HYDROGEN FUEL CELL & ITS POWER MANAGEMENT

A MAJOR PROJECT REPORT

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Of

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In

AEROSPACE ENGINEERING

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DEPARTMENT OF AEROSPACE ENGINEERING

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ABSTRACT

Fuel cell technology is a fast growing field with a lot of potential to sustain this world's future energy needs. With the use of renewable resources outgrowing their availability, fuel cells represent a cleaner and environment friendly way of producing energy. The technology was discovered long ago but has seen major progress only in the past decade. It has since been used in several automobile projects and several aircrafts. The technology has been found to be quite suitable to power a small aircraft. However, further developments are needed to make it usable in a larger aircraft and sustained flights.

Fuel cell technology is today on the verge of achieving feasibility and consistency as a power plant for long sustained flights. Its use in space applications is also considered to be major force in future. Some problems are still being sorted out but its potential is undoubted.

In our project we represent a PEM hybrid fuel cell that can power an aircraft and uses an auxiliary Li-ion battery. The power voltage from the fuel cell is regulated by a DC/DC converter before integrating with the Li-ion battery, which provides energy to the drive motor. Such a hybrid fuel cell powered vehicle is governed by a power management model that is suited to its needs. In our project we have aimed to study the hybrid fuel cell technology, its need for the future, the principle behind the PEMFC and its working. A major part of our report is the power management model of the fuel cell. A power management model is incorporated in the system such that the power output varies in different conditions; including high power, low power, standard power, and charge modes.

We have aimed to find the most requisite fuel cell needed to power a 4 seater fuel cell powered aircraft being designed along with its other parameters. We aim to find the fuel cells stacks required to produce the requisite amount of power based on the power requirement of the given aircraft. We will also try to find the amount of hydrogen to be supplied to the fuel cell and its usage. Apart from this, the most suitable propeller configuration is also studied and its advantages and disadvantages. The aim of this thesis is to provide a comprehensive analysis of the major technologies and systems involved in the fuel cell powered aircraft.

THESIS CERTIFICATE

I hereby certify that the work which is being presented in the project report entitled **"Hydrogen fuel cell and its power management"** in partial fulfilment of the requirements for the satisfactory performance for B.Tech Aerospace Engineering, Major Project submitted in the Department of Aerospace Engineering, University of Petroleum and Energy Studies, Dehradun is an authentic record of my own work carried out during a period from July 2012 to April 2013.

SUBMITTED BY:

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This is to certify that the above statement made by the candidate is correct to the best of our knowledge.

Prof. Linsu Sebastian
Guide
Date: 18/04/2013

Head of the Department
Dr. Om Prakash
Date:

External reviewer
Date: 18/4/2013

ACKNOWLEDGEMENTS

It is with a sense of great satisfaction and pride that we are sitting down to pen out our major project thesis report. First and foremost we sincerely salute our esteemed Institution **University of Petroleum & Energy Studies, Dehradun** for giving this golden opportunity for fulfilling our warm dreams of becoming a bachelor.

The first and foremost person we would like to express our deep sense of gratitude and profound thanks to our guide **Prof. Linsu Sebastian,** Department of Aerospace Engineering, UPES Dehradun for his valuable advice, suggestions, insurmountable guidance which played a vital role in carrying out our project work successfully. Our thanks to **Prof. (Dr.) Om Prakash**, Head, Department of Aerospace Engineering, UPES, Dehradun for his valuable guidance towards our project.

We would like to thank **Prof. (Dr.) Ugur Guven,** for his help & encouragement during the work. We also thank all faculty, staff, and students of Department of Aerospace Engineering and for rendering help during various stages of the project work. We would like to thanks our parent, our sisters/brothers and our friends for their support and encouragement for carrying out our project work in a well sincere manner

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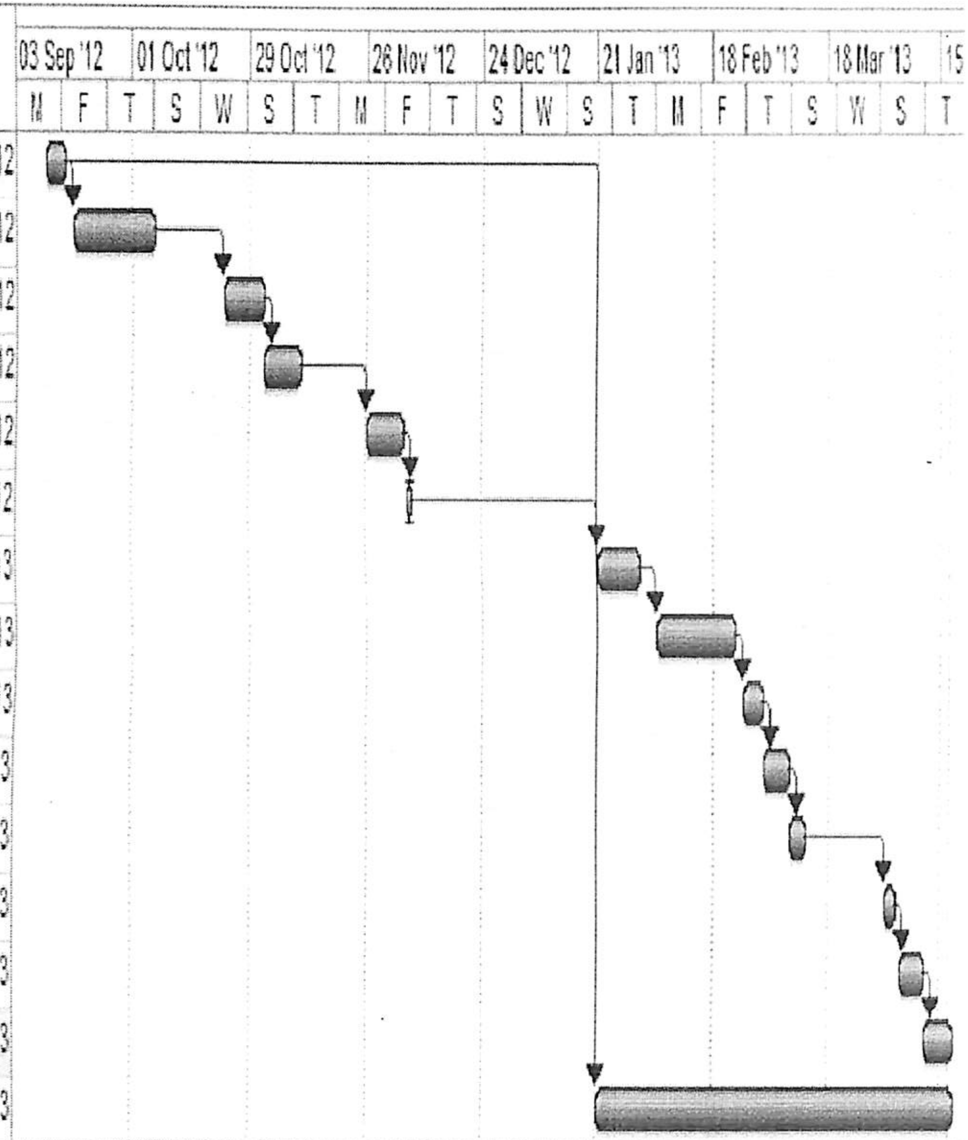
ABBREVIATIONS

DC	Direct current
DMFC	Direct Methanol fuel cell
HEV	Hybrid Electric Vehicle
PEM	Proton Exchange membrane
PEMFC	Proton Exchange membrane fuel cell
SOFC	Solid oxide fuel cell
SOC	State of Charge
AVGAS	Aviation Gasoline
EIA	Environmental investigation agency
IEMFC	Ion exchange membrane fuel cells
MEA	Membrane electrode assembly
FCS	Fuel conditioning systems
PTFE	polytetrafluroethylene
DFMC	Direct methanol fuel cell
MW	Mega watt
CHP	Combined heat power
YSZ	yttria-stabilised zirconia
NASA	National Aeronautics and Space Administration
FCHV	Fuel cell hybrid vehicle
FCV	Fuel cell vehicle
SUV	Sports utility vehicle
DLR	German Aerospace Centre
HTPEM	High temperature PEM fuel cell stack
UAV	Unmanned aerial vehicle
CNG	compressed natural gas
ANSI	American national standard institute
DOT	Department of transport
ISO	International Standard Organization
EIHP	European Integrated Hydrogen Project
TNT	Tri Nitro Toluene

PROJECT PLAN

ID		Task Name	Duration	Start	Finish
1		Topic selection	5 days	Mon 10-09-12	Fri 14-09-12
2		Understanding the topics	15 days	Mon 17-09-12	Fri 05-10-12
3		Collection of literature	8 days	Mon 22-10-12	Wed 31-10-12
4		Literature review of propellers	7 days	Thu 01-11-12	Fri 09-11-12
5		Preparation for mid-review	7 days	Mon 26-11-12	Tue 04-12-12
6		Mid review presentation	1 day?	Thu 06-12-12	Thu 06-12-12
7		Review of exisitng projects	8 days	Mon 21-01-13	Wed 30-01-13
8		Study of PEMFC	15 days	Mon 04-02-13	Fri 22-02-13
9		Choice of fuel cell for project	5 days	Mon 25-02-13	Fri 01-03-13
10		Study of power plant	5 days	Sat 02-03-13	Thu 07-03-13
11		Power plant calculations	2 days	Fri 08-03-13	Mon 11-03-13
12		Motor Selection	3 days	Mon 01-04-13	Wed 03-04-13
13		Hydrogen storage selection	4 days	Fri 05-04-13	Wed 10-04-13
14		Power management	5 days	Thu 11-04-13	Wed 17-04-13
15		Data and report compilation	64 days	Mon 21-01-13	Wed 17-04-13



CHAPTER 1

INTRODUCTION

1.1 Report Layout:

Chapter 3 is the literature review and covers in-depth study of various literatures referred. Chapter 4 is based on the various hydrogen production techniques and their advantages and drawbacks. All the different chemical processes being used are listed down. In chapter 5 we have showcased various old and existing projects based on the fuel cell technology both from the automotive as well as aerospace field. In chapter 6 we have written about the power plant of the aircraft and the power being derived by the fuel cell. We have also presented the number of fuel cell stacks required for this purpose. In chapter 7 we have given a detailed review on the electrical system used to link the propeller with the fuel cell hybrid system. We have also stated our choice of electric motor based on the power requirement. Chapter 8 focuses on the storage aspects of hydrogen gas as a fuel and the constraints it comes with. Hydrogen is stored in wings and fuselage in small cylinders specifically built for this purpose and the materials associated with building these cylinders. We have also stated the characteristic properties of different materials used for building the storage cylinders and also out choice for the project. Chapter 9 deals with the power management strategy associated with the hybrid fuel cell aircraft. It showcases the relationship between the Li ion battery as an auxiliary source and the fuel cell as a primary source.

1.2 Use of fuel cells

Fuels cell technology has been in practice since decades, but as the growing problems are increasing and there is dire need to solve these problems and reduce the dependence on expensive fossil resources, fuel cell technology has been recently developed into stationary power generation and automotive/aviation propulsion. Because of large money being invested by the automotive industry in this technology, fuel cells are becoming more and more competitive with existing gasoline piston engines. Aviation industries are also bound to face the same problems and there has been a lot of research done in this field in order to increase the specific power of fuel cells, and making this technology practically being applied to the aircrafts. Space industries have always been having this technology in practice since the Apollo missions in 1960's. Hydrogen storage is also a very big concern as liquid hydrogen is used as reactant in propulsion systems of launchers. It is quite clear that this hydrogen fuel cell technology has been studied for quite long time and it is on the verge of achieving sufficient power levels to be applied to aviation sectors. There are many technological problems which are yet to be solved, but its replacing the oil feature is widely accepted. The aim of this thesis is to propose a propulsion unit of the aircraft designed by the other group working on the project. The aircraft specification was provided by other group working on this project. Based on the available types of fuel cells available at most suitable one is selected. Also a most suitable motor is selected for the fuel cell specifications. A fuel cell propulsion system is proposed based on the power requirements and the efficiency of the fuel cell type.

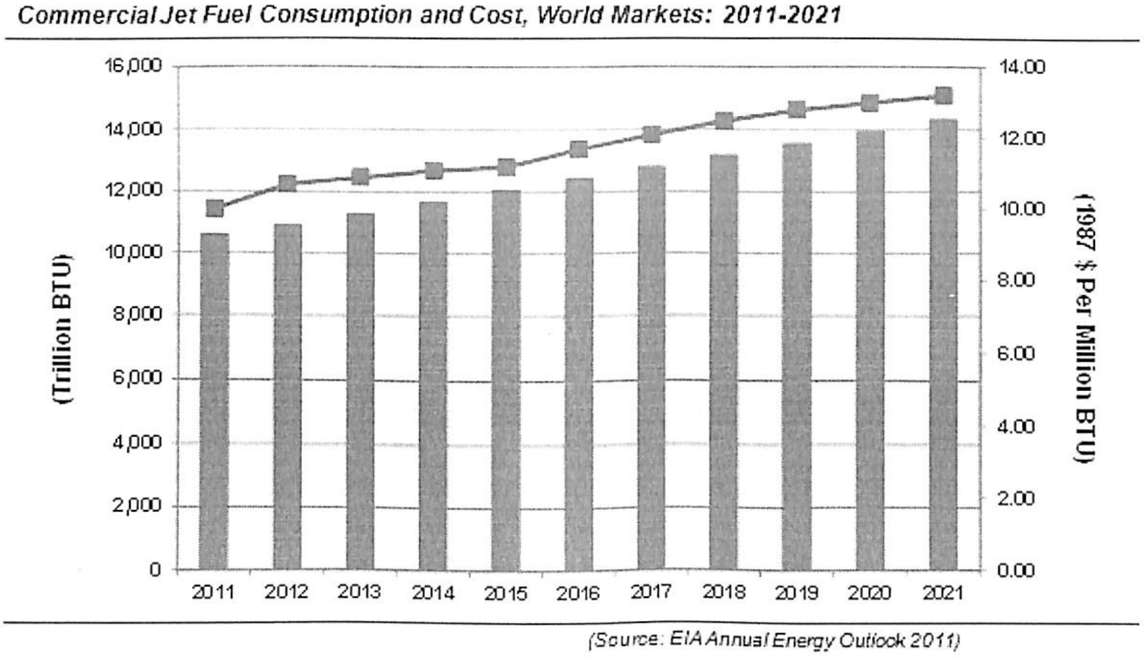
1.3 Oil prices Variations

A barrel of WTI crude is to be 100$ per barrel as forecasted by EIA, this increase price is in response to increased demand of fossil fuels as the recession gets over in 2012. This price is $6 per barrel more than its price in 2011. This EIA prices may even go further in tourist seasons. On the other hand chances of reaching this price over 125$ per barrel is only 6%. The price expected by the end of 2013 is expected to be 103.75$ per barrel. (Source: EIA, short term forecast)

Table 1.1: Oil prices

Month	Date	Forecast Value	50% Correct +/-	80% Correct +/-
0	Mar 2012	**106.19**	0.0	0.0
1	Apr 2012	**104.3**	1.9	4.3
2	May 2012	**98.4**	2.5	5.5
3	Jun 2012	**85.4**	2.9	6.4
4	Jul 2012	**92.0**	3.2	7.1
5	Aug 2012	**99.2**	3.4	7.7
6	Sep 2012	**106.1**	3.7	8.3

Due to rapid increase in the price of the crude oil per barrel and the rapid growth of Aviation sector the need of finding some alternate source which can fulfil the need of aviation fuel. The best alternative is fuel cell. This is enormous source of power and the by product is eco friendly.

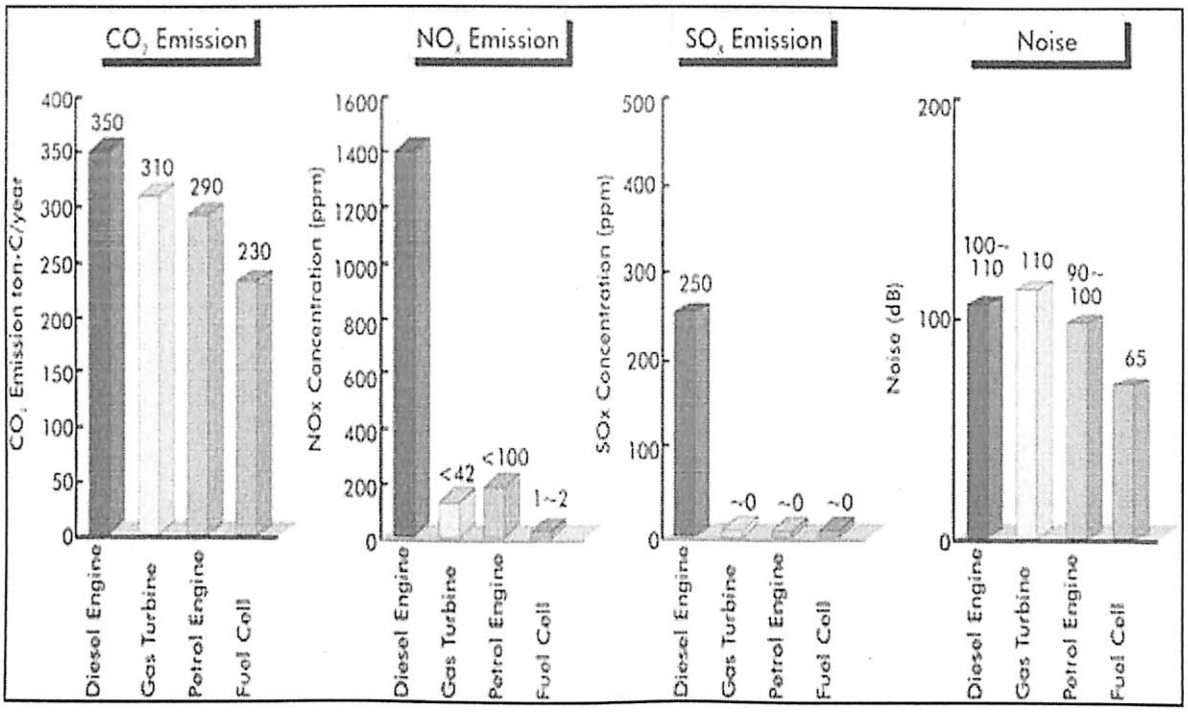


Plot 1.1: Estimated cost per fuel Consumption in Aviation [EIA Annual Energy Outlook 2011]

Previous reports says that in 2004, a report from the US department of energy, published three trends for the evolution of the crude oil barrel price, but in the past few months the barrel prices have risen up to un expectedly over the worse predictions. Over the past 24 months the crude oil price has risen from 40$ to 75$ and in 2013 they have reached 105$ per barrel. Because of emerging countries demand for energy, the price of crude oil will stay high or even increase. Due to these reasons alternative energy to fossil fuels become necessary, and a lot of efforts and money has been invested in research and development of fuel cell systems both for power plant and automotive applications.

1.4 Pollution Control

The biggest achievement of a fuel cell powered aircraft would be to reduce the emissions of greenhouse gases to zero or near zero. As we know that air transport and aviation sector is responsible for around 10% of the global warming effect and 3% of carbon emissions. The growing market of air transport will pollute even more; release more carbon and particles and NOx components.



Plot 1.2: Pollution- CO2 Emission [Source: EIA Annual Energy Outlook 2011]

Fuel cells are much more efficient that combustion engines, to compare fuel cell systems have efficiencies around 50% and by proper research it can be improved to 60% on the other hand combustion engines have efficiencies of 15%. In a sustainable development approach higher efficiencies up to a ratio of 3 means burning less fuel, and then reduce the energy necessary to produce the fuel (oil refinery or hydrogen production). Water steam is itself is a greenhouse gas and to eliminate the pollution created by this the cruising altitude has to be limited so that the emitted water returns back to its liquid state. If not then the water has to be kept on board which will make the landing weight heavier than take of weight which is not desirable at all.

On analysing the status of fuel cells, these are the only possible substitutes of other power sources such as gasoline, diesel and petrol because of the high efficiency of fuel cell and almost no polluting waste during the operational cycle.

1.5 Noise reductions

The use of electric motor and fuel cells reduces the noise produced significantly rather than a conventional piston engine. But although the noise reduction is significant we are very far from replacing turbofans by fuel cells. Fuel cells may reduce noise around airports.

