
| Fluidisation Medium           | Steam/Air | Air                |
| Temperature                   | T      | 800 - 900          | 20 °C |
| Density                       | ρ      | 0.3243 – 0.2967    | 1.1881 kg/m³ |
As mentioned in our earlier report on the resource assessment, we have more than sufficient methane availability. In precise, Miami Dade has 7615.97 scfu methane/h. However, molten carbonate based fuel cell DFC 3000 requires just 362 scfu methane/h, which is about 5% of available resource. The required amount of biomass to run DFC 3000 is about 16.18 tonne/h (Assuming that the whole process runs just for 18 h in a day or ¾ of an year).

Methane density= 0.68 kg/m³ at 1.013 bar and 15 °C (59 °F)
1 ft³ = 0.028 m³
Methane density= (0.68/0.028) kg/ft³ = 24.28571 kg/ft³
362 scfu= 362 ft³/min= 362 ft³/ (1/60) h = 21720 ft³/h = 608.16 kg/h ~ 0.61 tonne/h

As it is known that in the biogas, methane gas is diluted in carbon dioxide. Since biogas has 50-75% methane, it does not affect on efficiency of the fuel cell.

The required water for DFC 3000 ~ 1.22 tonne/h (Water/ Methane= 2/1)
Once the biogas and water is mixed, it is then passed through a heat exchanger as shown in Figure 2. After this, heated mixture is then feed into the DFC3000. Where, internal reformation reaction first takes place which is a very energy intensive process. Reaction that happens:

$$\text{CH}_4 + 2\text{H}_2\text{O} = 4\text{H}_2 + \text{CO}_2 \quad \Delta H_{298} = 165 \text{ kJ/mol}$$

The required energy to run this process for 608.16 kg/h of methane feed
= (165kJ/16 gm)* 608.16 kg = 6271.65 MJ = 1742.125 KWh

**Figure 2.5: FICFB Reactor Design**

The anode outlet gas composition based on wet condition suggests that about 10% is hydrogen gas. Assuming it to be
on molar basis, our calculation shows that 33.88 kg H₂/h is given out. Since hydrogen gas has an energy density of 141.86 MJ/kg. It implies that generated hydrogen in an hour has a total energy capacity of 1335.41 KWh. Carbon dioxide that is emitted out is 3355kg CO₂/h. Carbon dioxide needs to be fed back into the fuel cell in order to ensure its continuous operation.

![Figure 2.6: Process flow diagram using biomass fed FICFB gasifier integrated with DFC 3000](image)

To acquire pure hydrogen gas and run the fuel cell, it is necessary to separate hydrogen and carbon dioxide. The first step that we need to do is to cool down the anode outlet gas and then operates the water gas shift reaction. This reaction will emit water and only carbon dioxide and hydrogen gas will be remained in the composition. These two gases will now be separated using pressure swing adsorption method. Pure hydrogen gas is finally taken out and can be used for refueling gas station. Carbon dioxide with partial fraction of hydrogen is then used as an inlet for anode gas oxidizer chamber and finally CO₂ is fed into DFC 3000.

### 2.2.2 Power and heat distribution

The electricity that is generated from CHHP system is majorly going to be input FPL system, which is going to be detailed in section 3.1. Small part of the electricity is going to be used by CHHP system for self use.

The heat that is generated by CHHP system is going to be used by several aspects (detailed in section 3.2), such as DCF-ERG system, preheat the incoming air before DFC 3000, preheat the gasification problem, and generate hot water for campus and Sweetwater supply system. The Fig below shows the heat transferred to Compressed Gas to increase the pressure to power the generator for extra gas(DCF, ERG system)(Patel 2011).

### 2.2.3 Hydrogen Recovery and Cleaning System

We are going to use AET HRU technology for Hydrogen recovery and cleaning. This patented AET HRU technology utilizes non-cryogenic absorption to separate methane and heavier
hydrocarbons from the hydrogen containing gases that CHHP system generated. The purified hydrogen flows out of absorber column without significant pressure drop. By reducing the pressure of the absorber bottoms stream, the methane and heavier hydrocarbons are absorbed and flashed off from the solvent. The separated gases are going to serve as the fuel gas ready for use. The liquid could be used as a cycle and returned to the column. The AET HRU that is going to be applied in FIU CHHP system has the valuable ability to recover 95% of hydrogen from the input gas and produce a hydrogen product stream with 95% hydrogen purity which is good to hydrogen station standard.

