RENEWABLE HYDROGEN FUELLING STATION FOR IIT'S MAIN CAMPUS

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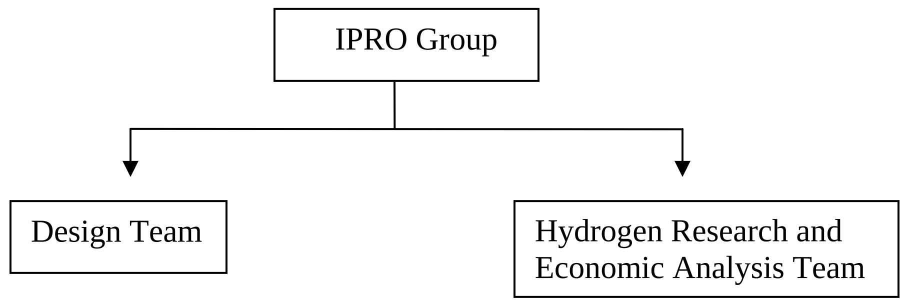
IPRO 301 Fall 2005

Mid Term Report

Inter Professional Projects Program
Illinois Institute of Technology
Chicago,
IL, 60616.

THE ORGANISATION



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HYDROGEN RESEARCH AND ECONOMIC ANALYSIS TEAM

Elijah Stine (Team Leader)
Daniel Charles
Jeffrey Cecil
Sandhya Duggirala

DUTIES AND FUNCTIONS

The following text enlists the duties and functions each team member performed in accordance with the team they were in.

Design Team

The main task of the design team is to:

i) Come up with various possible designs for the hydrogen fuelling station.
ii) Select the components and find the proper ratings for each design.

The design team came up with the list of the components required for the hydrogen fuelling station within a few weeks from the start of this IPRO. As a next step individual components were assigned to different members in the design team. The individual had to find out the supplier, and also find out the different ratings available for that particular component. The following enlists the task assigned to the different members in the design team.

Carlos Ceballos	:	PV Panels
Edgar Becerril	:	Wind Turbine
Javier Martinez	:	Electrolyzer
Matthew Furukawa	:	Peripheral components for interconnection.
Syed Ahmed	:	Reformer and Sorbitol
Srinivas Gundugurti	:	Electric Cars
Chinedu Igbokwe (Team Leader)	:	Battery Banks Co-ordinate the team with respect to their findings and come up with the designs.

Hydrogen Research and Economic Analysis Team

The Hydrogen Research and Economic Analysis Team had to,

i) Coordinate with the design team to find the suppliers for each component.
ii) Perform Economic Analysis for each of the design.
iii) Compare Hydrogen Vs. Gasoline operated systems.

The following table lists the tasks assigned to the individual team members in the economic analysis team,

Daniel Charles	:	PV Panels & Website Design
Jeffrey Cecil	:	Sorbitol.
Sandhya Duggirala	:	Wind Turbine
Elijah Stine	:	Electrolyzer

MIDTERM PROGRESS REPORT DESCRIPTION

As IPRO Team Fall'05 got into the aspect of corporal realization of the project, the main emphasis being on the commercial availability of the proposed components in the market, and their cost per unit information, there were many new challenges that came up which were not tangible at the initial stages of the project. Also, the data from IPRO in Spring '05 was rather vague and had few in-consistencies which needed a convergent attention. These were mostly in terms of the Design aspects. Henceforth, the afore-thought goals (that were considered at the beginning of the semester) were re-visited for appropriate modifications.

The design recommended by the IPRO 304B (Spring 2005) had the renewable sources (Wind & PV) entirely powering the "House of the future" & the "Hydrogen Fuelling Station". But after substantial research done by this IPRO, it is recommended to integrate the grid along with the design. Integrating the grid with the renewable sources has the following advantages:

i) The excess electricity produced by the renewable sources can be sold to the utility.
ii) The deficient electricity can be drawn from the grid when required.
iii) System stability will also improve.

The objectives of the Hydrogen Research and Economic Analysis Team (HREAT) have remained basically the same as those set forth at the beginning of the semester. The primary goal of the team continues to be to develop an in depth cost model for each fueling station layout produced by the DT. Once HREAT has determined the costs for each design, the team will make recommendations regarding the profitability and feasibility of each of those designs.