CHAPTER 2

AIM, OBJECTIVES AND METHODOLOGY

2.1 Aim

Aim of this project is to study and analyse the fuel cell technology and to assist the design of fuel cell powered aircraft with our findings.

2.2 Objectives

- To Study and analyse the various fuel cell technologies in use today.
- To Study of the PEMFC fuel cell.
- To find the fuel cell most suited for the fuel cell aircraft.
- To Study and analysis of fuel cell power plant.
- To calculate the number of fuel cell stacks required according to the power requirement.
- To calculate the amount of hydrogen being used.
- To Study of the electrical system and finding the most suitable motor for our purpose.
- To Study the hydrogen storage techniques and the storage cylinders with their material characteristics.
- To Study and analysis of the power management system that governs the fuel cell hybrid system of the aircraft.
- To explain the advantages and drawbacks of the propeller configuration to be used in the aircraft.

2.3 Methodology

We started our project with studying about the need for fuel cell technology in today's world and the advantages it brings with itself. Then we studied the fuel cells and the found out about the various existing projects in automobile and aerospace field on fuel cells. We then proceeded to learn about the PEMFC which is the fuel cell of choice for most aviation purposes. We did a detailed study on the PEMFC fuel cell and its various components. After that we studied and analysed the power plant architecture to be used in the fuel cell aircraft.

Based on the power requirements of the aircraft, we found the fuel cell to be used and calculated the number of fuel cell stacks required for it. We also found the hydrogen gas requirements and the rate of hydrogen consumption. After that we proceeded to analyse the electrical system to be used in the project and the various motor options. This helped us to find the motor most suited for our purpose based on the power plant. After this we studied the hydrogen storage technique and the difficulties in storing liquid hydrogen. Further study was conducted on the hydrogen storage tanks and a detailed review on the material characteristics of the storage cylinder was conducted. The best hydrogen storage chamber in the market was chosen.

After this we shifted to the power management of the hybrid fuel cell aircraft. We learnt about the assembly and simultaneous working of the fuel cell and the Li-ion battery. We studied about the power delivery from both these power sources and analysed the various power modes associated with the system, charge mode, high power mode, standard mode and the low power mode.

In our last segment we have discussed the advantages and the drawbacks of the pusher propeller configuration associated with the design of the fuel cell powered aircraft in conjunction with our project.

CHAPTER 3

LITERATURE REVIEW

3.1 Stacks [15]

A single fuel cell only produces a voltage of few Volts ranging from 0.6-1.2V thus many cells have to be combined in series to produce a voltage that is actually useful in running equipments. To connect fuel cells, anode and cathode of two different cells have to be connected so that the voltage and power of all the individual cells are being added up.

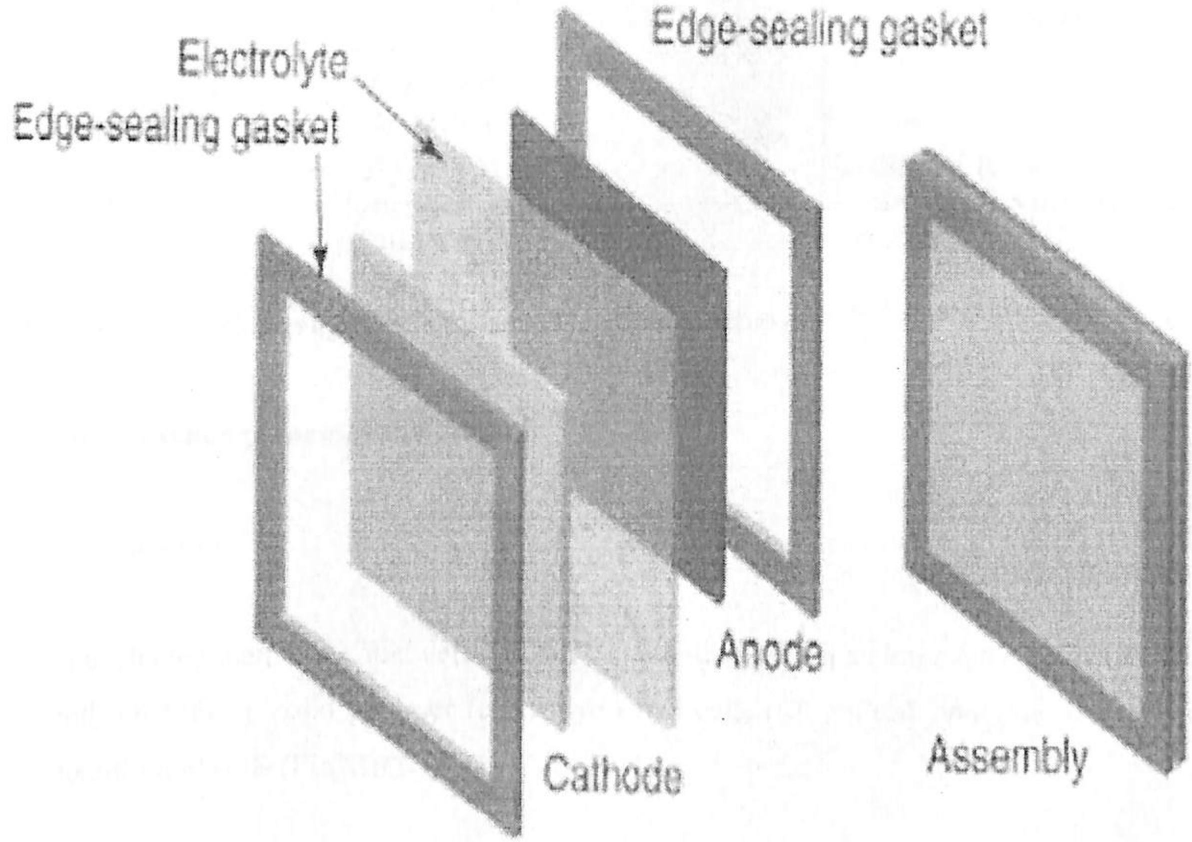


Figure 3.1: Stacks [Source: Cranfield University report 15]

To construct a compact design, bipolar plates are used, i.e. one plate act as cathode and another acts as anode. A stack is a combination of many cells connected through bipolar plates.

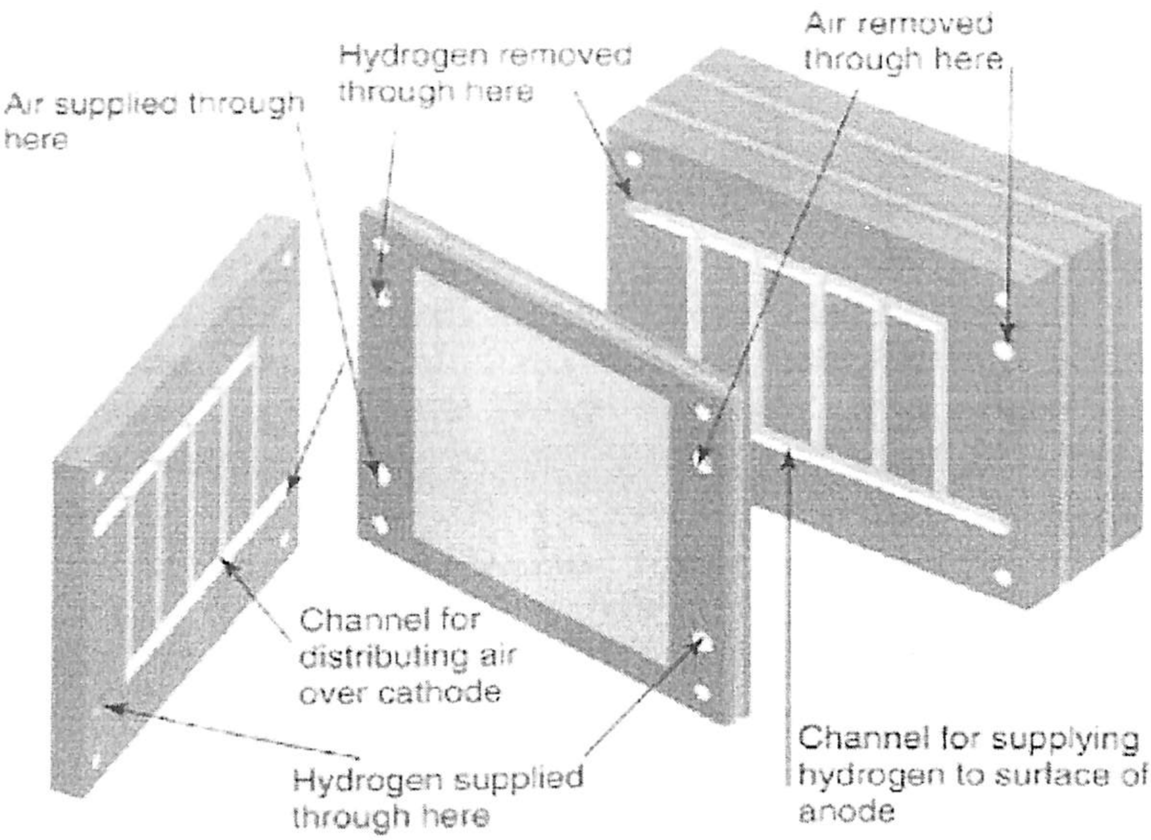


Figure 3.2: Stack arrangements for air and hydrogen removal [Source: Cranfield University report 15]

3.2 Proton exchange membrane fuel cell

3.2.1 Introduction:

Proton exchange membrane fuel cells (PEMFCs) are also known as ion exchange membrane fuel cells (IEMFCs), solid polymer (electrolyte) fuel cells (SP(E)FCs) , polymer electrolyte (membrane) fuel cells (PE(M)FCs) etc.

The electrolyte used in this fuel cell in PEMFCs is a proton conducting membrane cast in solid polymer form. Solid electrolytes have huge advantages over liquid electrolytes. It allows a simple and compact cell structure and operation, leading to relatively simple design and easy for manufacture. No free corrosive liquid electrolyte in the cell exists, giving rise to minimal corrosion of cell components and hence longer cell lifetime [15].

The solid electrolyte can be made in a very thin sheet, just as thin as 200um or even as thin as 50um, to produce low internal resistance cells because the resistance to ion mitigation in the electrolyte typically accounts for the absolute majority of the entire cell's electrical resistance, usually over 95% or even more. Therefore high energy and high output power density are obtained.

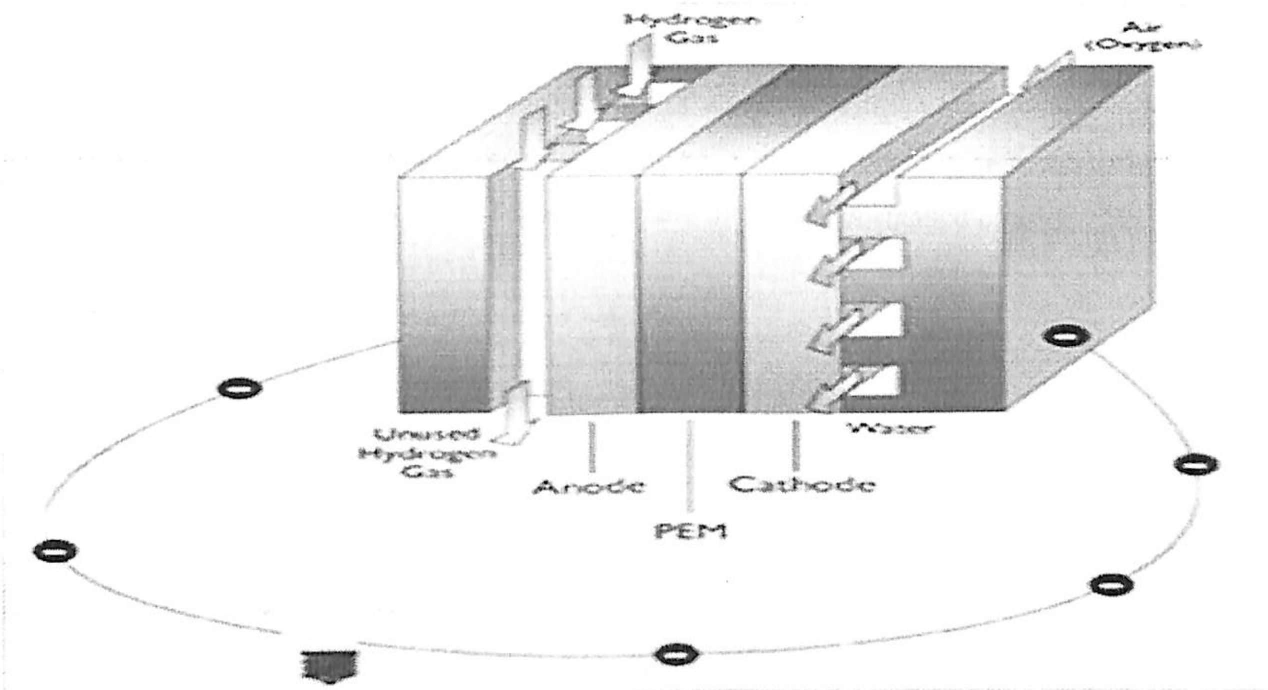


Figure 3.3: Introduction to Fuel PEMFC fuel cell [Source: Cranfield University report 15]

PEMFC is able to sustain large pressure differentials between the anode and cathode compartment and large pressure fluctuations in the reactant gas supply lines. As large as over 5 Mpa cross stream pressure differential has been reported for PEMFCs. As a result, expensive precision sensors and control units can be avoided for the PEMFC operation. This unique characteristic, coupled with its insensitivity to orientation due to solid electrolyte, makes PEMFC system ideal for mobile applications. The stability and lifetime of the membrane limits the cell operating temperature, typically to less than 100o C. Such a low temperature operation offers almost instantaneous power output, resulting in easy and quick start up, making PEMFC system ideally suited for transportation applications with frequent on and off operations.

It is important to emphasize that the polymer membrane used as electrolyte has acceptable conductivity to proton migration when it is fully humidified. The electrical resistance increases when the membrane is drying out, increasing Ohmic polarization and Joule heating at the same time

Local heating leads to further water evaporation and accelerate the local drying; resulting in vicious self-accelerated destruction of cell performance. The membrane is unstable at high temperatures, and local heating also limits the lifetime of the membrane electrolyte, hence the cell lifetime as well. However excessive presence of water floods the electrode pore regions, giving rise to the so-called water flooding phenomena, which severely reduce the rate of reactant mass supply to the reaction sites and degrade the cell performance considerably [15].

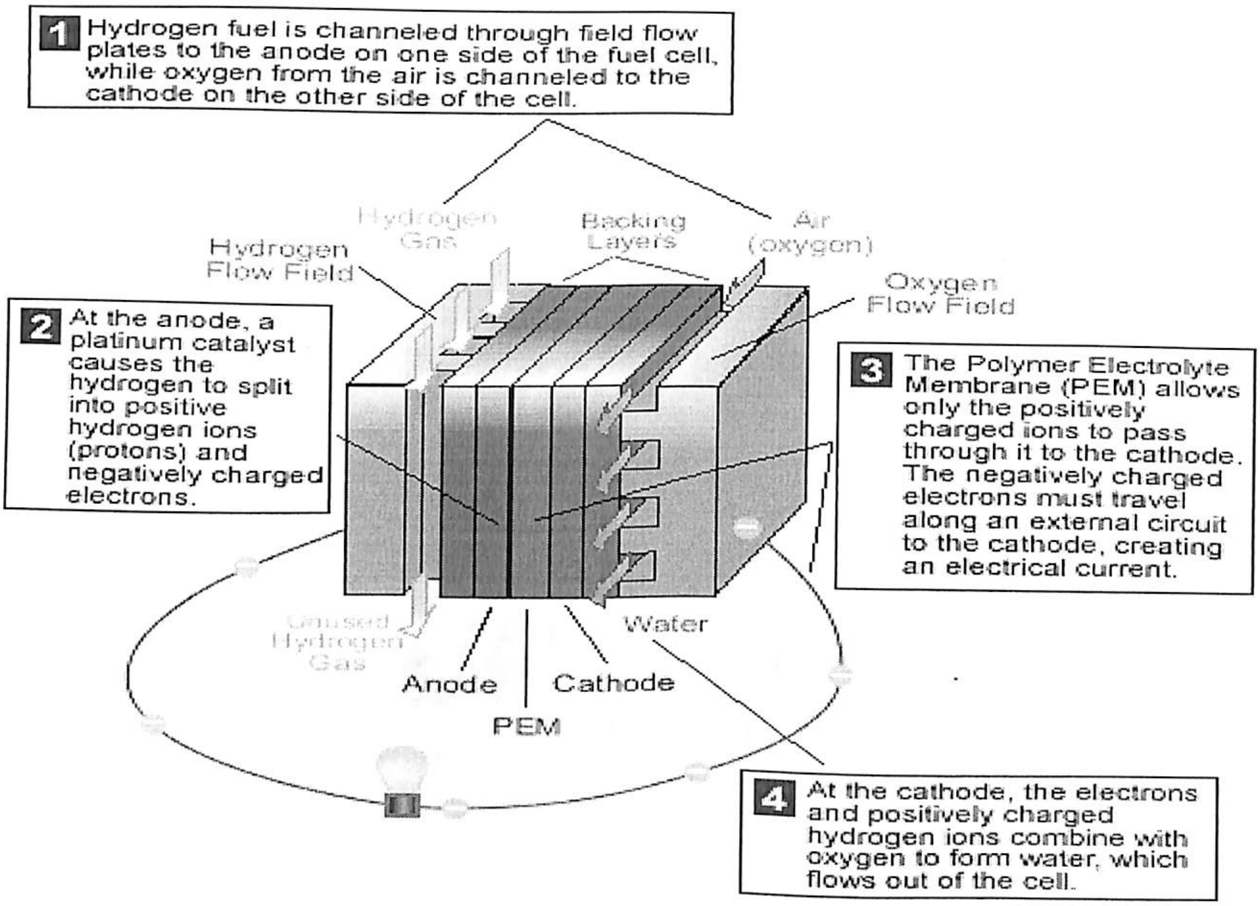


Figure 3.4: Fuel Cell Actual Circuit [Source: Cranfield University report 15]

3.2.2. Basic Principles and Operations [15]

A single cell proton exchange membrane fuel cell unit as shown and many such units connecting in series form a PEMFC stack. Each cell is composed of a solid polymer membrane acting as the electrolyte, which is sandwiched in between the two platinum-catalyzed carbon electrodes. The two electrodes and the membrane electrolyte are often mechanically compressed by screws or pneumatic pressure to form a single piece, commonly referred to as the membrane-electrode assembly (MEA).

Humidification anode- and cathode- feed gas are supplied to each electrode through the flow distribution channels produced on the bipolar plates positioned between each MEA in the stack. Therefore, the bipolar plate is often referred as the flow- field plate (or the flow distribution plate). Convection mass transfer occurs between the flowing gas stream in the flow channels and the electrode backing-layer surface. The transport of a gas mixture through the porous backing layer is primarily by molecular diffusion in the direction of cell thickness for typical PEMFC operating conditions, even though convection in the flow channels penetrates into the porous backing layer for flow in the direction parallel with the flow channels (the longitudinal direction).