![DCF ERG system](image)

**Fig. 2.7 DCF ERG system.**

**AET Process® Hydrogen Recovery Unit**

![AET hydrogen recovery unit model](image)

**Fig. 2.8 AET hydrogen recovery unit model**

### 2.2.4 Hydrogen Compressor, Storage and Dispensing / Distribution System

In this part, we are going to purchase the standard tank, pipeline and valves which are commercially available to build our hydrogen storage system. The mainly distribution, storage and dispensing system is going to be the hydrogen storage tank underground in Hydrogen station, the hydrogen station for automobiles and small fuel cells, the hydrogen compressor and the hydrogen pipeline, which is going to be talked in detail by section 3.3.
2.2.5 Safety equipment, mechanical and electrical design

The safety equipments for eye protection, head protection, hand protection, hearing protection, Emergency Wash Systems, Fire and Rescue Gear, ergonomics, First Aid, Safety Clothing, Workplace Safety, Facility Maintenance, material handling will is designed in CHHP’s system. Other safety system will be analyzed and designed in section 4.

A small conveyer is designed to transfer the biomass and landfills in to gasification system. Several motors are applied as drivers. The pipelines for transferring wastewater are also designed with self-cleaning system and water pump.

Electrical design is going to be talked in detail in section 3.1. The power demanded by CHHP system is mainly supplied by CHHP itself. The electrical chain is shown in fig. 2.10. The DC current is transfer in to AC then mostly go to grid to supply the community. Partial of the power will be used as self-supply power for CHHP system. As a back-up the CHHP system is also designed with a back-up power system by connected to the grid directly.
3 Energy End-Uses on Campus from CHHP System

3.1 Electricity Use
Since the DFC3000 has an optional AC output voltage of 12,700V with the frequency of 50Hz, which means this device has a DC-AC converter imbedded in itself, and we don’t need to design specific DC-AC converter for it. In the ideal operation situation, the output power is constant 2800kW, and there is no variance of the output voltage, so a common 12,700V/110V transformer can be used to decrease the voltage and connect the DFC3000 to the FIU AC grid system. But if we take the consideration of shortage of fuel and other environment variances, the output power may vary from the rated operation point. So in order to get high quality maximum output power, instead of using the AC output power, we can direct use the DC output power before it’s converted into AC. By doing this, together with the output power from FIU’s future PV system and plug-in electric vehicles (PEVs) charging system, a grid-connected DC hybrid power system can be built. The power generated by DFC3000 and PV can be direct used as the main energy source for buildings in campus, also the charging of PEVs. Furthermore, because of PEVs can be viewed as mobile energy storages, power can flow either from the DC system to PHEVs or from PEVs to the DC system and AC grid, which is known as vehicle to grid (V2G). Also, because the load curve is varying during the whole day, so we don’t need to run the DFC3000 during the night hours, and PEVs’ batteries can supply enough power for restarting of DFC3000 in the early morning.

In order to fulfill these functions described above, firstly a buck converter is needed to decrease the output DC voltage of DFC3000 to 318V, which is the operation voltage of the DC power system. The buck converter is shown in Fig. 3.1. In contentious working model, there are two states: on-state and off-state. During the on-state, the IGBT is closed, the voltage across the inductor is $V_L = V_{in} - V_{out}$. The current through the inductor rises linearly. As the diode is reverse-biased by the voltage source V, no current flows through it. During the off state, the IGBT is opened, the diode is forward biased. The voltage across the inductor is $V_L = -V_{out}$ (neglecting diode drop). Current $I_L$ decreases. So the relationship between input and output voltage can be expressed in equation (3.1). Fig.3.2 (a) and (b) show the current flow of the buck converter under on-state and off-state.

$$D = \frac{V_{out}}{V_{in}}$$ (3.1)
where the D is the duty cycle of the PWM signal.

Fig. 3.1. Single-phase DC-DC buck converter

Fig. 3.2 (a) Current flow of buck converter in on state (b) Current flow of buck converter in off state.