HREAT was also given the task of identifying suppliers for the various components that would be needed in the construction of the fueling station. While this has occurred to some degree, mostly in regard to the identification of Sorbitol suppliers, PV Panels and Wind Turbines, the DT has been the main force behind identifying component suppliers. This has occurred because, in order for the DT to make decisions about which components to use in their designs, they first had to determine what kinds of components were commercially available. Consequently, HREAT went ahead with contacting the suppliers for Wind Turbines, PV Panels, and Electrolyzer. There are still few components left for which the specifications are to be decided upon. HREAT is awaiting the feedback from the DT in the same regards.

REVISED GOALS

The revised objectives till now may be summarized as follows:

- *Design an attractive fossil-fuel-free hydrogen producing and fueling station.*
- *Use environmental friendly / sustainable technology in the production of H_2.*
- *Come up with a series of possible designs that will produce the desired amount of Hydrogen for use in the fueling station.*
- *Choose the most efficient and economical components.*
- *Resolve issues with system components, and produce output data for each proposed design.*
- *Draw a comprehensive assessment of H_2 operated system Vs. Gasoline operated system.*
- *Develop an in-depth cost analysis for all the proposed designs.*
- *Test their economic feasibility, and hence try and maximize the potential financial and economic returns over a certain period of time (though it is understated that the immediate proceeds may not be tangible).*
- *To provide a basis for ranking the proposed systems in terms of profitability and/or social-environmental benefits.*

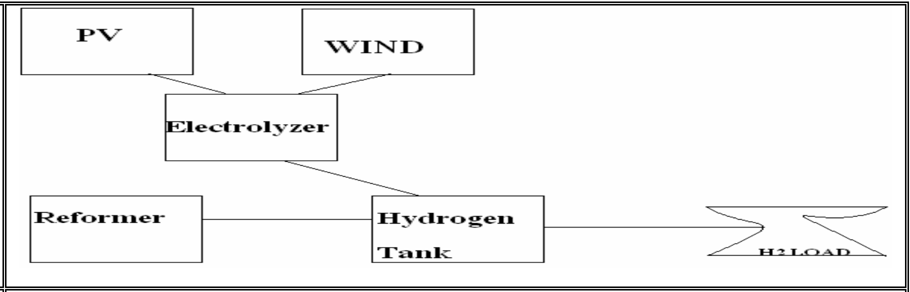
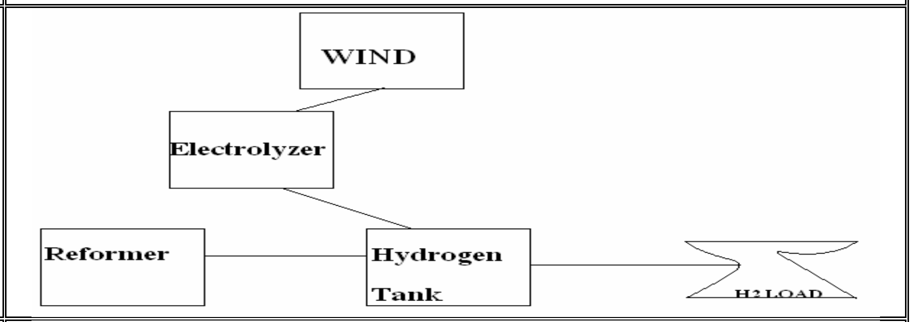
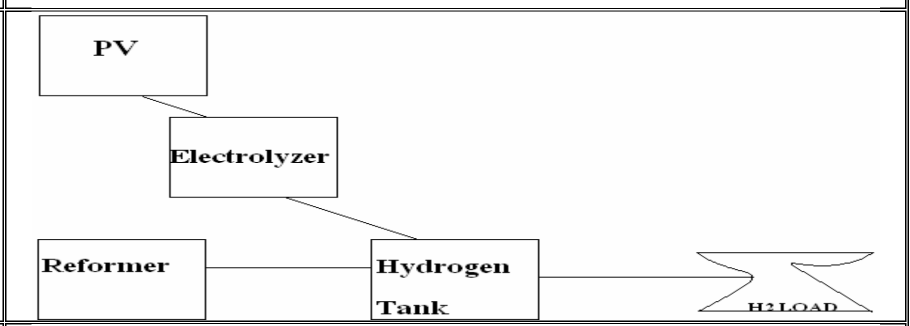
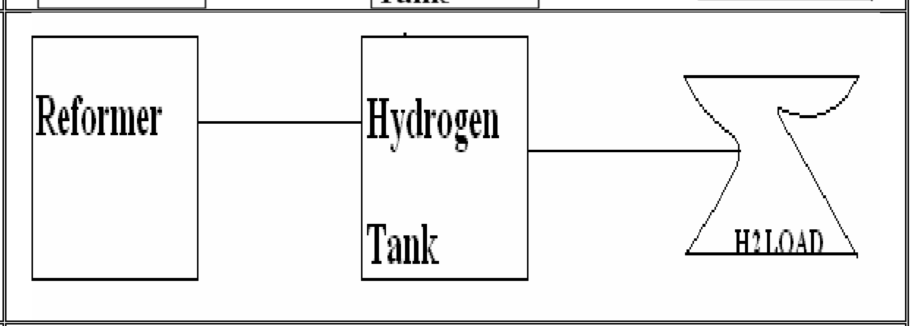
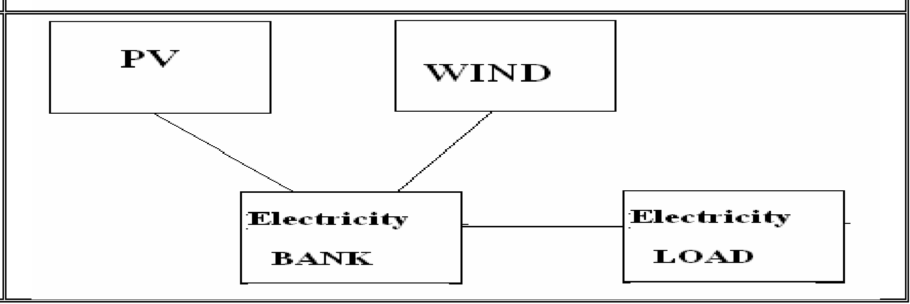
SUMMARY OF ACTUAL RESULTS