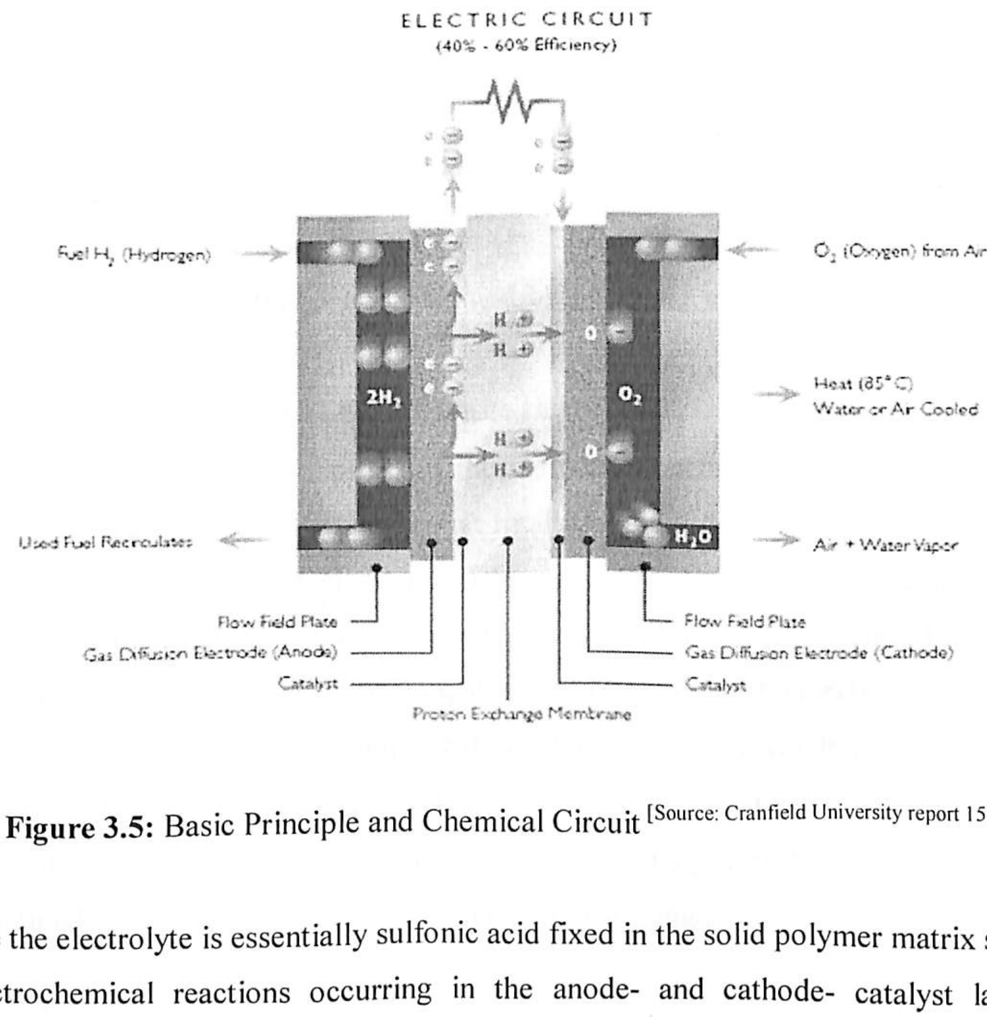


Figure 3.5: Basic Principle and Chemical Circuit [Source: Cranfield University report 15]

Because the electrolyte is essentially sulfonic acid fixed in the solid polymer matrix structure, the electrochemical reactions occurring in the anode- and cathode- catalyst layers are identical to those in the phosphoric acid fuel cell. At the anode catalyst layer, electro oxidation of hydrogen occurs with the production of protons and electrons.

At the anode: H2 2H+ + 2e-

The protons are transported from the anode to the cathode side through the hydrated membrane electrolyte under the effect of electric double layers near the two electrodes; therefore, the proton migration is influenced by the electric field effect, proton concentration gradients which would exist if the membrane is not fully hydrated or local drying of the membrane occurs, and convective motion if the pressure differential exists between the anode- and the cathode- feed gas streams. The proton migration from the anode to cathode side through the membrane electrolyte is in the form of the hydronium ions, thus taking or dragging ξ number of water molecules per proton along with it – the phenomenon is often called electro osmotic drag effect. This often results in less molecules of water on the anode side of the membrane, especially at high current- density operations and increases water concentration on the cathode side of the membrane.

At the cathode the catalyst layer, the oxygen molecules, supplied from the oxidant flow streams in the flow channels, combine with the protons and electrons originated from the anode catalyst layer to form product water:

At the cathode: $1/2O_2 + 2H^+ + 2e^-$ H_2O

As a result the entire cell reaction is obtained by summing up the two half cell reactions shown in the Equations:

Over all cell reaction: $H_2 + 1/2O_2$ H_2O + Waste Heat + Electrical Energy

The reaction product water is formed at the membrane- catalyst interface in the cathode catalyst layer, typically in the liquid form at the PEMMFCs operating condition, and seeps into the porous structure of the electrode backing layer, water removal and control become one of the major issues in PEMFCs. Because the chemical energy stored in the reactant hydrogen and oxygen cannot be completely converted into the useful electrical energy, waste heat is produced in the conversion process due to both reversible and irreversible mechanisms. Therefore, the water and waste heat are the two reaction by-products accompanying with the production of electric power and they need to be properly managed for the optimal performance of the PEMFC stacks and systems.

3.2.3 Components and Configurations

This section describes the typical components and the geometrical configurations involved for the single cell fuel cell, a PEM fuel cell stack, and a PEM fuel cell system.

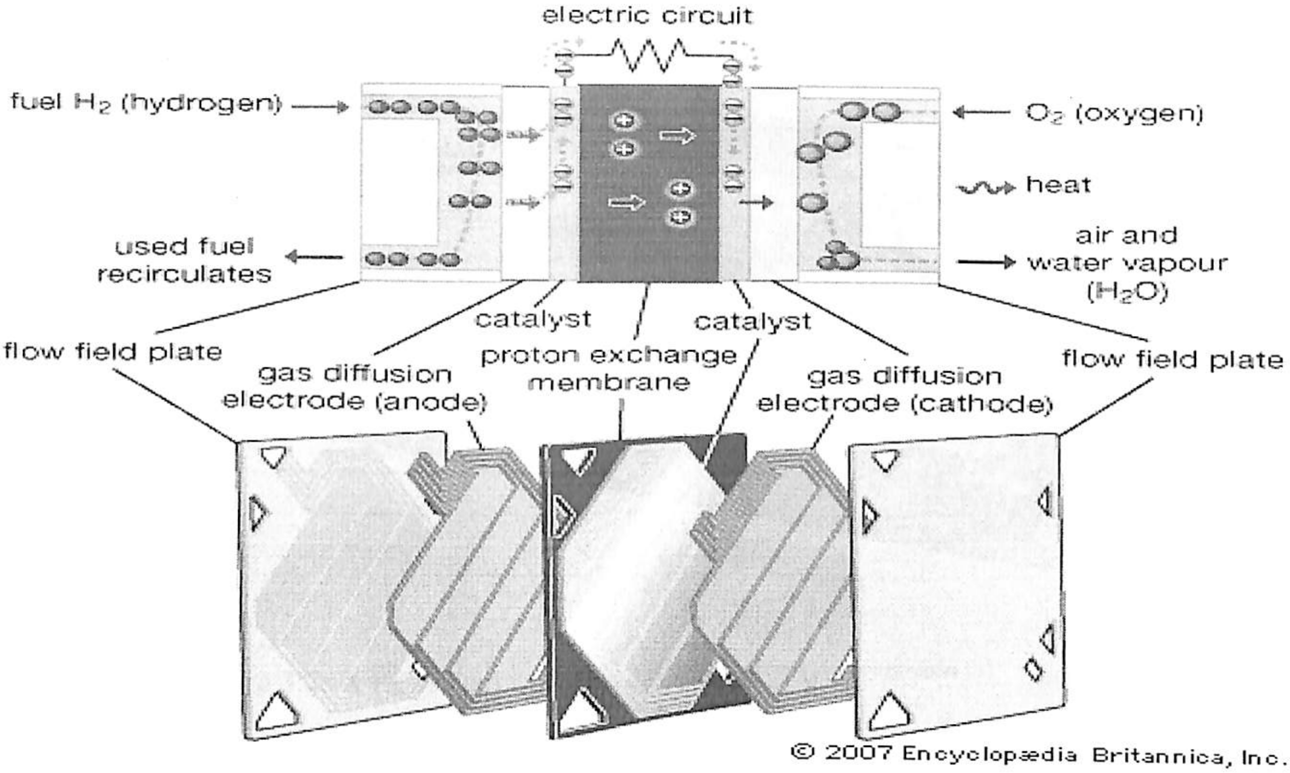


Figure 3.6: Component and Configuration [Source: Encyclopaedia Britannica 2007]

A single cell PEM fuel cell typically used for the laboratory purpose provides the corresponding illustration of the cell components. Such a single cell often consists of a membrane electrolyte, two catalyzed electrodes, two Teflon masks and two endplates. The catalyzed electrode has a thin porous layer applied on to the gas diffusion backing layer. And the membrane electrolyte is normally about 50-175μm thick. The membrane electrode assembly is fabricated by hot pressing two electrodes onto the membrane with the catalyst layer bonded to the membrane. The catalyst layer may be considered macro-homogeneous, consisting of dispersed catalyst particles and membrane electrolyte surrounding the catalyst particle.

3.2.4 A PEM Fuel Cell Stack [15]

Single fuel cell units in context of a fuel cell stack with a cross-sectional view. Many such cells connected together in series, but separated by bipolar plates, form an integral stack for the desired power ratings. Majority of the PEM fuel cells stacks are in planar form, although other configurations such as tubular structures have been proposed.

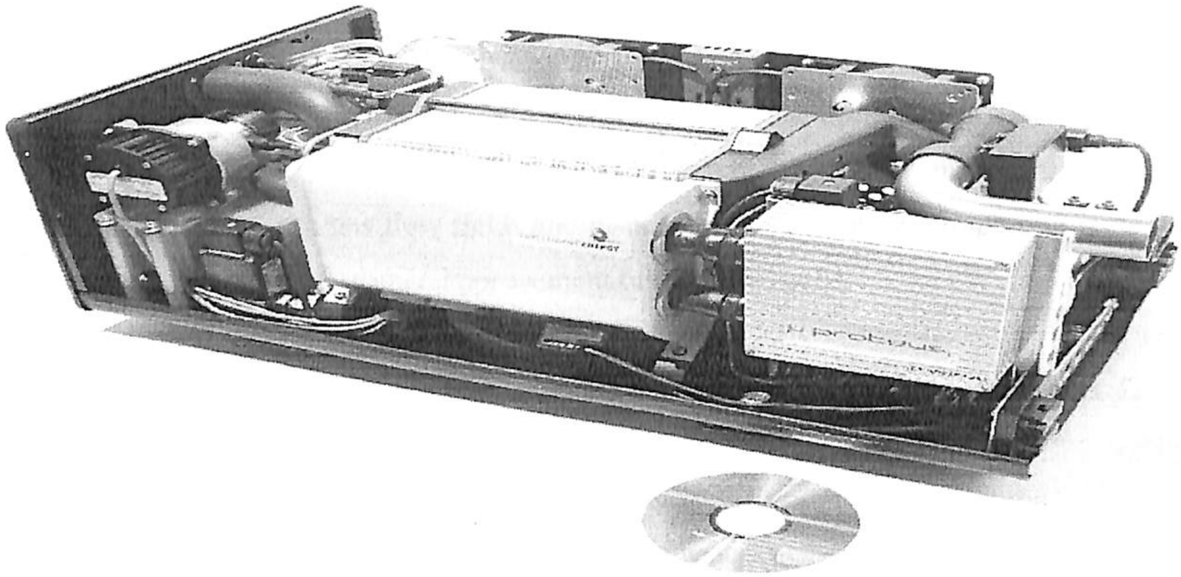


Figure 3.7: A PEM Fuel Cell Stack [Source: Cranfield University report 15]

In a typical fuel cell stack, the membrane electrode assembly is pressed in good electric contact on its both major surfaces with two electrically conductive plates called bipolar plates.

These plates have at least one flow passage engraved or milled on the surface facing the MEA, therefore, these plates are also referred to as fluid flow-field plates. The flow channels direct and distribute the fuel to the anode and oxidant to the cathode electrode. The function of the bipolar plate is to serve as the collector for the electric current generated in MEA, to provide mechanical support for the MEAs, to provide flow channels for the distribution of fuel and oxidant to the respective anode and cathode electrodes, for the effective removal of product water formed in MEAs. An effective design for the flow channels is to distribute the reactant gas over the electrode surface as uniformly as possible to utilize effectively all the active area of the electrode and to allow for the gas reactant stream to take the product water away avoiding the water flooding of the electrode during the operation of the fuel.

3.2.5 Design of the Fluid Flow – Field Channels on Plates

Despite the rapid progress being made, substantial cost reduction and cell performance improvement are required before PEMFC can reach widespread commercial use. It has been recognized that one of the main obstacles to large-scale commercialization are (i) gas flow fields and bipolar plates, including the development of material and light weight material the best design for the material its fabrication methods and impacts on the PEMFC performance (ii) the most promising direction for performance improvement is based on the minimization of all transport resistances, which depend substantially on the design of reactant gas flow fields. As much as 50% increase in the output power density has been reported just by appropriate distribution of gas flow fields and bi-polar plates remain one important issue for the cost reduction and performance improvement of PEM fuel cells.

For an operating fuel cell, the MEA (<1-mm thick) is interposed between two fluid-impermeable electrically conductive plates, called the anode and cathode plates, respectively. The plates serve as current collectors, provide structural support for the porous and thin electrodes, and provide a means for reaction product water removal. When the reactant gas-flow channels are formed in the anode and cathode plates, the plates are normally called gas flow-field plates as well. In a stack, one side of a given gas flow field plate is anode plate for one cell, and the other side is the cathode plate for the adjacent cell. In such an arrangement, the gas flow field is also called a bi-polar plate.

The cross section of the gas flow channels is typically rectangular, with the channel width and depth in the range 1-2mm, and each bipolar plate is almost an order magnitude thicker than the MEA itself. A fuel cell stack usually has a coolant fluid, typically water, flowing in interior channels within the stack to absorb the heat generated. The cooling layers are located at periodic intervals along the stack, usually every cell or every few fuel cells. Therefore, the heat produced in each MEA within a stack is transferred by convection to reactant streams and conduction through the solid stack components before reaching the coolant in the cooling layers.

The proton conducting polymer membrane must be fully hydrated to have adequate ion conductivity. It becomes non-conductive when dried excessively and then not useful for ion transport in fuel cells. The membrane in fuel cells is subject to moisture removal by evaporation due to heat generated in the electro chemical reaction and current transport, and proton migration through the membrane, which drags water molecules along with it from the anode to cathode (the electro osmotic effect). Excess water is then accumulated on the cathode side, also due to the formation of liquid water there as the reaction product. Some excess water diffuses back to the anode due to the formation of liquid water there as the reaction product. Some excess water diffuses back to the anode due to concentration gradient, but it is always sufficient to prevent excessive membrane drying under high current-operating conditions. As a result, the fuel cell must be operated under conditions where the water removal must be balanced by water supply and the reactant gases, both hydrogen and oxygen, has to be humidified before entering each cell in order to maintain the saturation of the membrane within the MEA. Thus, water and thermal management become critical for efficient cell performance, are fairly complex, and require dynamic control to match the varying operating conditions of the fuel cell. Because of the limitations, the operating temperature of PEMFCs is usually less than 120o C. Current polymer electrolyte is made of per-fluorinated sulfonic acid membrane, such as Nafion from DuPont.

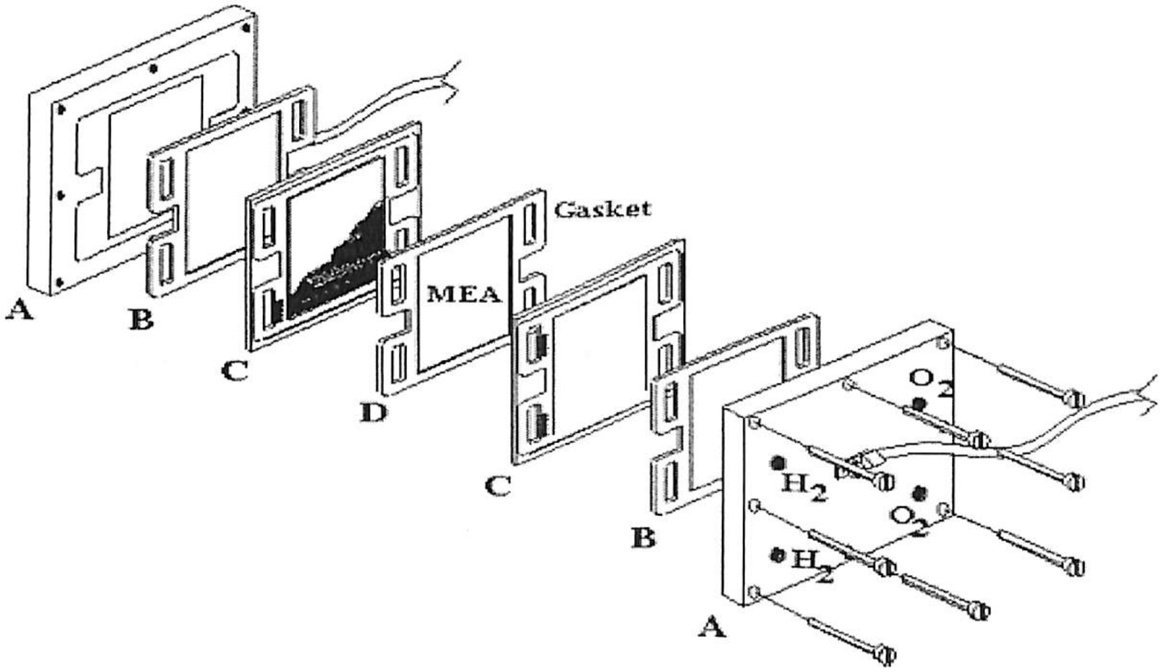


Figure 3.8: Design of Fluid flow Field Channels on plates [Source: Cranfield University report 15]

3.2.6 A PEM Fuel Cell System

A PEM fuel cell system usually have at least one multiple PEM fuel cell stacks for the generation of DC electric power. If a number of stacks are employed, they may be connected electrically either in series or in parallel, or a combination of them. Series connection provides higher voltage output while the electric current is relatively low, leading to lower

Ohmic losses both inside and outside the stacks among all the electrical connections. However, a series connection can result in a system break down if any of the cell or stack components break down, thereby increasing maintenance requirements and potentially limiting reliability and lifetime of the entire system.

3.2.7 Fuel Conditioning

It is simple if the pure hydrogen is used as a fuel and the only consideration is water addition for the humidification and temperature control since pure hydrogen in storage is normally at the temperature lower than the stack environment.

Because of the sensitive dependence of water saturation pressure on temperature, heating and humidification process are implemented in a single synchronized process. It might be noticed if the in-stack humidification unit can be removed along with the heat and water addition requirement, greatly simplifying the system design and control. This also reduces the size of the external radiator needed to reject the stack waste heat carried out by the cooling stream. Otherwise it is not trivial to provide the control and provision for the addition of heat and water as well as the humidity and temperature of fuel cell stream entering the fuel cell stack. Hydrogen exhaust is normally re-circulated back to the fuel cell stack.