After designing the buck converter, one maximum power point tracking (MPPT) algorithm should be chosen to generate the PWM signal to drive the IGBT of the buck converter. Perturbation and observe (P&Q) method is chosen to track the maximum power point. This method measures the fuel cell characteristics and perturbs the operating point of the fuel cell to the MPP direction. The fuel cell system reaches the MPP when \( \frac{\partial P_{\text{fuel cell}}}{\partial V_{\text{fuel cell}}} = 0 \). In order to calculate this, the system has to store the fuel cell output power \( P_{\text{fuel cell}}(n-1) \) and voltage \( V_{\text{fuel cell}}(n-1) \) for the former sampling period T, and then put a small increase \( \Delta V_{\text{PV}} \) to the fuel cell output voltage, and measure the present output power \( P_{\text{fuel cell}}(n) \). The change of output power can be calculated by using equation (3.2), after that the adjustment of the output voltage toward the MPP is based on the sign of \( \Delta P \). If the value is positive, it means the adjustment is towards the MPP and the output voltage should be continuously increased, otherwise, the present
adjustment has already put the operation point exceed the MPP, and the output voltage should be decreased in order to go back to the MPP.

\[ \Delta P = P_{pV}(n) - P_{pV}(n - 1) \]  

(3.2)

After the DFC3000 successfully connected to the FIU DC power system, the system can use a bidirectional DC-AC converter to connect the whole system to the utility system. Because of the bidirectional converter, power can flow either from DC system to the utility AC grid (when the DC system generate more power than the total load requirement, power can be sold to the AC grid) or from the utility AC grid to the DC power system (when the power generated by the DC system is not sufficient for the total load requirement, power can be bought from the AC grid). Also, because of the PEV smart parking system, V2G service can be realized in the future.

### 3.2 Thermal Use

We can use this for the supply of the whole campus’s hot water, for example, gym and dorms’s shower water and any other places that needs hot water supply.

The CHHP system generates significant amount of thermal energy (7,460,000 Btu/h at 120°F, respectively, it is about 7.9 GJ/h). In order to create an economically feasible system, we planned to use the majority of this heat for generating hot water for the community of FIU. If there is any extra hot water source, we will supply the Sweetwater apartments. In the design, the amount of thermal energy will be divided into several parts.

The majority of the heat is going to be transferred to Compressed Gas to increase the pressure to power the generator for extra gas(DCF, ERG)\(\text{(Patel 2011)}\)

As shows in fig 2.7, the pressure was increased by external heating from the extra heat generated by DFC3000. The pressured difference between high pressure line and low pressure line will generate the gas flow between the two lines. The gas flow will generate the generator (gas expansion turbine) for extra electricity. The extra electricity will increase the efficiency of the whole CHHP system.

As Declared by section 2, there will be around 1 GJ/h at 49°C applied to preheat incoming are for DFC3000 as well as the gasification system to increase the efficiency of CHHP system.

<table>
<thead>
<tr>
<th>Heat of CHHP</th>
<th>7.9 GJ/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat used for DCF-ERG</td>
<td>0.9 GJ/h</td>
</tr>
<tr>
<td>Heat used for Preheating incoming air for DFC</td>
<td>1 GJ/h</td>
</tr>
<tr>
<td>Heat used for generating hotwater</td>
<td>6 GJ/h at 49 °C</td>
</tr>
</tbody>
</table>

From the calculation below, we can approximately generate 75 ton hot water to 49 °C ideally. If we are going to count for the heat loss during delivery by pipeline, as well as the heating
efficiency, we can generate around 50 ton of hot water for the university per hour. 50 ton of hot water is beyond the needs of campus use. So we can also divide part of the hot water to supply the Sweetwater community.

Tab. 3.2 Calculation of hot water generated per hour

<table>
<thead>
<tr>
<th>Heat used for generating hot water GJ/h at 49 °C</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat capacity of water (averaged J/(g·K))</td>
<td>4.18</td>
</tr>
<tr>
<td>Cold water temperature °C</td>
<td>30</td>
</tr>
<tr>
<td>Hot water temperature °C</td>
<td>49</td>
</tr>
<tr>
<td>Temperature difference °C</td>
<td>19</td>
</tr>
<tr>
<td>Water could be heated /kton/h</td>
<td>0.075547721</td>
</tr>
</tbody>
</table>

So far as we know, the university campus has not built the central hot water supply system. So the cost of extra hot water supply system for FIU will be significant. From the marketing investigation, the hot water supply pipeline is averaged at $2/meter. If we are going to count for the isolation materials, installation labor as well as maintenance, the total could be $5/meter. The total cost will be $100,000.