The Design Team has, henceforth, come up with five primary designs. These take into account the different combinations of the various components to produce a varied amount Hydrogen (% of total Hydrogen per day). These designs were simulated in HOMER, and consequently the specifications for each design were established. For each design (with out the reformer) it was shown what specifications are required to produce either 5%, 10%, 15%, 20%, 30% of hydrogen needed for the fueling station. The following table shows the various combinations proposed;

Components	Design 1	Design 2	Design 3	Design 4	Design 5
Reformer	Yes	Yes	Yes	Yes	
Electrolyzer	Yes	Yes	Yes		
Wind Turbine	Yes	Yes			Yes
PV Panels	Yes		Yes		Yes

Data from the simulations brought forth the fact that some power may be sold to the grid rather than simply dumping the excess power produced. Also, it was decided upon that if selling the power to the grid was feasible enough then it would be a good idea to buy electricity from the grid at a slow rate when needed. This would make the Electrolyzer more efficient.

The block diagram for each design is as follows:

Design 1	
Design 2	
Design 3	
Design 4	
Design 5	

The specifications for all these designs is as follows ;

Design 1

H2 (% of TOT H2/day)	PV(KW)	Wind (KW)	Electrolyzer (KW)	Inverter (KW)	Rectifier (KW)	H2 Tank (Kg)
5% (1.35287kg/day)	5	30	5	5	5	2
10%(2.70574Kg/day)	2	80	10	10	10	10
15%(4.05861Kg/day)	2	80	20	20	20	20
20%(5.41148Kg/day)	20	80	20	20	20	40
25%(6.76435Kg/day)	20	80	30	30	30	50
30%(8.11722Kg/day)	20	80	40	40	40	50

Design 2

H2 (% of TOT H2/day)	PV(KW)	Wind (KW)	Electrolyzer (KW)	Inverter (KW)	Rectifier (KW)	H2 Tank (Kg)
5% (1.35287kg/day)	0	30	5	5	5	3
10%(2.70574Kg/day)	0	80	10	10	10	10
15%(4.05861Kg/day)	0	80	20	30	30	15
20%(5.41148Kg/day)	0	80	30	30	30	30
25%(6.76435Kg/day)	0	80	40	40	40	100
30%(8.11722Kg/day)	0	80	50	50	50	250

Design 3

H2 (% of TOT H2/day)	PV(KW)	Wind (KW)	Electrolyzer (KW)	Inverter (KW)	Rectifier (KW)	H2 Tank (Kg)
5% (1.35287kg/day)	45	0	10	0	0	150
10%(2.70574Kg/day)	60	0	30	0	0	300
15%(4.05861Kg/day)	200	0	30	0	0	250
20%(5.41148Kg/day)	200	0	50	0	0	260
25%(6.76435Kg/day)	220	0	70	0	0	330
30%(8.11722Kg/day)	260	0	100	0	0	290

Design 4

The fourth design has **only Reformer** being incorporated.