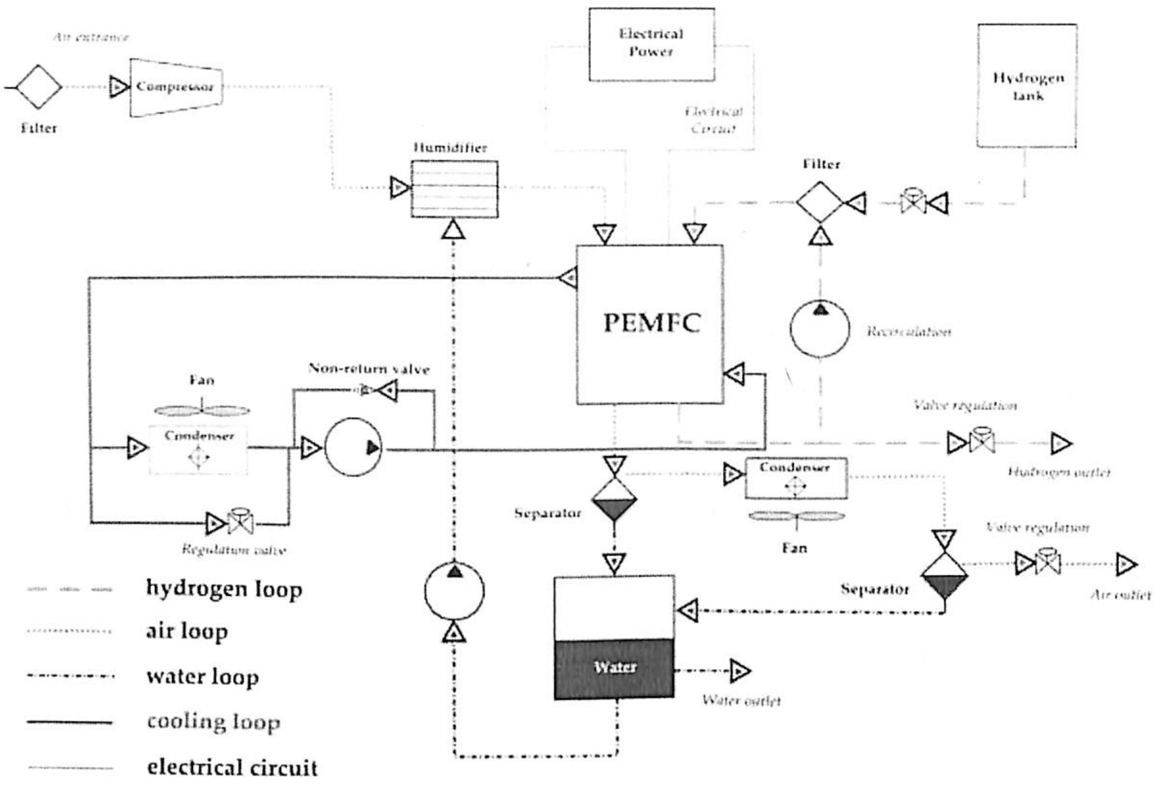


Figure 3.9: Fuel Conditioning System [Source: Cranfield University report 15]

3.2.8 Oxidant Cooling Subsystem [15]

It is most simple if pure oxygen is used as for space applications, where oxygen is typically dead-ended instead of circulated during operation. Then, proper pressure regulation to direct the oxygen in the high-pressure storage tank to the operating stacks is needed along with the temperature control and proper humidification. For terrestrial applications, it is imperative that air be used instead of pure oxygen. Then atmospheric air needs to be compressed to the stack operating pressure and air compression can consume as much as 30% of the power generated in the stack – a significant, and in fact the largest single parasitic power loss in the system. Also air temperature from the compressor is usually much higher than the stack operating temperature and heat exchangers are needed to cool the air stream and capture the heat for the other purposes, such as heating up the fuel system to improve the energy efficiency of the system

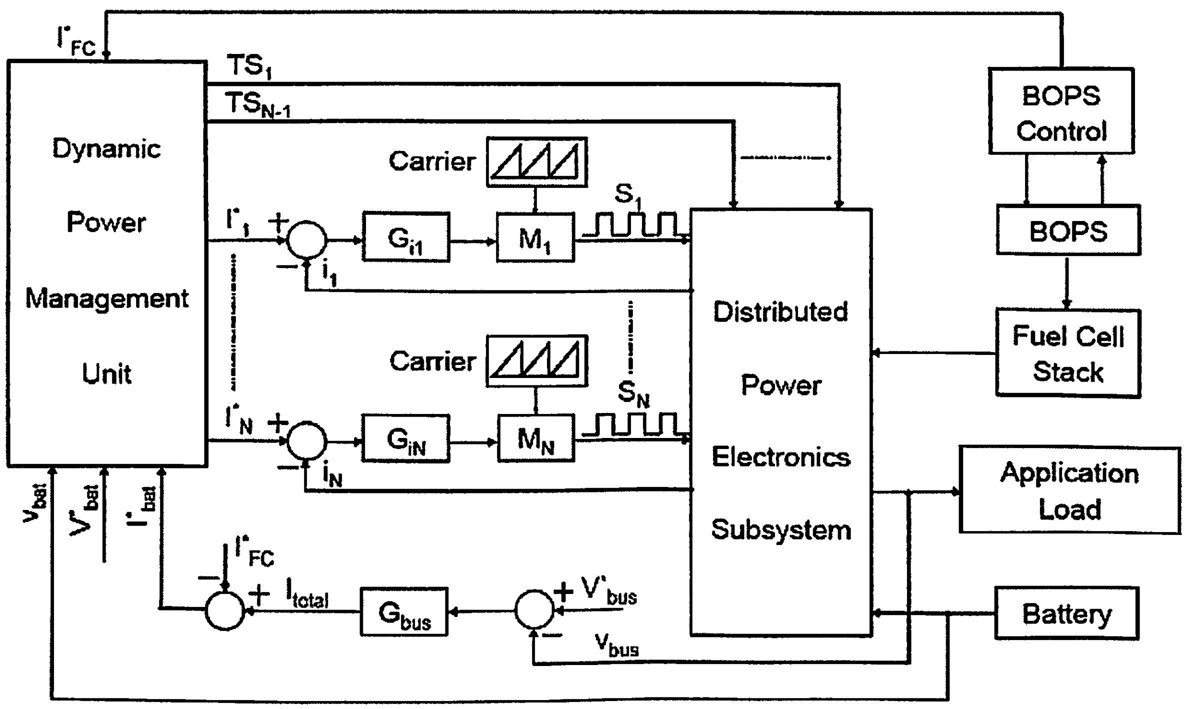


Figure 3.10: Oxidant Cooling Subsystem [Source: Cranfield University report 15]

3.2.9 Thermal Management Subsystem

Typically PEM fuel cells are designed to operate at the average cell voltage E of 0.6~0.7 V. For to form product water, the thermal neutral voltage E =1.48 V if the product water is in the liquid form (HHV), or less 1.25 V if the product is in the vapour state (LHV). Therefore, the chemical to electrical energy conversion efficiency is based on LHV. The rest of the chemical energy is converted into sensible thermal energy, or commonly referred to as waste heat produced in the fuel cells. Therefore, the amount of the waste heat generation is approximately the same as the stack's electrical power output.

It should be removed from the cells continuously for steady operation, efficiently for optimal system performance, and effectively for near isothermal temperature distribution across the cells; this is because best fuel cell performance is achieved for isothermal cells.

Depending on the stack size (power output) and the specific applications, waste heat removal from the PEM fuel cell stack can be accomplished in a variety of ways by using a cooling flow, attaching the entire stack to a cooler or fixing extended heat transfer surfaces (fins) to the stacks outside surfaces. However, cooling circulations most practical for commercial applications and any gas or liquid can be used as a coolant, although air water is the two common cooling agents. In principle evaporative cooling is the best to achieve isothermal cell operating condition.

3.2.10 Cooling Load

The rate of heat generation in a single cell has been derived as a function of the cell operating condition, the cell current density, and the cell voltage losses. This is convenient for the determination of waste heat generation during the actual cell operation. But for a stack design, it is more useful to express the rate of heat generation in a stack terms of the stack power rating and the average cell voltage which represents the two most important parameters in the stack design. Recognizing that the cell voltage losses due to both reversible and irreversible mechanisms can be written as, and the stack is composed of m active cells.

3.2.11 Natural Air cooling

For PEM fuel cell stacks intended to operate on the ambient air, the active cells in the stack may be arranged in the form of fins, imitating the compact h eat exchange design. Active cells are not connected by bipolar plates, rather they are connected in series with edge current collection and the cells do not physically contact each other on its two major surfaces. Instead active cells are separated from each other with spacing between them. This spacing is for ambient airflow by natural convection, which is aided by the water vapour in the air, formed from the evaporation of reaction product water.

3.2.12 Forced Air Cooling by Cathode Air Stream

For PEM fuel cells stacks of more than a few watts, the air stream in the cathode may be used for cooling as well and sometimes even excessive amount of the air may be implemented to achieve the cooling purpose as long as the product water evaporation can maintain relative humidity of 100% at the air-stream exit from the stack. Otherwise, membrane electrolyte dehydration occurs and the stack does not operate properly. For this case, the cooling and water management need to be considered at the same time.

3.2.13 Forced Water Cooling

As, the stack sizes are further increased, the amount of cooling air flows becomes excessively high and it is known that the pumping power required for air is orders of magnitude higher than for a liquid, and the flow channel size for air flow must be much larger than for liquid as well, both due to the orders of magnitude of smaller density of air. Therefore, for stack sizes of over 5 Kw or so, liquid water cooling becomes more energy efficient with more compact stack design, while for stack sizes between 2 and 5Kw and other considerations may decide the eventual choice of cooling is more popular for combined heat and power applications such as for residential or industrial co-generation applications.

3.2.14 Water Management Subsystem

PEM fuel cells are conceptually very simple and compact, but in practice, consisted of complex structures due to the need to remove reaction product water from the cathode side on one hand, and while at the same time providing adequate humidification to prevent the membrane electrolyte from dehydration, especially at the anode side of the membrane, yet avoiding excessive water from flooding the porous electrode structure. Therefore the management at the right place with the right amount is critical to the optimal performance of PEM fuel cells.

Water management is clearly composed of two interrelated issues: product water removal and complete hydration of the membrane electrolyte. Product water removal is accomplished often by employing wicks, gravity fed sumps, wet proofed electrode structures, and oxidant gas-flow stream. In reality, a number of these methods combined to their best effect. For example, a wet proofed electrode is almost always used in the PEM fuel cells for all designs. The porous electrode is made of carbon powders with appropriate amount of hydrophobic agents like polytetrafluoroethylene (PTFE) to avoid water from wetting the electrode surface due to capillary action. Thus water at the cathode catalyst layer tends to flow through such a hydrophobic electrode structure and beads up on the outside surface of the electrode adjacent to the oxidant flow channels.

3.2.15 Air management system-

The air management system provides filtered and pressurized air to the cathode manifolds of the fuel cell with controlled flow rate control. Variable flow rate control is especially very important in a self-humidified fuel cell system because of the risk of under humidification at low current densities. For the self-humidified fuel cell, there are no humidification requirements for the reactant gases and the air enters the fuel cell at the ambient humidity ratio.

3.2.16 Hydrogen storage/management system

The H storage and management system store vaporized H and delivers the H to the cell at a controlled pressure and flow. H is keep on board of the craft in a very carbon fibre/epoxy cylinder with atomic number 13 tank liner. The H utilization is outlined by the magnitude relation of the purge H flow to the entire H flow. As a result of the H purge cycle amount is simply a weak perform of the present output of the cell, the anode ratio varies as a performance of output current.

3.3 Materials and manufacturing techniques

A PEM fuel cell power system is made up of PEM fuel cell stacks, it is made up of membrane electrode assembly (MEA), the bipolar plates of the reactant over the active surface and the cooling plates for temperature management stacks. MEW is made up of two catalysed electrodes and also membrane electrolyte. The cooling plate is designed as same as the bipolar plate, mostly with the same construction methods and same materials and also very similar not necessary identical geometric configurations as well. So this section describes about the components which explains the construction of MEA and the generalized bipolar plates with the explanation about the generalized bipolar plates being cooling plates as well.

3.3.1 Electrodes

The electrodes in this PEM fuel cells are porous structured so as they allow the reactant gas transport through in order to let it react with the catalyst layer, the water gets transferred to the anode side and water is removed (by product) from the cathode catalyst layer. Electrodes are also used to collect electrical current generated in the cell. By electrode, we mean electrode backing layer within this subsection. It is usually made of carbon powder, mixed with hydrophobic agents such as PTFE, in the form of porous carbon cloth or carbon paper.

3.3.2 Catalysts used

Due to the acid nature of the membrane electrolyte and the low temperature operation of the PEM fuel cells, platinum remains the most effective or the best possible catalyst for the facilitation of both the hydrogen oxidation and oxygen reduction reaction in the PEM fuel cells, although other materials like ruthenium, palladium as well as non precious metals may be used as the catalyst with the reduced performance, to be described later in association with the reactant streams, especially carbon monoxide. Because the slow kinetics of oxygen reduction reaction (ORR) plays the key role in the performance limitations of the PEM fuel cell when pristine hydrogen is used as fuel, various measures have been taken to increase the ORR kinetics. The most effective measure is to increase significantly the effective surface area of the platinum catalyst, which has been achieved by using dispersed and small platinum particles and maximizing the platinum particle utilization in the reaction.

3.4 Polymer Electrolyte Membrane-

For the complete functioning of the membrane, the membrane must only conduct protons not the electrons. These protons are as hydrogen ions. If the electrons are allowed to pass through this membrane then there might be short circuit in the fuel cells. Also this membrane must not allow any gas to pass through it, if it does then a problem known as gas crossover takes place. Also the membrane should be resistant to the reducing environment which is at cathode and oxidising surroundings at the anode. Hydrogen molecule is split easily using a platinum catalyst. However splitting an oxygen molecule is very difficult, and while doing so it may cause substantial electric losses. A good catalyst material for this purpose has not been yet discovered. So we are left with the next best option which is platinum. But there is a catalyst which is much cheaper than platinum is iron, nitrogen, carbon they have been long known to help in promote the reactions but the rates which they make react are not practical. The reaction rates are very slow.

Recently researchers in Quebec have significantly increased the performance of this iron based catalyst. The material synthesized by them produces 99 amperes per cubic centimetre at 0.8 volts.

This result is 35 times better than the nearest cheap metal catalyst synthesized till now and very close to the goal of the department fuel cell catalyst that is 130 A/cm3. This performance is very close to the performance of a platinum catalyst. The biggest problem at hand is the durability as after 100 hours of testing the reaction rate by this catalyst dropped to half. Another reason for loss is the resistance offered by the membrane to proton flow, this is overcome by making it as this as possible, as much as 50um.

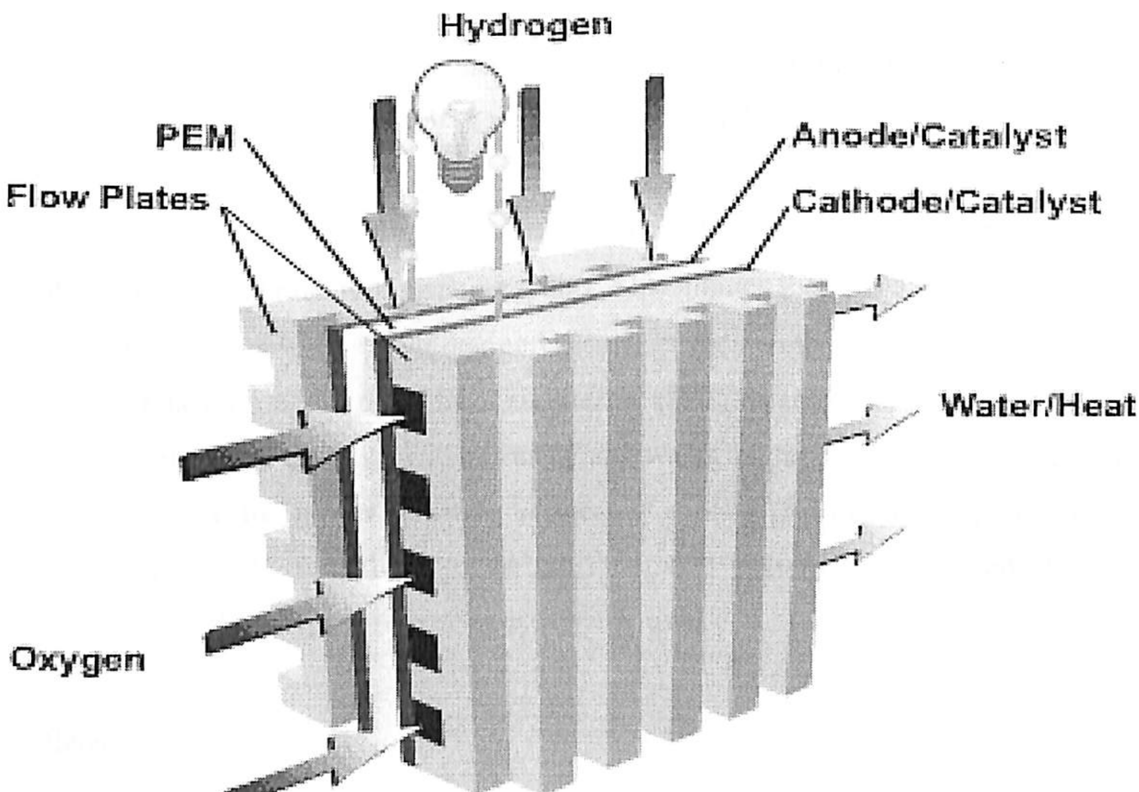


Figure 3.11: Polymer Electrolyte Membranes [Source: Cranfield University report 15]

The PEMFC is widely used in automobiles as well as other small applications as small as mobile phones, because of its compact design. Water management plays a very important role in its performance. As too much water will flood its membrane and very less water will dry the membrane, in both situations the power output decreases. There are many solutions to manage the water which exist including integration of electro osmotic pumps. Also the platinum catalyst on the membrane can be easily poisoned by carbon monoxide. This should not be more than one part per million. Also the membrane is sensitive to things like metal ions which can be produced by corrosion of bipolar plates or the metallic components in the fuel cell system or from impurities in the fuel.

PEM system using reformed methanol were also proposed as in Daimler Chrysler nectar 5, this means to make it react in order to obtain hydrogen, this is however a very complicated process that needs the purification from the carbon monoxides. Platinum –ruthenium catalyst have to be used as some carbon monoxide may reach the membrane. This level must not exceed 10 parts per million. Interestingly the start-up time of such reformer reactor is almost half an hour. On the other note methanol as well as some other bio fuels can be used to feed the PEM fuel cell directly, there is no need for reforming. This makes a direct methanol fuel cell (DFMC). However the success of these devices is limited.

The most popularly used membrane is Naflon by Dupont; this depends on liquid water humidification of membrane to transport protons. This implies that this design is not feasible to use temperatures above 80 to 90 degree Celsius, as the membrane will dry. Most recent and different types are based on Polybenzimidazole (PBI) or phosphoric acid and they can withstand the temperature of 220 without using any water, higher temperature in these gives better efficiencies, better power densities, easiness of cooling (because of larger temperature that can be permitted), sensitivity to carbon monoxide poisoning is reduced and better controllability, but these types are not yet commonly used.

3.5 Efficiency of PEMFC:

The maximum theoretical efficiency using the Gibbs free energy equation that is $\Delta G=-237.13$ kJ/mol and using the Low Heat Value (LHV) of Hydrogen $\Delta H=-285.84$ kJ/mol) is 83%.

$$\eta = \frac{\Delta G}{\Delta H} = 1 - \frac{T\Delta S}{\Delta H}$$

The practical efficiency of a PEM's is in range of 40-60% as it used the higher heating value of hydrogen (HHV). Major factor that creates losses are:

1. Activation

2. Ohmic
3. Mass transport

3.6 Catalyst-

Much of this analysis on catalysts for PEM fuel cells may be classified as having one in all 2 main objectives:

1. To get higher chemical action activity than the quality carbon-supported atomic number 78 particle catalysts employed in current PEM fuel cells or

2. To cut back the poisoning of PEM cell catalysts by impurity gases. Samples of these 2 approaches area unit given within the following sections.

3.6.1 Catalytic activity (Increase)-

Platinum is out and away the foremost effective part used for PEM cell catalysts also almost all recent PEM cells use atomic number 78 particles on porous carbon supports to turn each chemical element chemical reaction and gas reduction. However, attributable to their high price, current Pt/C catalysts don\'t seem to be possible for commercialisation. The U.S. Department of Energy estimates that atomic number 78-based catalysts ought to use roughly fourfold less platinum than is employed in current PEM electric cell styles so as to represent a sensible various to burning engines. Consequently, one main goal of catalyst style for PEM fuel cells is to extend the chemical process activity of atomic number 78 by an element of 4 so solely simple fraction the maximum amount of the valuable metal is critical to realize similar performance.

One technique of accelerating the performance of Pt catalysts is to optimize the scale and form of the Pt particles. Decreasing the particles' size alone will increase the full area of catalyst accessible to participate in reactions per volume of Pt used, however recent studies have incontestable further ways that to form any enhancements to chemical action performance. For instance, one study reports that high-index sides of Pt nano particle (that is Miller indexes with giant integers, like atomic number 78 (730)) give a larger density of reactive sites for O reduction than typical Pt nano particle.

A second technique of accelerating the chemical process activity of noble metal is to alloy it with alternative metals. For instance, it had been recently shown that the Pt3Ni (111) surface contains a higher element reduction activity than pure Pt (111) by an element of 10. The authors attribute this performance increase to modifications to the electronic structure of the surface, reducing its tendency to bond to element-containing ionic species gift in PEM fuel cells and therefore increasing the amount of accessible sites for oxygen sorption and reduction.

3.6.2 Reducing Poisoning

The other well-liked approach to rising catalyst performance is to cut back its sensitivity to impurities within the fuel supply, particularly CO (CO). Presently, pure gas isn't economical to construct by electrolysis or the other suggests that. Instead, gas is made by steam reforming light-weight hydrocarbons, a method that produces a combination of gasses that additionally contains CO (1–3%), carbon dioxide (19–25%), and N2 (25%). Even tens of elements per million of CO will poison a pure Pt catalyst, thus increasing platinum's resistance to CO is a vigorous space of analysis. As an example, one study reported that cubic Pt nano particle with (100) faces displayed a fourfold increase in chemical element reduction activity compared to arbitrarily faceted Pt nano particle of comparable size.