Tab. 3.3 Cost analysis

| hot water supply pipeline /dollar per meter   | 2 |
| installation labor and maintenance /dollar per meter | 2 |
| Isolation materials /dollar per meter         | 1 |
| total /dollar per meter                       | 5 |
| total length for the pipeline /km              | 20 |
| Cost /dollar                                  | 100,000 |

3.3 Hydrogen Use

3.3.1 Hydrogen Compression

Since we will generate large amount of hydrogen from our CHHP system, the high efficiency and high power compressor is demanded. We are going to choose RIX industry’s product RIX-4VX as our compressor in CHHP system. It featured with necessary properties that matches our demands very well: the maximum Horsepower is 40 HP which is large enough to compress all the hydrogen generated by CHHP system in time with a flow range up 200 SCFM; it does not need specified medium for cooling but air or water; the largest discharge Pressure is going to be 6,000 PSIG which is already match our needs for the hydrogen tank (~6000PSI)

As well, the RIX 4VX gas booster features heavy-duty crosshead construction in a "V" cylinder arrangement with oil-Free Gas or Air compression to 6000 psig; one to Five Stages of Oil-Free Compression; Air or Water Cooling; Crosshead Construction; Pressure-Lube Crankcase; Continuous Duty; Compact, Easy to Maintain Design, etc.
3.3 Hydrogen Storage

Fig. 2.3 shows the design of a gas station. The major part for hydrogen storage is the hydrogen tank underground. The Dashed line shows the hydrogen tank underground which is connected to CHHP system by a short hydrogen pipeline with the length of 200 meters (The distance between CHHP and hydrogen station is about 150 meters). The hydrogen comes from fuel cell plant with high pressure of ~50psi. Then the gas was piped into the underground hydrogen tank up to 6000 psi by a RIX 4VX compressor. The highest pressure of the Hydrogen tank is about 300-800 bar (~4350-11600Psi). The hydrogen tank is built underground 5 to 15 meters deep for safety concern. The tank’s volume is large enough to store the hydrogen amount that DFC 3000 generated for a month.

3.3.3 Hydrogen Dispensing

As declared in section 2, the hydrogen dispensing system is majorly our hydrogen station. The hydrogen station is designed for future application to PEM Fuel Cell automobiles. Although these automobiles are under development, it has a large marketing potential. The hydrogen station is also designed to charge small fuel cells that are going to be used for communities and families, such as farms, hospital, etc. The hydrogen distribution nozzles are designed as H35 - 35 MPa at 15 \text{\textdegree}DC and H70 - 70 MPa at 15 \text{\textdegree}mDC, respectively. These hydrogen distribution nozzles are designed to serve light duty vehicle fueling for vehicles with storage capacity from 1 to 10 kg for 70 MPa and 1 to 7.5 kg for 35 MPa.
4 Safety Analysis

Hydrogen has been proved to be one of the most clean and green energy resources. However, due to those significant properties of hydrogen, like colorless, odorless, tasteless, flammable, and high pressure, the implementation of hydrogen needs to go through a very careful safety and risk analysis to make sure the public safety and guarantee public interest. In this section, we will first identify all the possible safety risks that may occur, and then give out our design consideration, risk mitigation measures during operation and plans under emergency situations regarding to those potential risks.

4.1 Potential Risks and Failure Models

The table below listed the failure models and their corresponding effects. We also use a 1-10 scale to evaluate the possibilities of occurrences and its severity.

<table>
<thead>
<tr>
<th>Tab. 4.1</th>
<th>Potential Risks and Failure Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure Model</td>
<td>Source</td>
</tr>
<tr>
<td>Electrolysis Failure</td>
<td>Electrolyte Leak</td>
</tr>
<tr>
<td>Hydrogen Leak</td>
<td>Life and health damage, Fire</td>
</tr>
<tr>
<td>Oxygen Leak</td>
<td>Life and health damage, Fire</td>
</tr>
<tr>
<td>Compression Failure</td>
<td>Stop Working</td>
</tr>
<tr>
<td>Hydrogen Leak</td>
<td>Life and health damage, Fire</td>
</tr>
<tr>
<td>High Temperature</td>
<td>Explosion, Fire</td>
</tr>
<tr>
<td>Overpressure</td>
<td>Explosion</td>
</tr>
<tr>
<td>Hydrogen Storage Failure</td>
<td>Hydrogen Leak</td>
</tr>
<tr>
<td>Overpressure</td>
<td>Explosion</td>
</tr>
</tbody>
</table>

4.2 Design Consideration

Regarding to these potential risks, designs to ensure safety need to be taken into consideration in the design phase. For example, the pressure and temperature detectors are installed in key nodes of our system. Once the pressure of temperature arrive the critical point, the system can start its power-off protection automatically. Another example is that we would set up effectively isolation wall and alerting signs to make apart the hydrogen generating system with the students learning and living places.