Design 5

The fifth design has **PV Panels and Wind Turbine** being incorporated.

The DT now has the necessary information of the Virent Reformer to integrate it into the Hydrogen Fueling Station Designs. It has found that the Virent Reformer can be used in a Fueling Station application. The DT has updated and completed the vehicle fueling station schedule to incorporate new hybrid vehicles and hydrogen internal combustion engines. A line of communication was opened with Eric, a Virent contact about the reformer and future reformers. The DT was informed from Virent that a ten-kg of Sorbitol to one-kg of hydrogen ratio exists with its reformer. The DT was also informed that their reformer made to be completed in December will produce a half kilogram of hydrogen per hour. A reformer schedule was made to produce the hydrogen demand per week (one hundred seventy three kilogram per week).

HREAT has worked a great deal merely to familiarize itself with the concepts and terms central to an economic analysis. Payback periods, value factors, and life cycle costs are only a few of the ideas researched thus far. Thus far the only tangible economic analysis that has been produced is that of the current gasoline based system, the basic knowledge that the team has gathered will make the analysis process much more efficient for each of the design concepts once they are undertaken.

In addition, HREAT has worked extensively in areas relating to gasoline usage and costs. While gasoline will not play a role in the hydrogen fueling station itself, it is important to understand current and future gasoline costs and usage levels in order to determine the current and future costs that IIT will need to pay in order to continue operating its current fleet of campus vehicles. Such information is necessary in order to compare the costs of a hydrogen system to those of a gasoline system. The team has obtained information from the IIT Department of Facilities, Public Safety and Shuttle Bus Services regarding current gasoline usage levels and has used these figures to compute an approximate gasoline consumption cost for the current year. Also, the team has used inflationary modeling to project these costs through the year 2025.

HREAT has also made great progress in learning about and determining a supplier of Sorbitol. Sorbitol is a sugar alcohol used in a wide variety of commercial products such as confections, tobacco, cosmetics, and adhesives. It is purchased as a clear, syrupy solution. The hydrogen fueling station will convert Sorbitol solution to hydrogen via a sugar reformer and this hydrogen will then be used to power campus vehicles

HREAT has also made progress with identifying the suppliers of components, viz., PV Panels, Wind Turbines and Electrolyzer. KCT190GT PV cell's (KYOCERA), dealer (Heavenly Winds, Compton, IL) was contacted for a rough estimation of the cost of the unit and installation costs. For Wind Turbines (WES18, FL30, FL100) dealer were located in US, as WES is a Dutch affiliated Organization and Fuhrlaender is a German Organization. These manufacturers were decided upon, as they were the only manufacturers who could provide the "design-requisite" turbines. Both the unit's cost and the installation costs are readily available. Electrolyzer price is also being looked upon as of now.

With the price of the main components being determined, HREAT is still awaiting for the specifications of the peripheral components.

EVENTS SCHEDULE

The overall organization of the IPRO team has remained the same. The team is still divided into two subgroups: the Hydrogen Research and Economic Analysis Team and the Design Team. The members of each team remain the same as they were at the beginning of the semester.

UPDATED TASKS AND TEAM ORGANISATION

There were a lot of issues which came into light while exploring the aspects of actual realization of the project. The following text enlists the tasks accomplished, the final decisions made as far as the components are concerned and the tasks which are at the verge of completion till date.

Sorbitol: Sorbitol is a sugar alcohol used is variety of commercial products. The industry standard Sorbitol solution is 70% USP (United States Pharmacopoeia). Weight/Volume at 77F is about 10.8 lb/gal. The maximum demand of Sorbitol per day is approximately 300kg (considering 10:1 ratio of Sorbitol and Hydrogen) of 50% Sorbitol solution. This converts to about 215 kg per day of 70% Sorbitol Solution.