The authors finished that the (111) aspects of the at random formed nanoparticle guaranteed additional powerfully to sulphate ions than the (100) aspects, reducing the quantity of chemical action sites hospitable element molecules. The nanotubes they synthesized, in distinction, had nearly solely (100) aspects, that are notable to act with sulphate additional infirm. As a result, a bigger fraction of the extent of these particles was obtainable for the reduction of element, boosting the catalyst's element reduction activity.

3.7 Solid Oxide Fuel Cell [15]

3.7.1 Principle-

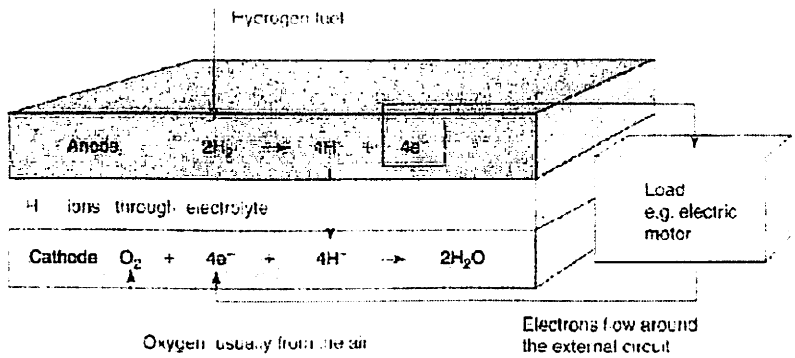


Figure 3.12: A Solid Oxide Fuel Cell [Source: Cranfield University report 15]

A solid oxide fuel can use fuel such as a flow of hydrogen or carbon monoxide (CO).

It operates at higher heat, it can be anywhere between 800 and 1000°C. Some late researches have been oriented towards a lower operating temperature (around 650°C). The higher internal temperature is a disadvantage because longer starting times are required, but the fuel cell is more tolerant to fuel impurities than any other types of cells.

The higher operating temperature means with an efficiency of around 50%, that heat is produced in large quantities, and can be recycled. Bottoming cycles, which is taking advantage of this heat produced from the exchangers, may be possible.

SOFC are used currently on stationary powers where large powers, up to 10MW, are produced in CHP (Combined Heat Power) stations. The electrolyte is a ceramic material named Zirconium (ZrO2), combined with 8-10% of yttrium Y2O3. This electrolyte is a solid material which gives its name to the cell. Electrodes are made out of high porosity materials to enlarge the reaction area.

The anode is made out of Nickel and YSZ (yttrium-stabilised zirconium), whereas the cathode is LaSr (strontium and lanthanum) combined with manganese oxide MnO3, which is a semiconductor. There are two main lay-outs for the FC: planar and tubular. In the tubular design, anode, electrolyte and cathode are concentric cylinders, thus maximizing the reaction surface.

3.7.2 Performances

SOFC is one of the favourite fuel cell types used in NASA for its aerospace applications because it has high power density and successful for high power units. There is a huge drawback that this technology is not yet matured as well as PEMFC, this technology is believed to reach power densities of 2kW/kg in next few years.

3.8 Direct Methanol Fuel Cell (DMFC)

In order to avoid storage, distribution and production issues of hydrogen, fuel cells using methanol as a fuel have been developed. Methanol is stored very easily, can be produced in large quantities but it his highly dangerous in comparison to hydrogen.

CHAPTER 4

HYDROGEN PRODUCTION TECHNIQUES

From the three systems presented in the previous section, two fuel can be employed both having their advantages and drawbacks. In order to select the best system, production and storage problems must also be addressed, so that a good balance between performances and environmental issues is made through the whole life cycle of the product. For both methanol and hydrogen, the production techniques have been seen as its impact on environment, its cost and its feasibility. Storage problems have been studied by analyzing the storage system's weight and volume, also the energy per volume unit. Then the possible installation of infrastructure supporting both fuels has been looked at:

4.1 Hydrogen Production Techniques [15]

4.1.1 Steam Reforming

Methane steam reforming can be used to produce hydrogen

The reaction is: $4\,CH_4 + H_2O \rightarrow CO + 3\,H_2$

The heat required to start the reaction is created by burning some of the methane flow

The reaction is: $CO + H_2O \rightarrow CO_2 + H_2$

The process used above is not 100% clean, it produces carbon dioxide but in spite this technique is used very commonly. One major problem is that the heat produced by the combustion of methane is lost at 50% into the output steams.

4.1.2 Partial Oxidation

A catalyst Ni/SiO2 is used in the partial oxidation of oxygen and methane. These are mixed in the catalyst. It is a faster process for reforming, the reaction taking place is:

$CH_4 + 1/4O_2 = CO + H_2$

This process is much faster and very useful for mobile applications such as cars. Hydrogen can be used to store methane in order to avoid storage issues, but methane is heavier and it adds extra weight. It compromises the environmental issues as for every couple of hydrogen molecules carbon monoxide is produced which is highly toxic in nature.

4.1.3 Water Electrolysis:

Electrolysis is exactly the reverse process of a fuel cell; the hydrogen produced is used as energy storing. Both electricity and water is provided to the fuel cell, and reactions takes place are as follows:

Cathode (reduction): **$2\ H_2O\ (l) + 2e^- \rightarrow H_2\ (g) + 2\ OH^-(aq)$**

Anode (oxidation): **$4\ OH^-(aq) \rightarrow O_2\ (g) + 2\ H_2O\ (l) + 4\ e^-$**

CHAPTER 5
PROJECTS EXISTING

5.1 Automotive products [9]

On the second stop of its world tour, the Toyota FCV-R electric cell conception vehicle can create its European premiere at the Geneva machine show next month. The hydrogen-powered conception debuted at the Yedo Motor show late last year. Few details concerning the FCV-R were shared, however the compact seats four and features a cruising vary of concerning 434 miles on a full tank. Toyota is presently holding field trials of the Highlander electric cell chemical element Hybrid Vehicle (FCHV) within the U.S. though it is not clear what\'s going to become of the hydrogen-powered SUV, the FCV-R conception is predicted to enter production in 2015.With eighty three chemical element potency and nil pollution.

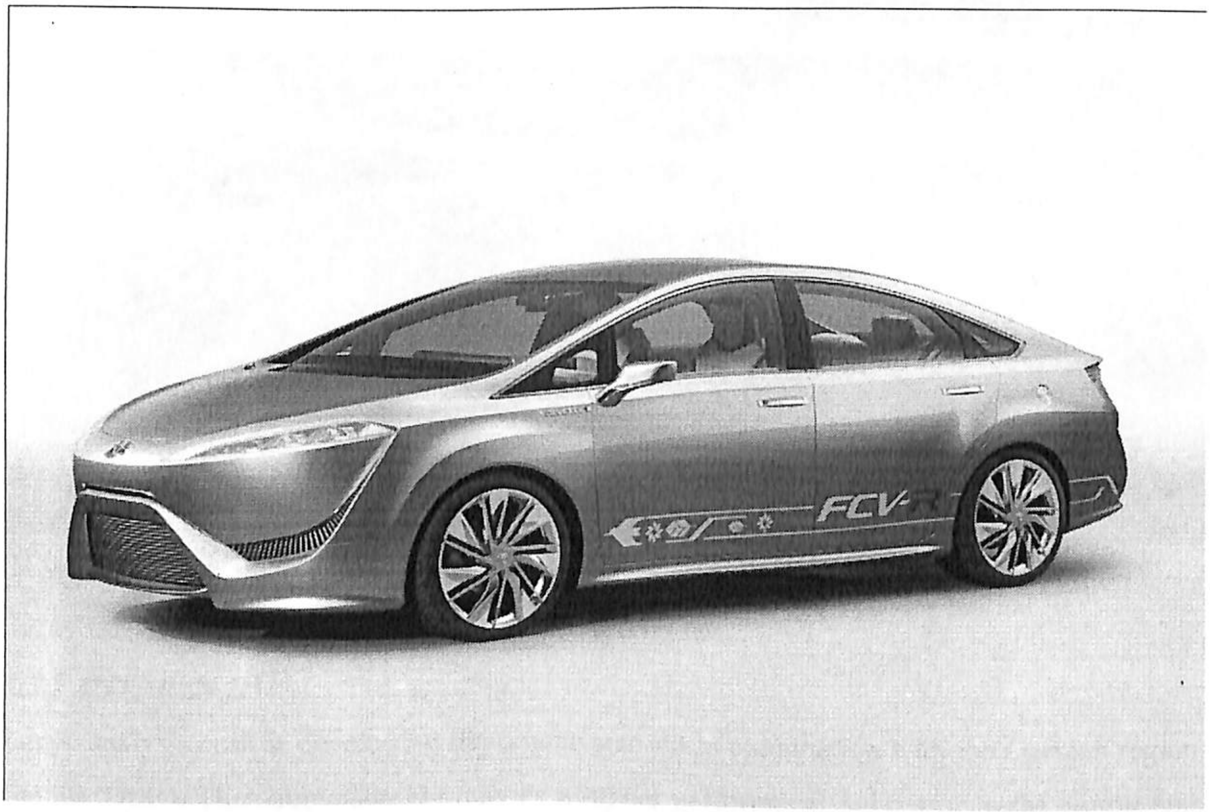


Figure 5.1: Hydrogen Fuel Car demonstration model [Source: Lange Aviation]

5.2 Aviation projects

5.2.1 ANTARES DLR H2 [3]

Antares DLR-H2 is that the world's initial piloted craft capable of kicking off mistreatment solely power from an electric cell system. On July 8, 2009, the craft was with success flight tested before AN audience at the urban center landing field. The craft sets new standards within the field having high efficiency and having zero emission energy conversion and clearly demonstrates the potential of Serenergy's HTPEM electric cell technology. The analysis craft is collaboration between German region Centre (DLR), Lange aviation, Serenergy's (fuel cell stack subsystem) and BASF (electrolytic membrane and catalysts). Four serenus 390 Air C electric cell stack modules area unit used because the propulsive energy supply provision the required peak power for take-off.

Figure 5.2: ANTARES DLR H2 [Source: Airliners.net]

5.2.2 ANTARES H3 [2]

Lange analysis craft is developing the double star H3 in conjunction with the German region Center (DLR). The double star H3 may be a higher performance successor to the double star DLR-H2, the world\'s initial piloted craft capable of playacting a whole flight high-powered by fuel-cells solely. The double star H3 can set new benchmarks within the areas of endurance. This project began in August 2010. The primary flight is regular to require place in 2011.

Technically, the new craft is predicated upon the double star 20E moreover because the cell high-powered double star DLR-H2. The Lange Aviation double star 20E may be a selflaunching motor sailplane with electrical propulsion that has been asynchronous production since 2004. The fuel cells use atomic number 1 as fuel. The atomic number 1 is reworked into power during a direct and non-combustive chemical science reaction with O taken from the encompassing air. The sole reaction product emitted is water. The craft flies greenhouse gas neutrally, if the atomic number 1 is made exploitation regenerative energy.

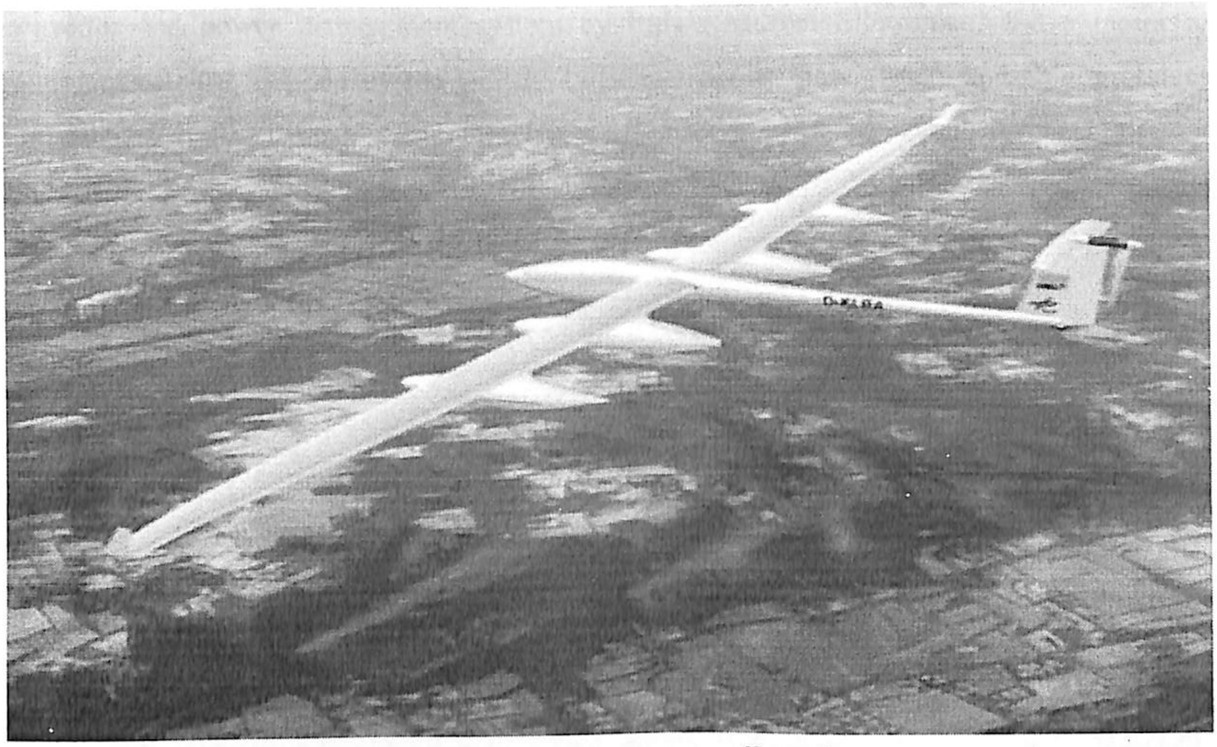


Figure 5.3: ANTARES H3 [Source German aerospace centre]

In 2010 the project partners tested however fuel cells perform in aviation, mistreatment the flying test-bed, the double star DLR-H2. Throughout one in every of these tests, associate degree altitude record of 2560 m (8400 ft) was set. The double star H3 can demonstrate considerably raised performance: The developers decide to reach a variety of up to 6000 click (3200 Nm), associate degree and endurance of quite 50h. For the double star H2, these values were severally 700 click (405 Nm) and five hours. The craft can have a wingspread of twenty three m ((75 ft), a most takeoff weight of one.25 metric tons (2756 lb), and it'll carry payloads of up to two hundred kilogram (440 lb). The craft can use four external pods to deal with fuel cells and fuel.

5.2.3 ENFICA- FC[14]

Professor Guilio lover of the Politecnico First State urban center, European country could be a man of the many firsts. Last year, his team fielded Skyspark, a Pioneer three hundred power-driven with an electrical motor fed by batteries. This year, in a very entirely new development, faculty member lover coordinated the activities resulting in a palmy hydrogen-powered electrical craft, and set a world speed record to fill up that accomplishment. The Skyleader one hundred fifty Zero greenhouse gas lightweight sport craft, designed by JIHLAVAN airplanes, Ltd. within the European nation, was fitted with Intelligent Energy nucleon exchange membrane (PEM) fuel cells from the UK, Associate in Nursing electrical converter and power management system by Italy's Marvel Elletronica, and a motor a minimum of part designed by the University of metropolis, Italy. Tanks and an aggressive fuel delivery system were created by the UK's Air product restricted.

Figure 5.4: ENFICA- FC [Source: Airliners.net]

ENFICA-FC created a two-minute maiden flight on May 2010.On May 26, the plane created a speed dash of 4 consecutive runs over a three-kilometre course (FAI Sporting Code – category C), and averaging one hundred thirty five kilometres per hour (83.7 miles per hour). On the side, pilot Marco Locatelli pushed the plane for many sprints at 145-150 km/hr (89.9-93 mph).

The heavier-than-air craft features a forty power unit motor, equipped by 2 twenty power unit fuel cells and protected, for safety's sake, by twenty power unit atomic number 3 compound batteries that give redundant power just in case of issues with the fuel cells. The liquid-cooled (eight litres of bi-distilled water tucked into the correct wing) fuel cells give 100-110 Amps at 200-240 Volts and square measure furnished with atomic number 1 at 350 bar (over five, 000 pounds per sq. inch). Despite the air mass, the fuel cells never exceeded seventy degrees C (158 degrees F) throughout the record flight. Project personnel square measure wanting forward to apply the teachings learned from ENFICA-FC to a doable commuter liner being developed with Associate in Nursing Israeli Region Company, leading the means toward a zero CO future.

5.2.4 UAV SCAN EAGLE[8]

A propulsion module made of a one; 500-watt electric cell by United Technologies and a gas provision answer by the military service science lab were integrated into the Scan Eagle at in situ facilities in Washington. This Scan Eagle is lighter than the standard model, therefore operation prices area unit lower and there's a lot of area for instrumentation. The corporate aforesaid. And with gas fuel, the craft left behind no harmful emissions throughout the two-and-a-half-hour check run. The Scan Eagle evolved from the ocean Scan miniature robotic craft that was debuted in 1998 by Insitu and designed to observe faculties of tuna and guide business fishers within the ocean around them. Once Boeing and also the U.S. military took Associate in Nursing interest, the Scan Eagle was created for police work and reconnaissance information or communications relay. It's been utilized by the U.S. military in Iraq to gather necessary military science data since 2004 and a lot of recently by military organizations in many different countries together with Australia, Canada, Italia and also the European nation.

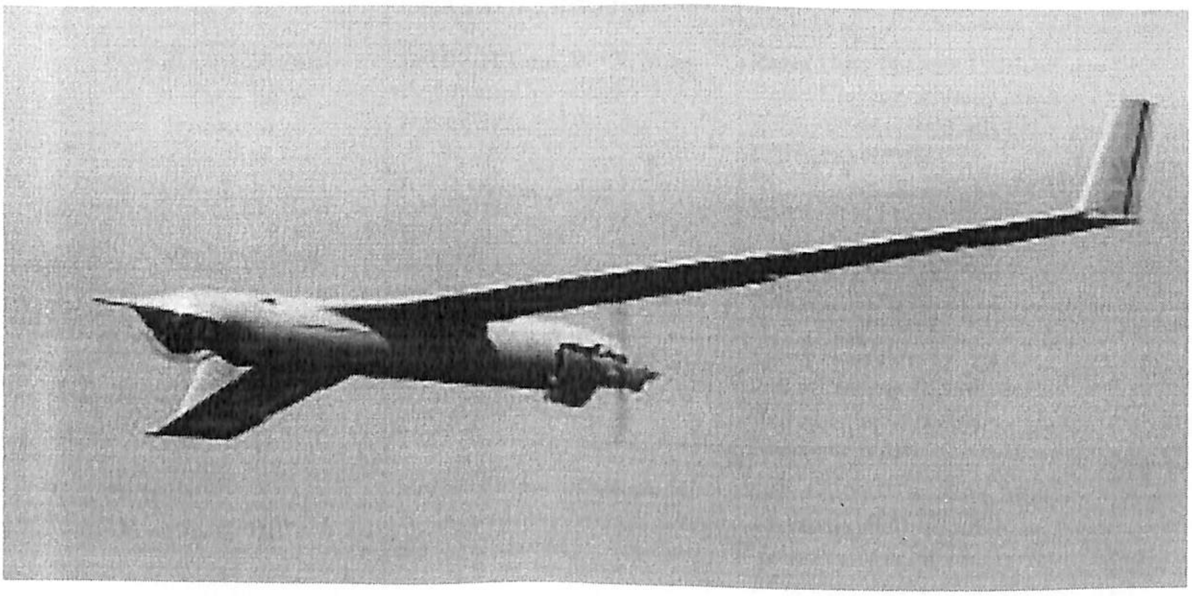


Figure 5.5: UAV SCAN EAGLE [Source: Airliner.net]

The Scan Eagle functions autonomously however will be controlled from a far off laptop station. If communications fail, the remote-controlled craft is programmed to come back to a planned home base.

CHAPTER 6

POWER PLANT

6.1 Fuel cell power plant

6.1.1 Mission Requirement: A fuel cell capable of producing the required power of 123.44 Kw is required. Since the fuel cell will have an efficiency of 71% hence we will select a fuel cell capable of producing 173.86 Kw.