These design consideration can control the risks before accidents really happen. Therefore, design consideration about safety is the most effective way to ensure safety.

4.3 Risk Mitigation Measures during Operation
The operation stage is the period when danger is most likely to occur. In one aspect, there are many vehicles transporting raw material through the hydrogen generating system. In another aspect, the gases are most active when the reaction is in progress, and a major accident may occur if the pressure and temperature has a rapid change. So during this phase, a safety inspected team is employed in our system to check the safety of the main components every four hours, trying to discover the precursor and eliminate hidden dangers.

4.4 Emergency Plan
Emergency plan is to make sure right measures can be taken to reduce the losses after accidents happen. Sufficient fire-fighting equipment should be stored in all necessary locations. Also an evacuation plan is prepared beforehand.
5 Economic/Business Plan Analysis

On average, about 250 thousand tons/year of biomass was used in South Florida. In Miami, number of biomass could reach 250-500 thousand tons per year; since it is where abundant of everglades can be providers for forest residues and grasses.

5.1 Capital Costs

The cost of Biomass-Based Integrated Gasification Combined-Cycle (BIGCC) power systems has been calculated in the paper Cost and Performance Analysis of the Biomass-Based Integrated Gasification Combined-Cycle (BIGCC) power systems (1996). The cost of our CHHP system can be estimated and modified based on that of the BIGCC system. The method and assumptions that were used are based on those described in the EPRI Technical Assessment Guide (TAG) and reflect typical utility financing parameters. A summary of the economic assumptions is presented in the Appendix 1. Since the capital cost is based on the year 1990, we have to adjust it with CPI inflation rate 173%.

Table 5.1 Capital Cost Summary

<table>
<thead>
<tr>
<th>Section Description</th>
<th>High P, derive gas turbine</th>
<th>High P, greenfield plant</th>
<th>High P, utility gas turbine</th>
<th>Low P, indirect, utility gas turbine</th>
<th>Low P, direct, utility gas turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste Handling</td>
<td>3759.29</td>
<td>3759.29</td>
<td>7518.58</td>
<td>7612</td>
<td>6016.94</td>
</tr>
<tr>
<td>Waste Drying</td>
<td>4712.52</td>
<td>4712.52</td>
<td>9425.04</td>
<td>9425.04</td>
<td>7542.8</td>
</tr>
<tr>
<td>Gasification</td>
<td>36281.56</td>
<td>36281.56</td>
<td>76941.75</td>
<td>24540.05</td>
<td></td>
</tr>
<tr>
<td>Gas Cleanup</td>
<td>4671</td>
<td>4671</td>
<td>9342</td>
<td>9342</td>
<td></td>
</tr>
<tr>
<td>DFC 3000</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>785.42</td>
<td></td>
</tr>
<tr>
<td>Direct Quench</td>
<td>25.95</td>
<td>25.95</td>
<td>51.9</td>
<td>51.9</td>
<td>57922.13</td>
</tr>
<tr>
<td>Gas Turbine</td>
<td>22768.53</td>
<td>22768.53</td>
<td>29790.6</td>
<td>30880.5</td>
<td>29790.6</td>
</tr>
<tr>
<td>Steam Cycle</td>
<td>5420.09</td>
<td>5420.09</td>
<td>20197.75</td>
<td>21915.64</td>
<td>20587</td>
</tr>
<tr>
<td>Boost</td>
<td>1020.7</td>
<td>1020.7</td>
<td>2041.4</td>
<td>9845.43</td>
<td></td>
</tr>
</tbody>
</table>

Figure 5.1 Biomass Resources--Florida
### 5.2 Operating Costs

#### Table 5.2 cost analysis

<table>
<thead>
<tr>
<th>Item</th>
<th>Cost/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Biomass</td>
<td>$599,111</td>
</tr>
<tr>
<td>2. Operating Labor (including driver)</td>
<td>$247,324</td>
</tr>
<tr>
<td>3. Electricity ([$2,743,632]*</td>
<td></td>
</tr>
<tr>
<td>4. Maintenance</td>
<td>$735,840</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>($1,161,357)</td>
</tr>
</tbody>
</table>

(*Since the electricity it generated exceeds the one it consumed, this item is net income)

Operating costs are estimated as a combination of the necessary supply of biomass, electricity, water and maintenance costs for the implemented technologies. Biomass includes paper, grass, residuals and sugar waste, which produces 277800 kWh each day. The waste paper is priced at $164.14 per ton on average, (assuming we obtain waste paper from campus and neighbor
communities, so that we can get it with the lowest cost.) Grass, residuals waste water and sugar waste are assumed to be negligible cost factors.