Eventually two likely Sorbitol suppliers were identified: SPI Polyols, Inc. (SPI) and Archer Daniels Midland (ADM). SPI provided a quote of $0.27 per pound of solution while ADM provided a quote of $0.42 per pound of the same solution. Both quotes were based on a bulk order of at least 40,000 pounds. A delivery of this size would satisfy the needs of the fueling station for a minimum of 3 months. Although SPI has a higher freight charge ($793.46 per delivery) than ADM ($37.50 fueling charge + $25 deposit), SPI is still the cheaper supplier and will likely be recommended by HREAT as the preferred Sorbitol supplier of the IIT campus.

Reformer: It was eventually decided upon the Virent Reformer to be incorporated in the designs. And hence, the primary task was to get much information about the Virent Reformer, to create new Fueling Schedule based on recent data on vehicles and to create a reformer schedule based on its production rate.

Virent Reformer requires a 50% Sorbitol (50% refers to sugar/water ratio) feed and 10 kg of Sorbitol will produce 1 kg of hydrogen. Virent provides a unit which incorporates an internal combustion engine that heats water and heats the reactor. Ten percent of the hydrogen will be burned to heat the reactor. Sorbitol prices are low and, if bought in bulk, can be a very economical solution to produce hydrogen.

Electrolyzer: Hydrogenics, Proton Energy Systems, and Stuart Energy are three companies that provide electrolyzers of two main types of electrolyzer technology, namely Bipolar Alkaline and proton exchange membrane (PEM). Unlike Bipolar Alkaline technology which uses KOH or NaOH as electrolyte (these are corrosive), PEM electrolyzers use a solid electrolyte membrane that can be expected to last the lifetime of the electrolyzer. No caustic alkaline or acidic fluid electrolyte is required for PEM electrolyzer (HyLYZER 65). It is scalable, allows scaling up for higher hydrogen generation, and no corrosive substance is involved. The specifications for HyLYZER 65 are enlisted as follows:

- Electrolysis stack operates at 100 VDC
- Water is deionized on site before it is stored on site
- 2.5 kg/hr hydrogen production rate
- 50.44 kWh/kg power consumption
- $44,444 cost/unit
- Based on Hydrogenics H2X-701E platform
    - Dispenses 99% pure hydrogen @ 140 psi
    - 78% efficiency
    - 75 lpm water flow
    - 90 kPa stack water pressure drop
    - 80 degrees C inlet temperature
    - 5 MW*cm water quality
- Generates hydrogen up to 65 kg/day, allowing to fuel up to 20 electric vehicles per day
- *PEM technology

Wind Turbine: WES18, 80KW wind turbine was selected for all the designs. After the analysis with HOMER the team considered 80kW as the most reliable option. The life expectancy is of at least 20years. And at an average wind speed of 5-6 m/s the cost per KWh is approx 8 Euro cent. Technical Specs for WES being:

- Generator
    - Type= asynchronous
    - nominal power = 80 kW
    - number of poles = 4
    - nominal voltage = 230/400 volt
    - frequency = variable: 40 - 80 Hz.
    - weight = 450kg protection IP 55
- Grid Connection
    - converter
    - diode bridge - mutator
    - converter principle
    - AC - DC - AC power supply 400 V / 3 phase / 50 or 60 Hz. (deviating voltage and frequency are available as an option)
- Tower
    - Type: cylindrical tube
    - number of sections 3
    - hub height = 31 m or 41 m
    - material = hot dip galvanized steel

Following are a few attractive aspects being the characterization of the turbine, namely,

• easy maintenance
• high reliability
• easy installation, even at hard to reach locations
• low loads on the gearbox and axle
• the AC/DC/AC principle which allows the turbine to follow the grid current
• mechanical passive blade pitch and active yaw

PV Panels: Kyocera KC190GT model was chosen because KYOCERA is the leader in PV Technology. These PV panel have the highest efficiency in power and price range. This particular model holds an efficiency of greater than 16%. It produces an output power of 190 W, and is priced at $836 per panel. Optimal performance is achieved if the tilt angle is adjusted such that the sun's rays hit the panels as perpendicularly as possible. Due to the different heights of the sun throughout the different seasons, the sun is going to cast shorter shadows in summer and longer shadows in winter. It is important to consider this when planning the layout and spacing of one's arrays. The shading of just one cell in a panel can cause the power output of a panel to drop by as much as 50%. Another thing to consider when setting up the array system is to try and have the panels facing "true south", this will ensure that your panels absorb most of the sun's rays throughout the day. Also, it is important to know that panels when wired in series give a higher output voltage and smaller current while wiring in parallel gave the opposite results. The general specs may be summarized as follows :