6.1.2 PEM State of Art: The temperature at which the fuel cell is operating has a significant impact on the PEFC performance. Increasing operating temperature decreases the Ohmic resistance of the electrolyte and accelerates the kinetics of the electrode reactions. Mass transport limitations are also reduced at higher temperatures. This results in an improvement in cell performance. Sub classification of polymer electrolyte type fuel cell Ballard offers various types of PEM fuel cells.

6.1.3 Layout configurations of various Polymer Electrolyte fuel Cells

Table 6.1: Various fuel cells and their specifications

PRODUCTS	PHYSICAL CHARACTERISTICS	PERFORMANCE
FC VELOCITY 9SSL	L=107-313mm, W=707mm, H=60mm, Dry Weight=17kg, No. of Cells =110.	Rated Goss Power= 19.3Kw, Rated Current=300amp, D.C Voltage= 64volts, Cell Efficiency= 71%
FC VELOCITY HD6	L=1446mm, W=871mm, H=496mm, Dry Weight=355kg, No. of Cells =Not Applicable	Rated Goss Power= 150Kw, Rated Current=240amp, D.C Voltage= 626volts, Cell Efficiency= 71%
FC GEN 1020A CS	L=110-495mm, W=103mm, H=351mm, Dry Weight=15kg, No. of Cells =80.	Rated Goss Power= 3.4Kw, Rated Current=65amp, D.C Voltage= 51volts, Cell Efficiency= 67%
FC GEN 1300	L=230-530mm, W=490mm, H=180mm, Dry Weight=29kg, No. of Cells =125.	Rated Goss Power= 11.3Kw, Rated Current=amp, D135.C Voltage= 84volts, Cell Efficiency= 64%
FC GEN 1030	L=347mm, W=158mm, H=259mm, Dry Weight=12kg, No. of Cells =46.	Rated Goss Power= 1.2Kw, Rated Current=40amp, D.C Voltage= 31volts, Cell Efficiency= 63%

6.1.4 FC Velocity 9SSL [1]:

As per the fourth generation stack technology, the Ballard power system offers a proton exchange membrane PEM fuel cell stack. The selected fuel cell is designed to perform in various conditions and is available now to the market with stack integration capabilities.

It is scalable as per the customer requirements and the stacks are available in power increments from approximately 4 to 21 kilowatts. The FC Velocity 9SSL provides stable electrical power to a system over a wide range of operating and environmental conditions. FC Velocity 9SSL is a liquid cooled, hydrogen-fuelled product, and uses Ballard's standard cell components.

The FC Velocity 9SSL establishes a new standard of performance by optimizing reliability, power density and compatibility with the system requirements and is suitable for motive applications.

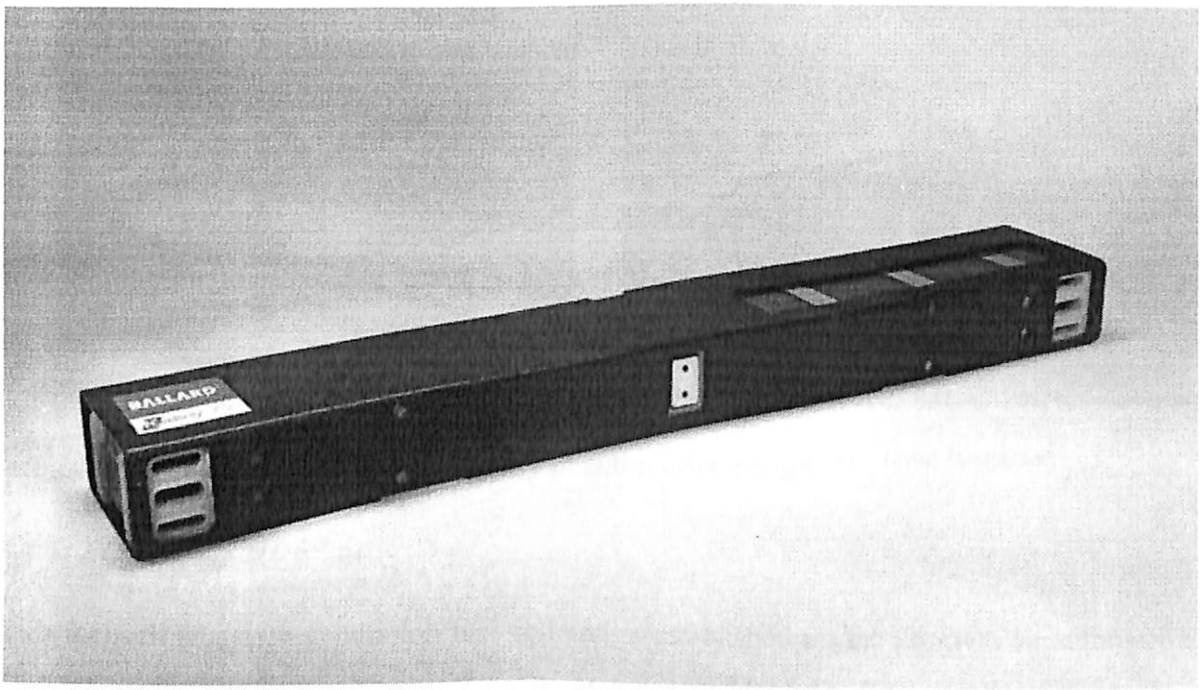


Figure 6.1: FC Velocity 9SSL [Source: Ballard.com]

- **Length:** 22 ft
- **Width:** 92 in
- **Maximum Gross Weight:** 20500 lb
- **Curb Weight:** 15500 lb
- **Traction Motor:** 174 hp AC induction with flux vector control
- **Transmission:** single speed trapezoidal chain drive
- **Governed Maximum Speed:** 45 mph
- **Batteries:** Flooded Ni-Cd, 300V nominal, 2 strings, 100 Ah each
- **Fuel Cell:** Ballard Mark 9 SSL, 19.4 kW gross
- **Range:** 180 miles
- **Fuel Economy on H2:** 12 miles/kg

Figure 6.2: Use of FC Velocity in automotive parts [Source: Toyota Europe.com]

6.1.5: FC Velocity HD6[4]:

This fuel cell is a sixth generation fuel cell and is established on the progressive automotive fuel cell stack. The fuel cell module proposes a design idealistic for consolidation into bus applications.

The fuel cell bases a fresh and modern standard for cost, through design for volume fabrication, and compatibility with the requirements set up by the customers. The power module is of heavy duty and has a control unit that can port with a system controller, making it user friendly and easy by having a plug and play interface for any fuel cell.

The next-generation module also proposes substantial advancements in durability, power density and fuel efficiency.

Figure 6.3: FC Velocity HD6 [Source: Ballard.com]

6.1.6: FC GEN-1020ACS[5]:

FC GEN-1020ACS is factory-made by the Ballard Power Systems; this cell proposes associate cool, ascendible nucleon exchange membrane cell stack worthy for a good vary of sunshine duty applications. The vital requirements are sturdiness, dependableness and a simplified equilibrium of plant.

The FC GEN-1020ACS has been musical group to integrate progressive open cathode technology and state of the art self humidifying membrane conductor fabrications. These characteristic options utterly rule out the necessity for the consolidation of humidification systems and alter the systems. The result is a simple, low price style delivering reliable operation over a decent varies of adverse conditions.

With no moving parts and high efficiency, the cell produces a clean DC power with a coffee thermal and acoustic signature. The cell stack is also scaled to satisfy power desires from 300W to 3KW and integrated into varied user applications.

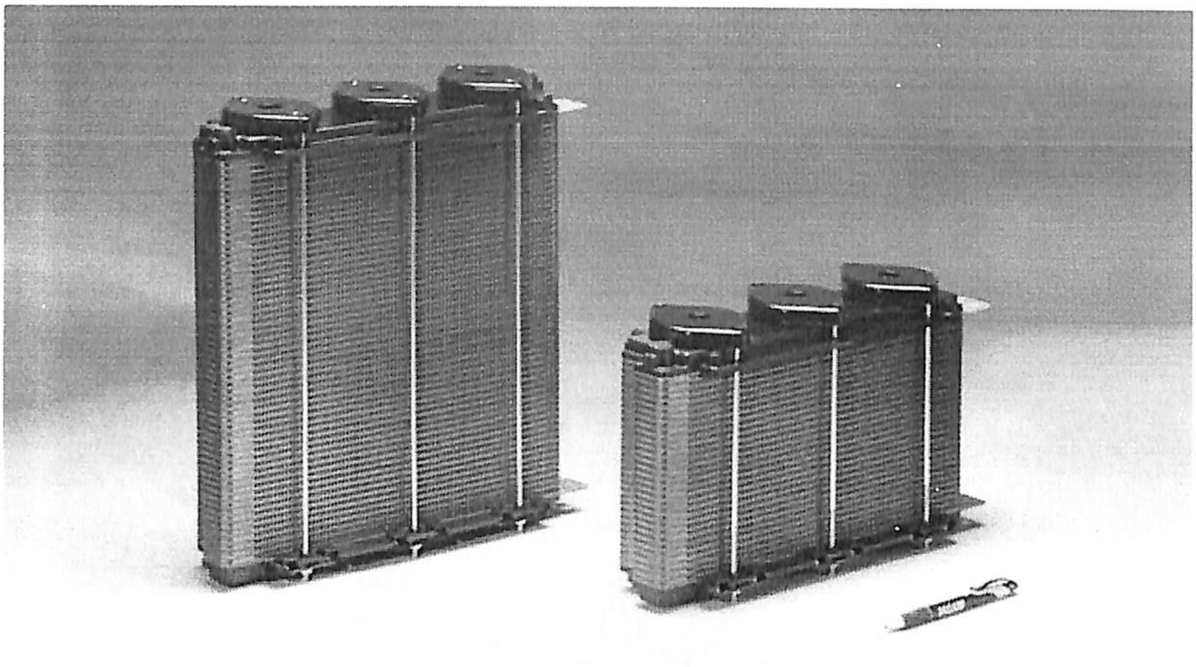


Figure 6.4: FC GEN 1020 ACS [Source: Ballard.com]

6.1.7 FC GEN 1300[6]:

Ballard's FCgen®-1300 electric cell may be a low-priced, liquid-cooled nucleon exchange membrane (PEM) fuel cell line of business specifically designed for stationary applications. Obtainable currently to customers with electric cell stack integration capabilities, the merchandise is particularly suited to incorporation into systems developed for the backup power and distributed generation markets.

Capitalizing on its leadership position in PEM fuel cell analysis and development, Ballard has developed an electric cell product appropriate for applications wherever load-following capability, reliability and value improvement area unit key requirements.

The electric cell stack offers long life, whether operated unceasingly for base load power generation, or intermittently, providing peak power throughout times of high demand. This reduces overall system maintenance, delivering a strong economic come over the lifetime of the product.

The atomic number 1 fuelled Fcgen–1310 product is available currently in production quantities during a number of cell configuration choices. This fuel cell stack powers Ballard's CLEARgen distributed generation system. The next generation of this product, capable of operational on reformed fossil fuel, is presently beneath development.

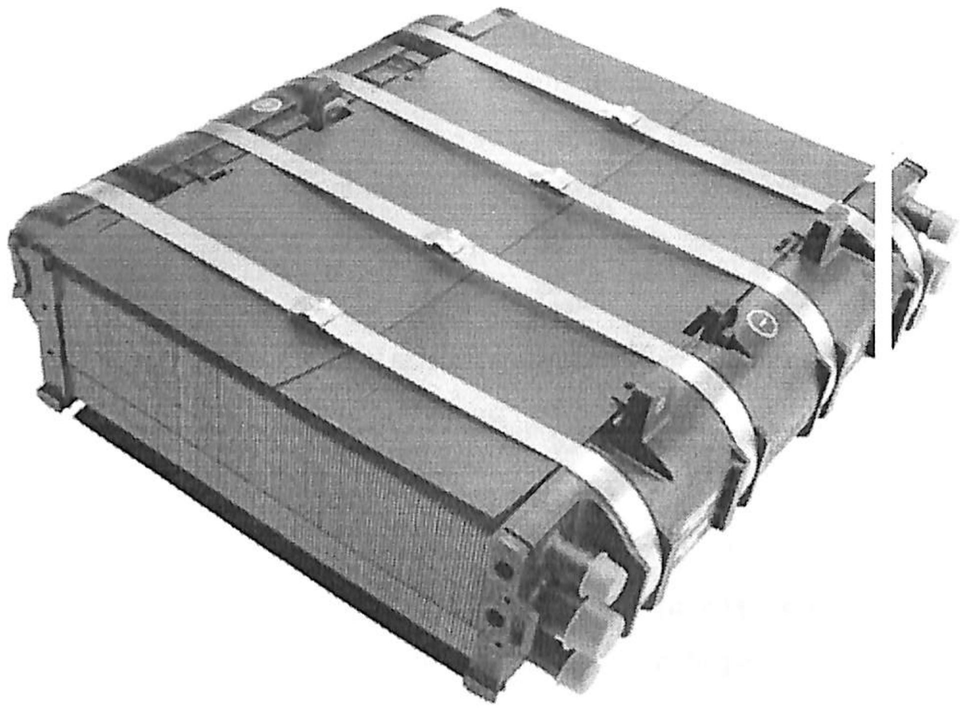


Figure 6.5: FC Gen 1300[Source: Ballard.com]

6.1.8 FC GEN 1030[7]:

Ballard Power Systems with pride powers its third generation of reformate based mostly nucleon exchange membrane (PEM) electric cell stacks; designed to fulfil long life and high efficiency demands whereas providing a strong supply of energy.

Now on the market to customers with electric cell stack integration capabilities, the FCgen-1030V3 stack is incorporated into systems developed for the residential cogeneration market or alternative markets requiring a reformate based mostly electric cell stack. Building on the success of previous versions, the V3 powers similar performance with increased sturdiness, shrivelled pressure drop and significant reduction in size, weight and value.

The liquid cooled FCgen-1030V3 stack provides secure wattage to a system throughout its in operation vary. Additionally to the stack, a cell voltage observance harness is on condition that will connect on to the customerÕs observance system.

With years of development and field-testing expertise within the Japanese residential conglomeration market, Ballard's FCgen-1030V3 stack powers performance, dependableness and durability to the system measuring system. Ballard Power Systems conjointly powers application engineering support to make sure period of time and performance is maximized through the system development method.

6.2 Choice:

FC VELOCITY 9SSL is the final selection of fuel cell and the reasons for the selection is:

1. Good efficiency.
2. Even weight distribution due to multiple stacks.
3. Gross power of the fuel cell selected is 19.3 Kw so the required number of fuel cell stacks is 10 which can be used to generate the required power of 173.86 Kw.
4. It is easily available and can be installed in series or parallel as per the desired value of voltage and current.

6.3 Justifications:

To verify the compatibility the fuel flow rate per ampere of current is to be calculated. The hydrogen required to generate 1.0 ampere of current in a fuel has to be calculated. The fuel cell anode releases two electrons for every molecule of hydrogen that reacts within the fuel cell. Every fuel cell releases two electrons but the calculations followed are for the polymer exchange fuel cell.

1 equivalence of electron is 1 g mol of electrons or 6.023×10^{23} electrons, this quantity of electrons has the charge of 96,487 coulombs (C) Faraday's constant.

$$H_2 \rightarrow 2H^+ + e^-$$

$$nH_2 = (1.0A)\left(\frac{1\ coulomb/sec}{1A}\right)\left(\frac{1\ equivalence\ of\ e^-}{96500\ coulombs}\right)\left(\frac{1\ g\ mol\ H_2}{2\ equiv.of\ e^-}\right)\left(\frac{3600\ sec}{1\ hr}\right)$$

The result of the calculation is 0.018655 g mol/ hr H_2 per 1.0 ampere.

Now we calculate the kilograms of hydrogen per ampere, using the above result.

$$mH_2 = \left(\frac{0.018655\ g\ mol\ H_2\ per\ ampere}{hr}\right)\left(\frac{2.0158\ g}{1\ g\ mol\ H_2}\right)\left(\frac{1\ kg}{1000\ g}\right)$$

The value obtained is 37.605×10^{-6} kg hydrogen per ampere

$$\text{Or } 0.037605\ \frac{Kg\ Hydrogen}{KA}$$

The power required is 123.44 KW so we calculate the current using fuel stack with a cell voltage of 700mV or 0.7V, on pure hydrogen with a fuel utilization of 80%.

Power = current x voltage; P= V X I or, I= P/V

$$\left(\frac{173.86kw}{0.7v}\right)\left(\frac{10^3W}{1kw}\right)\left(\frac{1VA}{1W}\right)\left(\frac{1KA}{1000A}\right) = 248kA$$

This gives the value for 1 ampere current so we calculate for 123.44 KW how much current is needed.

Hence we find the required hydrogen per hour; 0.037605 x 248=9.326kg

The hydrogen consumed will be; 2.54 x 9.326 = 23.72 kg hydrogen per hour

If efficiency is 80% than the fuel flow rate to generate 23.72 kg hydrogen per hour;

23.72/0.80 = 29.65 kg hydrogen per hour.

***6.3.1 Number of stacks required*:** The number of stacks required can be easily calculated by dividing the required power with the rated gross power of the fuel cell. The rated gross power of the fuel cell is 19.3 KW and the required power is 173.86 KW.

Therefore, the number of stacks is 173.86/19.3 which equals to approximately 9.1 so we found it appropriate to use 10 fuel cells for the aircraft power plant.

***6.3.2 Specifications*:**

Table 6.2: FC Velocity Specifications

PRODUCTS	PHYSICAL CHARACTERISTICS	PERFORMANCE
FC VELOCITY 9SSL	Length=107-313mm, Width=707mm, Height=60mm, Dry Weight=17kg, No. of Cells =110.	Rated Goss Power= 19.3Kw, Rated Current=300amp, D.C Voltage= 64volts, Cell Efficiency= 71%

CHAPTER 7

ELECTRICAL SYSTEM

7.1 Mission requirement:

Since the required power is 123kw hence two power plants of approximately 60-70 KW power are needed to run the system, so a motor most suitable for the selected fuel cell is to be studied and chosen from the table [10].

	HVH250-090-SOC3 Standard Winding Configuration A HVH250	HVH250-115-SOC3 High Torque Winding Configuration A HVH250	HVH250-090-POC3 Standard Winding Configuration B HVH250	HVH250-115-POC3 High Torque Winding Configuration B HVH250
Measurements				
Overall Length (mm)	147	180	147	180
Stator Outside Diameter (mm)	242	242	242	242
Rotor Inside Diameter (mm)	132	132	132	132
Mass - Complete Motor (kg)	33.5	43	33.5	43
Performance				
Continuous Power Output (kW)	60	63	176	185
Peak Power Output (kW)	76	78	297	305
Continuous Torque Output (N-m)	275	325	225	288
Peak Torque Output (N-m)	320	408	320	408
Max. Input Current Continuous/Peak (Amps)	200/300	200/300	300/600	300/600
Peak Efficiency (%)	See Efficiency Map			
Max. Operating Speed (rpm)	10,600			
Base Speed (rpm)	2300	1600	4000	3000
Operating Voltage (VDC nom.)	320		650	
Max. Temperature Limit	CLASS H (180°C)			
Internal Oil (ATF) Cooling				
	70°C Oil Inlet Temperature			
Conductor Type				
	High Voltage Hairpin			

Figure 7.1: Motor specifications [Source: RemyHVH.com]

7.2 Remy's HVH motor [10]:

Remy's HVH 250 motor – the one Steve Burns, president of Advanced Mechanical product, Inc.(AMP), once known as "simply the most effective [electric motor] on the market today" – can realize a home between the fenders of Odyne's medium- and industrial trucks for the "long-term."

Waukesha, WI-based Odyne Systems, a manufacturer of lawman hybrid systems for giant trucks, has inked a motor offer touch upon Remy electrical Motors, the Pendleton, IN-based automotive provider. Beneath terms of the agreement, Odyne can utilize Remy's proprietary High Voltage pin (HVH) electrical motors in their plug-in hybrid systems. Odyne says that its plug-in setup will increase a truck's on-road fuel potency and provides electric-launch assist. Once stationary – like once place at a construction web site – the work trucks area unit able to use juice from Odyne's hybrid system to power on-the-scene instrumentality while not firing up their engines. Odyne claims that its plug-in hybrid system reduces a fleet's operational prices and, betting on duty cycle, allows trucks to get fuel economy enhancements of up to fifty p.c compared to diesel-only rigs.