<table>
<thead>
<tr>
<th></th>
<th>The lowest Price ($/Ton)</th>
<th>The Highest Price ($/Ton)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Papers</td>
<td>110.026</td>
<td>117.885</td>
</tr>
<tr>
<td>Old Cardboard</td>
<td>127.3158</td>
<td>141.462</td>
</tr>
<tr>
<td>News and PAMs</td>
<td>165.039</td>
<td>172.898</td>
</tr>
<tr>
<td>Over-issue News</td>
<td>165.039</td>
<td>188.616</td>
</tr>
<tr>
<td>Sorted Office Waste</td>
<td>157.18</td>
<td>172.898</td>
</tr>
<tr>
<td>Light Letter</td>
<td>196.475</td>
<td>212.193</td>
</tr>
<tr>
<td>White Letter</td>
<td>227.911</td>
<td>235.770</td>
</tr>
<tr>
<td>Average</td>
<td>164.141</td>
<td>177.389</td>
</tr>
</tbody>
</table>

The recommended amount of waste is 10 tons of paper, 10 tons of grass, 10 tons of residuals and 25 tons of sugar waste per day, so 4 or 5 of trucks would be needed each day to transit the waste. Transfer Fee for waste delivered to the Regional Transfer Stations is $12.32 per ton, which is the price we use to estimate the transportation (labor fees included) cost. According to the report of Average Energy Prices in Miami-Fort Lauderdale (Nov. 2011) the electricity cost is $0.116 per kWh ($0.00003.4 per BTU). According to Biomass Gasification, the range of gasifiers is up to 100KW, since the electricity produced by our system is 2800kWh, which exceeds the input of electricity, the net income for electricity is $2,743,632. Since it is assumed that our system produce enough Hydrogen to supply the whole campus, there is no need to calculate the cost of Hydrogen. The DFC system maintenance cost is assumed to be 3 cents per KWh, so that annual maintenance fee is $ 735,840 for the system.

5.3 Comparison to Conventional Fuel Cost
The energy demand for FIU is 21189004 kWh annually. Without the new system, the electricity cost for FIU is $ 2,457,924 per year (with the electricity cost --$0.116 per kWh). As calculated before, our new system will generate 2452800kWh of electricity annually. So that FIU would save $387323.53 annually for electricity. Besides, there will be further improvements to hydrogen production systems in the future whereby the costs to produce hydrogen will reduce. This is highly marketable for those considering this energy-saving and environmentally-friendly system.

5.4 Marketing Price

<table>
<thead>
<tr>
<th>Year</th>
<th>Revenue</th>
<th>Cost</th>
<th>Profit</th>
<th>ROI</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$2,743,632</td>
<td>$9,102,004</td>
<td>($ 6,358,372)</td>
<td>-69.86%</td>
</tr>
<tr>
<td>2</td>
<td>$2,743,632</td>
<td>$2,662,004</td>
<td>$ 81,628</td>
<td>3.07%</td>
</tr>
<tr>
<td>3</td>
<td>$2,743,632</td>
<td>$2,662,004</td>
<td>$ 81,628</td>
<td>3.07%</td>
</tr>
<tr>
<td>4</td>
<td>$2,743,632</td>
<td>$2,662,004</td>
<td>$ 81,628</td>
<td>3.07%</td>
</tr>
</tbody>
</table>
The survey of current status of gasification technology has been carried out by Foley and Barnard. Most of the gasifiers (up to 100 kW range) being sold by different manufacturers show a leveling off price of $380/KW for plant prices and about $150/KW for basic gasifier price. However, for small systems the prices are extremely high, if the potential buyer wishes to purchase the exact system. This must be added the transportation costs (especially for shipment to developing countries). These prices therefore can make the gasifiers uneconomic. However gasification is a recently rediscovered technology and most of the development is still on learning curve.