Electrical Specifications	
Model	KCT190GT
Maximum Power	190 Watts
Tolerance	10% / -5%
Maximum Power Voltage	26.1 Volts
Maximum Power Current	7.28 Amps
Open Circuit Voltage	32.5 Volts
Short Circuit Voltage	8.08 Amps
Length	1425 mm (56.2 in)
Width	990 mm (39.0 in)
Depth	36 mm (1.4 in)
Weight	18.5 kg (40.7 lbs)
Efficiency	>16%
Thermal Parameters	
Nominal Operating Cell Temperature	47° C
I_{sc} Current Temperature Coefficient	(3.8 x $10^{-3)}$ A/°C
V_{oc} Voltage Temperature Coefficient	(-1.23 x 10^{-1}) V/°C

It is, thus far, decided to have the panels connected in parallel. This combination gives an output of 52.5 Volts. Also, the panels would approximately provide 55.1 kW output power.

Battery Bank: The possibility of inclusion of battery bank in the design was explored. But it eventually was decided inclusion of battery bank isn't a very good idea. For one, between charging and discharging a battery there is a significant loss of energy. Batteries heat up rapidly when being charged with a large load, which would lead to the batteries loosing efficiency and lifetime.

Peripheral Components: These are the components requisite for efficient interconnection between the units. One component discovered was a PV combiner box. It take's up to six arrays and gives an output of 100 continuous amps and 12, 24, or 48 volts. This allows to control the power output. DC-DC converters take an input DC current & voltage and output a different DC current & voltage. The best solution is to get a custom made DC-DC converter.

With all these additions are deletions being taken care of by the Design Team, it was time to simulate and find out the results for these proposed designs. HOMER was used to simulate each design.

WES18, KCT190GT, HyLYZER 65 etc: Dealers have been contacted for the approximate price of each unit and their respective installments costs.

KCT190GT (PV Panels), specifications like the area available for "panel mounting", the requisite shadow analysis etc was communicated with. The response is awaited.

WES18 (Wind Turbine) approximate unit price and installments cost are available.

HyLYZER 65 (Electrolyzer), the details and feasibility is still being looked upon for. Nevertheless, the present projected price seems rather in-feasible.

BARRIERS AND OBSTACLES

There was kind of ambiguity prevailing at the beginning of the semester as per the goals of the IPRO is concerned. But in a time of two weeks, issues and concerns were clarified and hence teams now had a clearer picture of the goals to be accomplished and explore the areas which were left un-addressed previously.

- The Reformer considered in Spring '05 was too small for the design that is being proposed.
- The Reformer proposed is still in the experimental stage (Virent is working on it). New information led to more calculations and the degree of uncertainty that lies in very new technologies.
- Since a transaction is proposed with the grid, there, now, is a need to look into components that will synchronize the phase shift between the generated

electricity and the electricity of the grid. Also, this issue is in regards with the interconnection of renewable energies to the utility network. this issue is partially handled by PURPA which looks into the QFs (qualifying facilities) of the system.

- In the present proposal, the output is required to be in DC. The outputs from Wind and PV are AC. All of the DC power converters are not rated for the amount of power that is going to be used. To meet this requirement, several converters are to be wired together. AC-DC converters too pose the same problem.
- It was first thought of to connect the PV panels in series, but the O/P voltage was too high to handle. Hence it was decided upon that the panels will be connected in parallel. But this in turn posed another problem of high current and low voltage, which would eventually increase the losses in the system in terms of heat dissipation.
- Mounting of PV Panels posed yet another challenge. The rooftop of Stuart Building had many other objects which cast long shadows. This is not a very good thing as the panels themselves would be casting shadows which are to be taken care of.
- Several companies that HREAT has contacted regarding pricing and product information have either been slow to respond to our inquiries or have been completely non-respondent. This has hampered our efforts to gather information and to move ahead with our analysis.
- There are lot of things that are to be answered before the actual economic analysis has be carried out on the designs.
- HREAT is yet to get started. Though the major components of the design are taken care of, there are still few peripheral components left out that are to be accounted for.