Figure 7.2: Utility motor [Source: RemyHVH.com]

7.3 Choice:

The most suitable choice as per our requirement would be the **HVH250-115-SOC3 High Torque winding Configuration A HVH250**[10] since the continuous power output of the motor matches the power required of about 60-65kW per power plant.

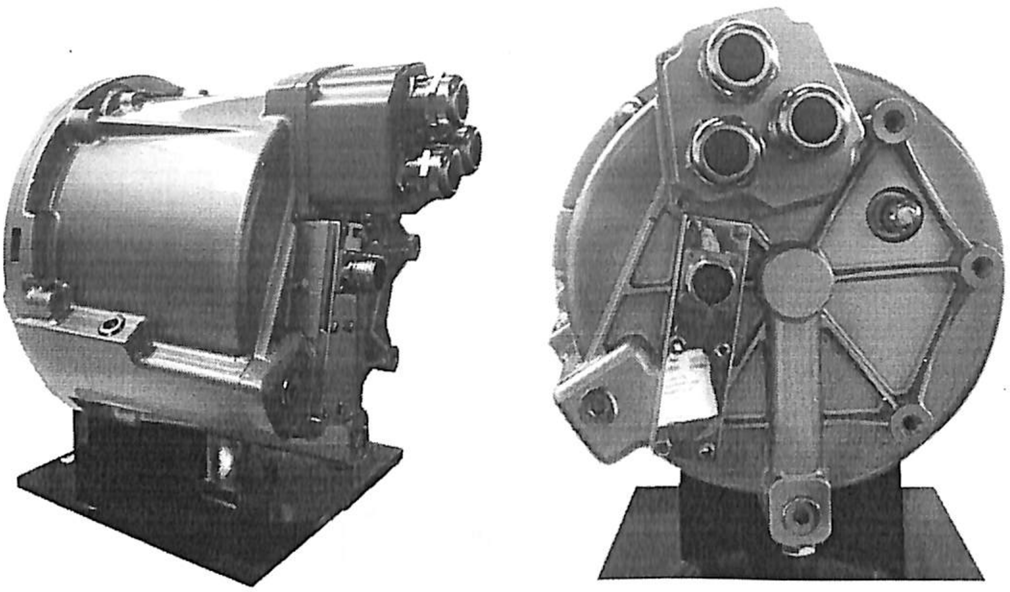


Figure 7.3: Remy's HVH250 motor [Source: RemyHVH.com]

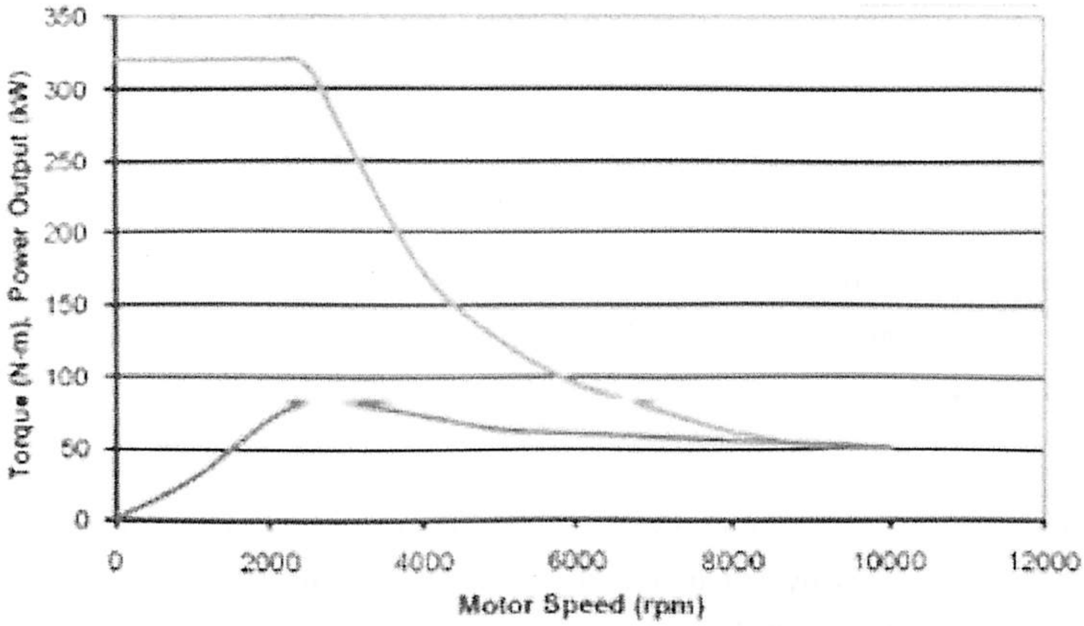
Table 7.1: Motor Specifications

Measurements	HVH250-115-SOC3 High Torque winding Configuration A HVH250
Overall length	180mm
Stator outside diameter	242mm
Rotor inside diameter	132mm
Mass of the motor	43kg

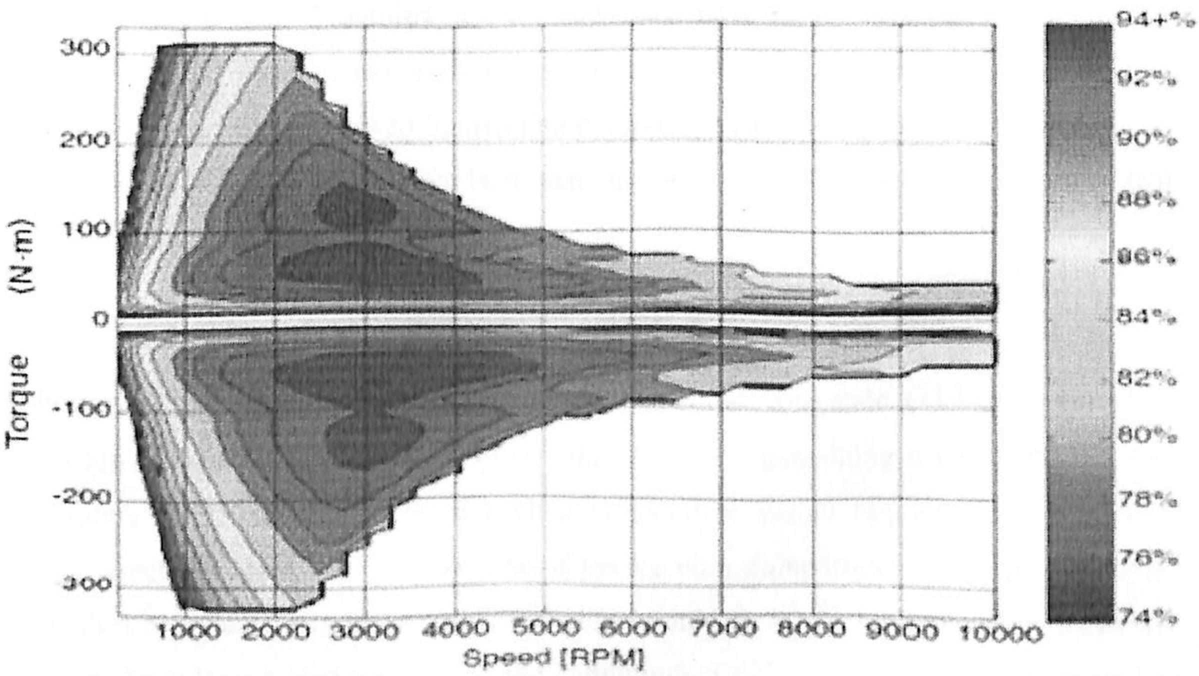
Performance	
Continuous power output	63kw
Peak power output	78kw
Continuous torque output	325 N-m
Max. Input current conditions	200A
Peak input current conditions	300A

Maximum operating speed	10,600 rpm
Efficiency	90%
Base speed	1600 rpm

Operating voltage	320 V
Maximum temperature limit	180 degree Celsius
Internal Oil (ATF) Cooling	70 degree Celsius
Conductor Type	High voltage Hair Pin



Plot 7.1: Torque power output vs. motor speed [Source: RemyHVH.com]



Plot 7.2: Torque vs. Speed [Source: RemyHVH.com]

CHAPTER 8

HYDROGEN STORAGE

8.1 Mission requirements

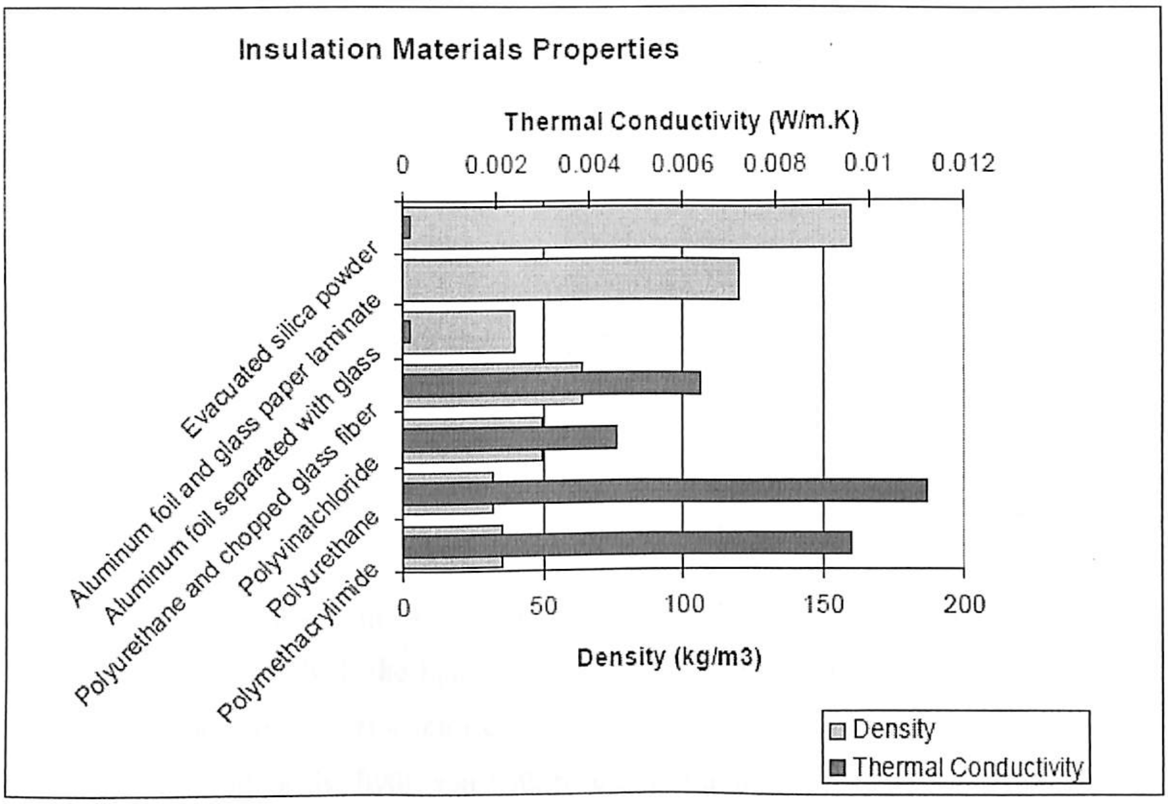
The hydrogen gas used in fuel cell is stored in wing tanks. The temperature inside the tank should be kept at -253 degree Celsius to keep hydrogen in liquid state. Insulating material is also used to form a protective layer around the tanks and they occupy space which is normally used to store fuel.

The hydrogen requirement for one hour of flight is expected to be 72kg. To avoid leakage, we need cylinders that can withstand high pressure. Hydrogen can be stored in liquid as well as gaseous form with both having their share of advantages and disadvantages, alternative hybrid systems are also being designed. Hydrogen storage requires a lot of volume in gaseous state when compared to the high volumetric and specific density of liquid storage. To maximize this volumetric efficiency of gaseous hydrogen systems, high pressure devices have been developed. Pressures up to 700 bars have been investigated tested and commercialized. Composite materials are used to reduce weight and development of winding manufacturing technique allowed lightweight composite tanks to be produced. Power storage densities is up to 0.78 kWh/kg have been demonstrated in a 700 bars 85 kg composite tank carrying 2kg of hydrogen.

8.2 Liquid Storage [15]

Hydrogen has much greater density in liquid state than in gaseous state, (71 kg/m3) but which is still lower than AVGAS fuel. However, that requires maintaining a constant cryogenic temperature of 253°C. To maintain such a temperature would require either a vacuum insulation between tank and exterior, but if the vacuum compartment fails, the insulation would then be reduced to zero. Another technique would be to use solid insulating materials, foam for example or a mixture of glass and aluminium. Solid insulation also requires another layer of reflecting material to prevent heat transfer by radiations. To store decent quantities of reactant in a given volume, liquid hydrogen is the best way. Moreover, the technology has already been developed somewhat because of use of liquid hydrogen tanks in space launchers and rockets.

Colozza (2002) presents the different types of insulating materials used to cover hydrogen tanks. We can clearly see that evacuated aluminium foil and glass paper laminate, or Evacuated aluminium foil separated with fluffy glass mats are the best options.



Plot 8.1: Material properties [Source: Colozza 2002]

To ensure that no oxygen penetrates the tank by pressure or refuel valves, hydrogen is stored at a pressure of 20 psi (1.44 bars).

It is stored in the wings between the spars.

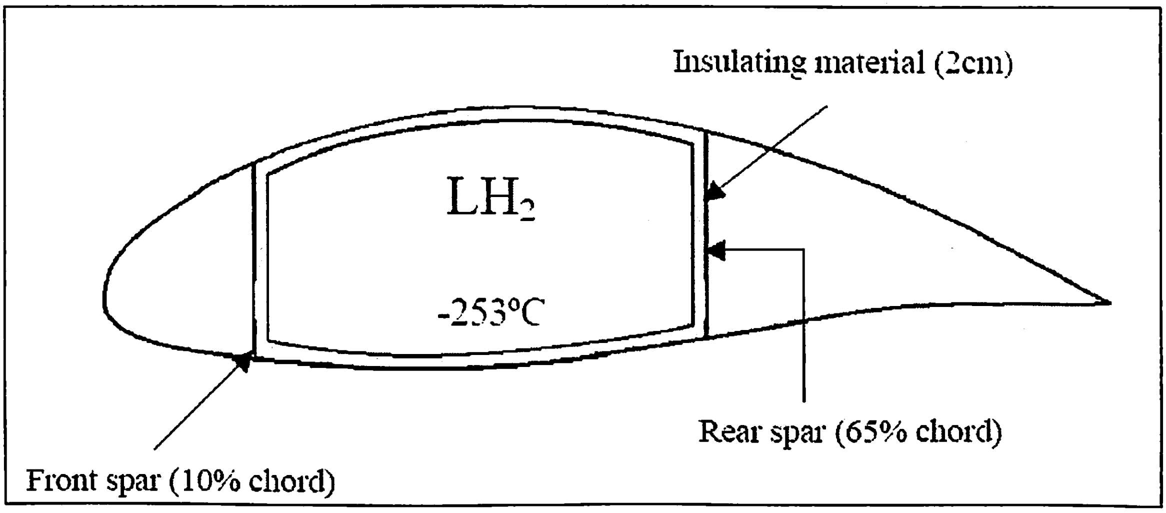


Figure 8.1: Liquid hydrogen storage concept [Design study of fuel cell powered aircraft, Cranfield University 2006]

8.3 Tank materials [15]

Storing hydrogen in liquid state at a temperature of -253°C creates some thermal constraints on the materials from which the tank is made. Material properties in strength and fatigue properties differ in very low temperatures.

Fuelling and de-fuelling the hydrogen tank results in thermal constrains cycles, which will have detrimental effect if the fatigue properties are insufficient.

8.3.1 Tensile properties

For metallic materials, aluminium alloys have only been studied for weight purposes. In general, tensile properties of alloys improve at cryogenic temperatures, both ultimate tensile strength and yielding strength.

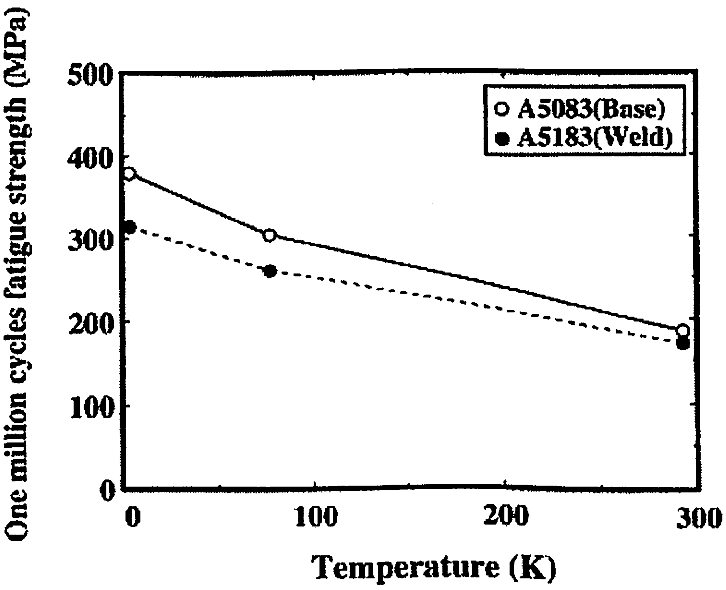
According to a study on the impact on the impact of cryogenic temperatures on composites, quasi static laminates have deteriorated properties at room temperatures. The average tensile modulus is only slightly increased (4%) at cryogenic temperature for storage of liquid nitrogen. However, the tensile strength gets reduced by 9 %.

It can be assumed that the strength properties will continue to decrease as the temperature for hydrogen storage (20° K) is lower than that for nitrogen storage (110 °K); unfortunately data was not available in the time of this project.

8.3.2 Fatigue properties

Tests on two manganese based aluminium alloy A5083 and A5183 for fatigue properties at cryogenic temperatures reveal that these two alloys have fairly better fatigue properties at cryogenic temperatures, and allow for higher repeated stress levels at cryogenics temperatures.

Also, compared to stainless steels, these two alloys show better fatigue properties at low temperature, because properties of steel decrease rapidly at cryogenics temperatures.



Plot 8.2: fatigue properties of 5000 series aluminium alloys [Source: Cranfield University report 15]

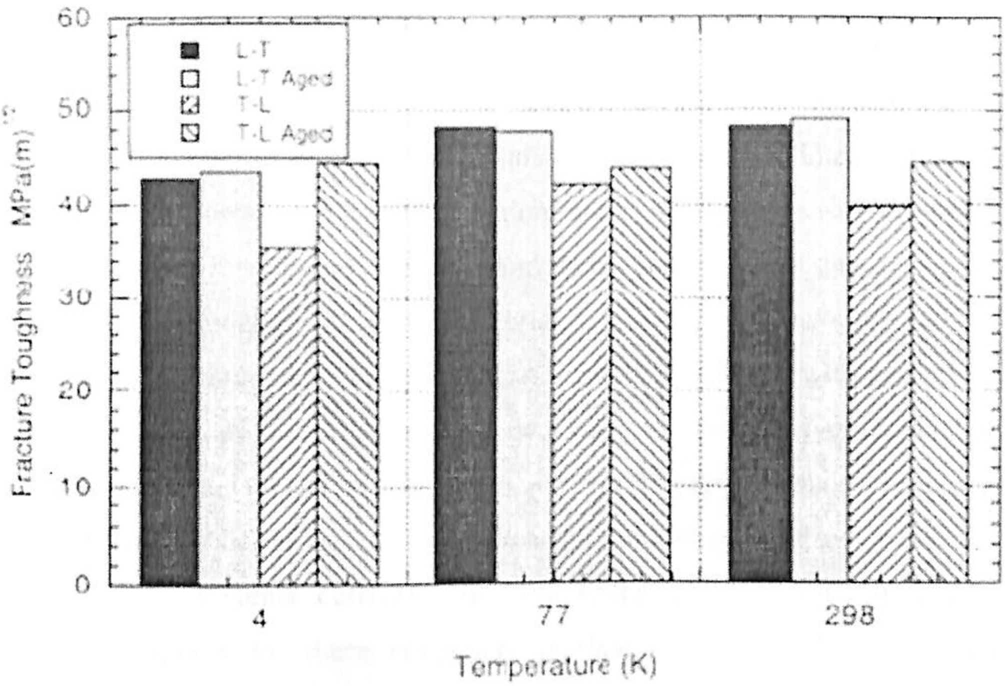
It was also found that thermoplastics resins have better properties in terms of strength and damage tolerance. While thermo set resins have lower properties at cryogenics temperatures. Initiation of micro-cracks in the structure is also reduced at lower temperatures.