5.5. Return on Investment Analysis

(1) Return on Investment Analysis

The total capital costs includes the following section (as shown in Table 5.1): High P, aero-derive gas turbine, High P—green field plant, High P—utility gas turbine, Low P—indirect utility gas turbine, Low P—direct utility gas turbine.

(2) Long-term cost comparison

<table>
<thead>
<tr>
<th>Year</th>
<th>Cost of existing infrastructure</th>
<th>Cost of CHHP System</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$27,342,150</td>
<td>$9,102,004</td>
</tr>
<tr>
<td>2</td>
<td>$27,615,571.5</td>
<td>$2,688,624</td>
</tr>
<tr>
<td>3</td>
<td>$27,891,727</td>
<td>$2,715,510</td>
</tr>
<tr>
<td>4</td>
<td>$28,170,644.49</td>
<td>$2,742,665</td>
</tr>
<tr>
<td>5</td>
<td>$28,452,350.93</td>
<td>$2,770,092</td>
</tr>
</tbody>
</table>

The cost of existing infrastructure mainly includes the electricity fees and waste disposal fees. As calculated before, the electricity cost for FIU is $2,457,924 per year. The annual production (2008) of papers and cardboards at FIU was about 1000 tons, and according to Department of Solid Waste Management Schedule of Disposal Fees, the cost of Contract Disposal per ton (including Transfer Fee) is $74.91, so that the annual cost for waste disposal is approximately $27,342,150. Taken the inflation rate (101%) into account, the cost is shown in the Table 5.5.2. It can be concluded that the CHHP system is both cost and energy saving.
6 Energy Savings and Environmental Analysis

Now Florida has not demonstrated any Renewable Portfolio Standard, however, there is a strong trend and it is necessary for Florida to promulgate a law to excite the market of green energy. So, building a CHHP system in FIU campus and put the end use energy into the renewable energy system of either FIU or FPL is favorable.

Hydrogen burns almost pollution-free and when combined with oxygen, produces water and electricity. For this reason it is viewed by many as the ultimate clean fuel. When fueled directly by pure hydrogen, the power station only emits only heat and water vapor.

In our hydrogen station, biomass waste is 10 tons of paper, 10 tons of grass, 10 tons of residuals and 25 tons of sugar waste per day, which produces 277800 kWh each day and reduces over 55 tons of solid waste per day. It equals to burn of 45 tons of coal per day, 16488 tons per year.

Hydrogen has many benefits.

First of all, hydrogen is a renewable energy, raw materials for the recycling of water resources, inexhaustible. Traditional oil, coal, natural gas and other energy are non-renewable resources, the limited reserves on Earth, will be depleted in the near future.

Secondly, the high value of hydrogen combustion, combustion products water vapor, cleans pollution-free.

Thermal conductivity of the hydrogen is 10 times higher than most of other gases.

Moreover, hydrogen has ideal calorific value. The calorific value of hydrogen is the highest of all fossil fuels, chemicals, fuels and biofuels, about 142,351 kJ / kg, three times the gasoline calorific value.

Compared with other fuels, hydrogen burning clean, it only generate water and a small amount of hydrogen outside the nitride is not harmful to the environment of pollutants such as carbon monoxide, carbon dioxide, hydrocarbons, lead compounds and dust particles. A small amount of nitride hydrogen after proper disposal will not pollute the environment, and the combustion of water can continue to hydrogen production, recycling. Product water is non-corrosive, non-destructive of the equipment. It reduces greenhouse gas emissions and can replace fossil fuels to maximize weakened the greenhouse effect.
7 Education and Marketing Plan

In order to build the energy saving awareness and encourage pension fund investments and public investments to biomass technology, several useful capital formation initiatives should be created. The first issue is to ease fears and apprehensions that the general public has towards new technologies, it is the job of those who are properly education and know the facts to educate on the advantages of the new technologies and re-assure them of their efficiency, safety and ability to reliably replace existing systems. An important part of creating acceptance for biomass and hydrogen power as well as other non-commercial or relatively new forms of power production is the way in which you reach the public and the specific message that you relay.

7.1 Education Plan

<table>
<thead>
<tr>
<th>Target Audience</th>
<th>Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 High-school students counselors</td>
<td>Energy Workforce Training and Education</td>
</tr>
<tr>
<td>2 University students</td>
<td>State University System/Electric Power Institute</td>
</tr>
<tr>
<td>3 The whole community</td>
<td>Community Colleges /Energy-Related Education</td>
</tr>
<tr>
<td>4 Consumers</td>
<td>Consumer Education and Awareness Initiatives</td>
</tr>
</tbody>
</table>

Energy Workforce Training and Education

Aims:
1. High-school students counselors
   a) Provide high-school guidance counselors with the basis to encourage appropriate students to pursue energy-industry careers and institute post-secondary level energy education curriculum and programs;
   b) Provide energy-sector educational curricula to be taught during middle school grades.
2) State University System/Electric Power Institute
   It is recommended that the State University System address (at both undergraduate and graduate levels) the following:
   a) Training in emerging fuels and power technology and management.
   b) Providing for a scholarship program within the Institute funded by the state’s electric utilities with matching funds provided by the State of Florida.
3) Community Colleges/Energy-Related Education
   In order for the public to have an opportunity to better understand energy issues and satisfy the increasing public desire to be involved as educated consumers in the decision process, It is recommended that, the Community College System should:
a) Incorporate energy-related curriculum into life-long learning and continuing education offerings, and
   
b) Develop and promote an energy certificate/degree program.

4) Consumer Education and Awareness Initiatives

It is recommended that the Legislature direct the Public Service Commission to encourage utilities to further develop comprehensive plans specific to their climate region to conduct public energy education and consumer awareness campaigns, above and beyond specific product and program marketing, to increase conservation and efficiency.

7.2 Marketing Strategy

Objectives
The important objective to address with this marketing campaign is to increase acceptance of biomass and hydrogen fuel technologies on the campus and in the community at large.

Target Markets
Our main targets consumers are schools, hospitals and other large public institution. As mentioned before, the prices for small systems are extremely high. These prices therefore can make the gasifiers system uneconomic for small institutions.

Competitive Forces
The DFC 3000 can be purchased with a 2% rebate. More importantly, our biomass system is high efficient, fuel flexible and high reliable. Compared with the traditional energy generating system, this design is cost-saving in the long run.

Communications
We will leverage social media and word of mouth for the vast majority of our marketing using platforms such as Twitter, Facebook and MySpace. These platforms are widely used by the customers in our demographic market. We will make announcements via regular tweets and updates to our fan page on Facebook.

Marketing Plan Strategy
The strategies to monitor our success are as follows:

Emphasize safety, efficiency and high reliability and technical services

Combine the education plan with the market plan to increase acceptance among people

Sales Forecast
Since the initial investment is extremely high, only a few buyers would be able to purchase it. However, since gasification is a newly rediscovered technology, the market is going to grow in the future.
Fig. 7.1 Advertisement of CHHP system of FIU
Appendix

Appendix 1 Economic Assumptions:
- December, 1990 dollars
- 30 year project life
- 30 year book life
- 20 year tax life
- General plant facilities = 10% of process plant cost
- Project contingency = 15% of plant cost
- Two year construction period
- Royalties = 0.5% of process plant cost
- Feedstock cost = $46/T ($42/t)
- Sixty days supply of fuel and consumable materials
- Accelerated Cost Recovery System (ACRS) depreciation
- Federal and state income tax rate = 41%
- Yearly inflation rate for calculation of current dollar cost = 4%
- Zero investment tax credit

Financial Structure

<table>
<thead>
<tr>
<th>Type of Security</th>
<th>Current Dollar</th>
<th>Constant Dollar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of Total</td>
<td>Cost (%)</td>
</tr>
<tr>
<td>Debt</td>
<td>50</td>
<td>8.6</td>
</tr>
<tr>
<td>Preferred Stock</td>
<td>8</td>
<td>8.3</td>
</tr>
<tr>
<td>Common Stock</td>
<td>42</td>
<td>14.6</td>
</tr>
<tr>
<td>Discount Rate (cost of capital)</td>
<td></td>
<td>11.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Security</th>
<th>Current Dollar</th>
<th>Constant Dollar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>% of Total</td>
<td>Cost (%)</td>
</tr>
<tr>
<td>Debt</td>
<td>50</td>
<td>8.6</td>
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<tr>
<td>Preferred Stock</td>
<td>8</td>
<td>8.3</td>
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<tr>
<td>Common Stock</td>
<td>42</td>
<td>14.6</td>
</tr>
<tr>
<td>Discount Rate (cost of capital)</td>
<td></td>
<td>11.1</td>
</tr>
</tbody>
</table>
References/citations

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