8.3.3 Fracture properties

A major concern when using materials at cryogenic temperatures is the toughness at these temperatures. For fracture properties, only data on the Al-Li alloy C-458 was found.

Al-Li being slightly anisotropic, toughness was tested in two directions, moreover ageing has also been investigated by exposing some of the samples to an ageing of 1000 h at 355° K.

Results show that toughness reduces at cryogenic temperatures, but the differences are minor. Compared to the previous Al-Li alloy, the reduction of toughness is less important. Ageing also does not have a significant effect on the results.



Plot 8.3: Fracture toughness at cryogenic temperatures for Al-Li alloy [Source: Cranfield University report 15]

8.3.4 Thermal compression

Another important subject is the thermal compression of materials at low temperatures. Allowance for compression is needed in the design of the hydrogen tanks, which may however create some issues for the attachments of the tank to primary structure.
The effect of drop in temperature when filling the tank after an empty period should also be investigated, because rapid temperature changes may induce important stresses in the fuel tank structure.

8.4 Metal Hybrids

Because of the small atomic radius of hydrogen molecules, hydrogen can be readily absorbed by other materials. The hydrogen molecules fit between the atoms of metal and penetrate the structure of the metal. Although the volumetric densities of reactant stored are promising, the technology is still immature and the metal hybrid storage systems quite heavy.

8.5 Carbon Fibre Cylinders [15]

High pressure compressed gas containers are generally made up of filament wound carbon fibre construction and their shape is cylindrical. A partial cross-sectional view (Quantum Technologies) is shown in Figure. The cylinders comprises of an internal liner, made with either a lightweight metal such as an aluminium alloy, or a high density polymer. The liner gas acts as the form for winding the fibre and forms a permeation barrier for the gas. The fibre wrap is then inundated with a filler material (e.g., an epoxy) and a protective outer coat. Metallic bosses are then used on hemispherical ends to connect with a regulator, valves, PRD, etc. This type of construction has been very successful in producing lightweight, robust, high strength tanks and can form the basis for a generic container that could then be used in solid-based or liquid-based, cryogenic adsorption, or pressurized gas storage systems. Carbon composite systems currently used, however, are prohibitively expensive. The manufacturing process for these containers is time consuming, hugely expensive, and requires multiple inspection steps. Scaling up production quantities and significantly bringing down unit costs at the same time will be particularly challenging.

Adapting this high pressure container to any of the other storage modes will also require some significant changes to the manufacturing processes. For example, with a solid-state system, one must also fill the internal volume with the storage media at some or the other stage of the fabrication. Also, some form of metal, plates, foam or fins must also be an integral part of the storage media structure to enhance its thermal management. Hence, the current method of fabricating the inner liner and subsequently the fibre wrapping is needed to be altered to allow manufacturers to insert material and then seal the container. Additionally, any storage method that operates below ambient temperatures (e.g., adsorptive carbon systems) would also need to include, low volume, low cost and lightweight thermal insulation into the manufacturing process. One final consideration to adapt high pressure composite cylinders to other, lower pressure storage options should be to explore the potential to fabricate these containers in non-cylindrical geometries, such as, for example, approximately rectangular shapes which allow the storage system to conform better with the existing volumes onboard the vehicles. As given earlier, a major issue with these current construction methods is unit cost. Presently, the costs of these containers, in small quantities, are of the orders of magnitudes, too high for widespread use as vehicular fuel tanks. One would expect scale economies to bring down the unit price, but the primary price driver is material cost, and specifically the carbon fibre. Carbon fibre cost accounts for 40%-80% of the container cost. It is also important to mention that carbon fibre cost may be mitigated to some extent for solid-state or any other alternative storage modes because these options generally operate at a much lower pressure (e.g., < 70 bar) rather than the 350 – 700 bar pressure range that is typically used for compressed gas storage.

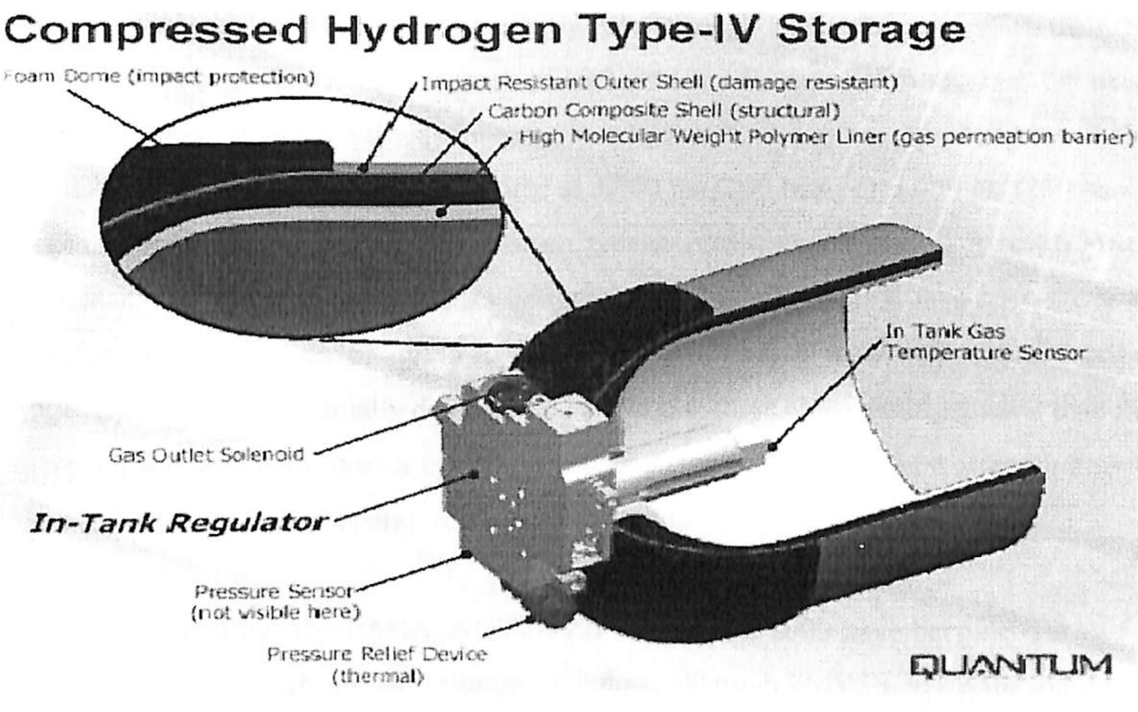


Figure 8.2: Storage tanks [Design study of fuel cell powered aircraft, Cranfield University 2006]

8.6 Choice and Justification

Designed and Developed at QUANTUM's Advanced Technology Centre in Irvine, California, the QUANTUM Tri-Shield all-composite hydrogen storage cylinder decimates the barriers to faster commercialization of hydrogen-powered fuel cell vehicles. QUANTUM has introduced this low cost, rugged, ultra-lightweight, storage efficient hydrogen storage tank to improve the range and safety of hydrogen powered fuel cell vehicles.

The QUANTUM advanced composite tank technology incorporates a —Tri-Shield‖ design philosophy The QUANTUM Type IV Tri-Shield cylinder, as shown below, and comprises of a seamless, one piece, cross-linked, permeation resistant, ultra-high molecular weight polymer liner which is overwrapped with multiple layers of carbon fibre/epoxy laminate and a proprietary external protective layer for resistance to impact. Tri-Shield hydrogen tanks feature a single-boss opening to reduce leak paths.

Tri-Shield hydrogen tank has been designed to accommodate QUANTUM's patented in-tank regulator, which limits high gas pressures within the tank and, thus, eradicates high-pressure fuel lines downstream of the fuel storage subsystem. By linking a check valve to assist tank filling, fuel tank pressure, fuel filtering and temperature monitoring, tank lock-off and pressure relief device in the regulation module the system cost can be considerably reduced.

Gaseous fuels, particularly hydrogen, inherently have a much lesser energy density than the liquid fuels, such as gasoline. Compression to high pressure is essential to increase the mass of hydrogen stored, and the subsequent vehicle range, within a given space on-board the vehicle. CNG, for example, is typically stored at 3,000 psi (200 bars) or 3,600 psi (250 bars). Hydrogen is needed to be compressed to even greater pressures because of its even lower energy density. Till date, hydrogen tanks designed for fuel cell vehicles have been made to store hydrogen at pressures of up to 10,000 psi (700 bars) to maximize vehicle range. Hydrogen cylinders are essentially designed to handle pressures considerably greater than the rated service pressure – to meet a minimum safety factor of 2.35 for burst strength and to accommodate a rise in gas temperature during fast filling.

Standards developed by ANSI/AGA, NGV2-1998 and NGV2-2000 have become crucial for industry acceptance of high-pressure storage cylinders, although FMVSS 304 is the minimum standard mandatory by the U.S. Department of Transportation (DOT). Since no international specifications or standards have yet been agreed upon for hydrogen cylinders, they are currently following the compressed natural gas (CNG) tank classifications, which fall into the following categories:

1. Type I - all metal cylinders

2. Type II – load-bearing metal liner hoop wrapped with continuous filament

3. Type III – non-load-bearing metal liner axial and hoop wrapped with continuous filament

4. Type IV - non-load-bearing non-metal liner wrapped with continuous filament

The International Standards Organization (ISO) is developing a fuel cell vehicle and hydrogen storage standards within the technical committees TC22/SC21 and TC197. The European Integrated Hydrogen Project (EIHP) has also formulated state-of-the-art hydrogen system standards. The standards, both those based on CNG and those being developed for hydrogen; lay down a number of tests to ensure reliability, safety and durability of the compressed hydrogen fuel storage system.

The various types of validation tests are given as:

- Hydrostatic burst
- Ambient cycle
- Gunfire penetration
- Flaw tolerance
- Drop test
- Hydrogen cycle
- Tensile properties
- Boss end material
- Extreme temperature cycle
- Acid environment
- Bonfire
- Accelerated stress
- Permeation
- Softening temperature
- Resin shear
- Boss torque resistance

The storage, transportation, and delivery of hydrogen are the most critical elements for a practical hydrogen energy system. The aim to develop efficient and cost-effective hydrogen storage systems is driven chiefly by the mobile applications for hydrogen, in which size and weight of a storage device are the major constraints. Other applications will also profit from the technological advances made for on-board hydrogen storage systems. Since the energy density of hydrogen gas is significantly less than that of conventional fuels, larger tanks are required for equivalent range. Furthermore, the geometry of traditional high-pressure cylinders generally does not conform to the available space on the vehicle, thereby raising tank packaging issues. Tank cost and weight also significantly influence the amount of fuel that can be carried.

Hydrogen poses both real and perceived challenges, as a transportation fuel. The most challenging application is the light-duty vehicle or, specifically saying, the automobile. Automobiles impose the greatest constraints with respect to the space available on-board the vehicle and consumer expectations regarding vehicle range. In the near-term, fuel cell vehicles will likely be the first to be introduced for fleet applications. Fleet applications will likely have centralized refuelling available, so a vehicle range of 100 – 150 miles (160 - 241 km) would be acceptable. In terms of mass of hydrogen, this range could be achieved with almost 3 kg of hydrogen being supplied to a fuel cell vehicle. Mature compressed and liquid hydrogen storage technologies of reasonable size and weight may well achieve this short-term goal. Metal hydrides, although providing more compact storage, would also impose a significant weight penalty.

8.7 Calculations of mass and volume

Mass of liquid hydrogen (D= 70g/l) for 90 litres volume = 70*90

=6.3 Kg

Mass availability for liquid Hydrogen with volume 90 L in a unit container = 6.3 Kg

Storage kit weight for liquid Hydrogen = 40 Kg

Total weight with fuel = 40+ 6.3 Kg= 46.3 Kg

Volume of container with dimensions 22 inches by 20 inches standard size =

3.14*25.4*25.4*55.88 c.c. =110 Litres per kit with 6.3 Kg fuel

Thus required volume in the wings/fuselage of the aircraft can be calculated, depending on the power and fuel supply.

From Fuel cell we have calculated that the required amount of 9.34 kg h2 per hour. Fuel flow rate is 29.65 at 80 % efficiency.

8.8 Safety [15]

8.8.1 Fuel storage

Using hydrogen as fuel means that additional safety measures are needed. However hydrogen is not as dangerous as it may seem, and compared to some other alternatives fuels is relatively safe. Hydrogen is the smallest element of the periodic table, and has a number of characteristic properties, a very low viscosity, a very low density, an extremely high conductivity. Compared to air, hydrogen leaks almost 3.3 times faster in a hole with identical diameter. Because of its very low density, hydrogen dissipates quickly in upward direction and does not concentrate in a small area. Unfortunately, hydrogen fire is invisible, and therefore is much more difficult to fight.

Table 8.1: Hydrogen ignition properties

	Hydrogen	**Methane**	**Propane**
Density kg.m-3	0.084	0.65	2.01
Ignition limits in air % (volume)	4.0-77	4.4-16.5	1.7-10.9
Ignition temperature °C	560	540	487
Min Ignition energy in air MJ	0.02	0.3	0.26
Max combustion rate in air m.s-1	3.46	0.43	0.47
Detonation limits in air % (volume)	18-59	6.3-14	1.1-1.3

From the above table we can see that hydrogen is mainly dangerous when mixed with air, but ignites at a considerably higher temperature than other fuels. Even if the ignition energy is lower, higher volumes of gas are required to ignite in air when compared to methane or propane, which in spite of all the safety concerns they raise, are used widely in domestic applications.

8.8.2 Material compatibility

Due to the very small radius of hydrogen molecules, hydrogen can easily travel through some materials having larger holes in microscopic structures. This is one reason why carbon composite materials are not hydrogen proof. Some metals are also not compatible with hydrogen storage, as hydrogen may penetrate their atomic structure. For example, resistance of ferrous alloys is quite low to hydrogen.

8.8.3 Difficulties in liquid hydrogen storage

1. It is a colourless and odourless gas.

2. It is highly susceptible to leakage.

3. It has a wide range of combustible air fuel mixture.

4. It is a light weight gas and therefore spreads over a longer area after leakage.

5. The temperatures required for liquid hydrogen storage are quite low (-150 to -273).

6. It has a negative Joule Thomson Coefficient i.e. it will self-ignite on leakage.

7. Contaminated LH2 with air may form highly unstable mixtures which may detonate with explosive effects similar to those produced by TNT.

8. It needs 4 times more volume in storage than that occupied by the petroleum products and hydrogen production is still somewhere dependent on petroleum.

9. The current technologies are still not appropriate enough and more research needs to be done.

10. It is more accident prone as skilled labour is required for handling the highly compressed liquid hydrogen bottles.

11. Ability to embitter metals.

8.8.4 Safety procedures

1. Some colorant or artificial odour also needs to be added so that the leakage can be detected.

2. Stainless steel gas cylinders are used with insulation thickness varying from 200 to 300 insulation foils. The insulation foil consists of alternate layers of plastic foils and aluminium foil.

3. Hydrogen's explosive range is 13- to 79 percent concentration in air. It is colourless and odourless and burns with an almost invisible flame. Hydrogen's wide explosive range, merged with its very low ignition energy, giving it a potential disadvantage as an

accumulation of hydrogen in a poorly ventilated vehicle interior may lead to explosion easily. Thus, a proper ventilation system is needed in the vehicle.

4. The ignition energy required for the hydrogen gas is as low as 0.02 mili joules, which is equivalent to the energy of a static electric discharge from the arcing of a spark. Thus, a spark free environment needs to be created. The environment without spark should include an extremely well-insulated electrical system and some or the other form of grounding for the crew so that they do not build up a static charge during the platform operation.

5. Since there is a possibility that hydrogen might leak into the crew compartment, hydrogen detectors must be used aboard platforms to detect explosive concentrations of hydrogen. A ventilation system could be used to exhaust the explosive mixture to the atmosphere.

6. The hydrogen fuel tanks should be kept at a position in the vehicle which is least prone to accidents.

7. A proper check valve and control valve system should be installed in the vehicle so that the gas supply is immediately blocked in case of accident thus preventing any explosion or uncontrolled combustion.

8.9 Fuelling refuelling

Hydrogen is highly dangerous in gaseous state mixed with air and hence air must be prevented from entering the fuel tank. For this reason, an inert gas like nitrogen must be used for filling the hydrogen tank when empty.

When the tanks are being filled, heat is transmitted to hydrogen through the insulating material at a very low rate. The heated hydrogen then turns to gaseous phase, thus raising the pressure in the tank. Ideally, this gaseous heated hydrogen should then be consumed by the fuel cell.

Hydrogen losses are created as a result of heat transfer from outside to the tank, but are necessary to maintain the pressure inside the tank, as the hydrogen is consumed. Eventually towards the end of the flight, almost all of the hydrogen would have been consumed and the remaining hydrogen would be mixture of gaseous and liquid phases.

The tank must be equipped with pressure release valves. When too much hydrogen is turned into gas, the pressure rises above 20 psi. Exceeding hydrogen is then let out by opening the pressure valves.

However, hydrogen leaks very fast because of its small molecular radius, and small viscosity, therefore very low heat losses should happen when the valves open.

Before maintenance, it is necessary to empty the tank by purging it with nitrogen (inert), in an open air area, so that the remaining hydrogen is exhausted and dissipates upwards. The same fire rules that apply when working with gasoline also apply when purging the hydrogen tank. Air has to be exhausted before refuelling with hydrogen after the maintenance.

CHAPTER 9

POWER MANAGEMENT OF FUEL CELLS

9.1 Design of control strategy [11]

The power management system provides reference signals to the fuel cell, motor and the DC/DC converter so as to distribute the energy from two power sources accurately. The battery SOC is monitored to determine the energy flow and maintain overall efficiency if the system. The management system for the Li-ion battery maintained the battery SOC within 40e80 % to avoid voltage collapse while controlling for the required power. The power management system controlled the power required for the motor, by which a function was used to distribute the power from either the Li-ion battery or the fuel cell. Additionally, the DC/DC converter current control was used to control the energy in the system [11].

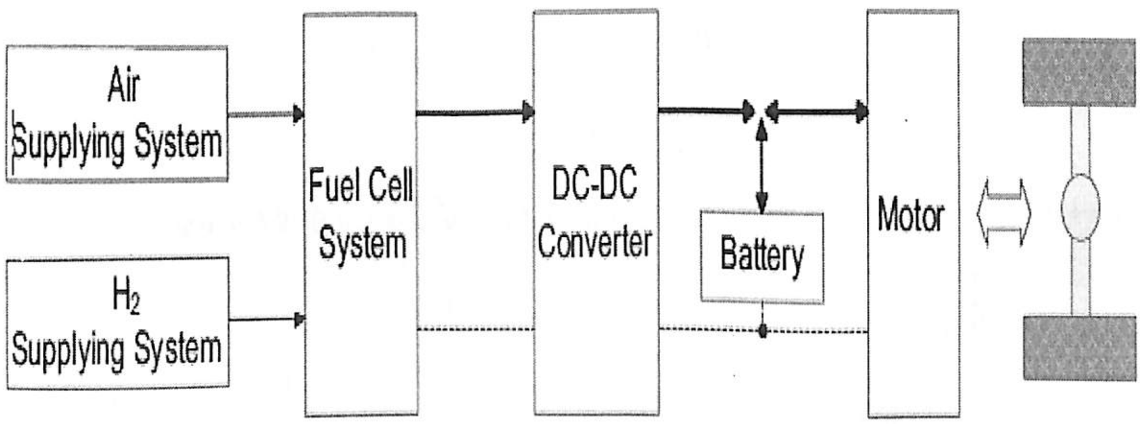


Figure 9.1: Structure of vehicle dynamics [Source: International Journal on H2 Energy 2012]

The operation of fuel cell is inadequate since it performs at either over or under the energy output range. Therefore, it is crucial to regulate the output power in the fuel cell. Separate control strategies are required for different power sources, whether the energy primarily originates from the fuel cell or the Li-ion battery.

9.2 High power mode

During a period requiring high power, if the required power exceeds the maximum output power provided by the fuel cell, the Li-ion battery starts to provide the power to the motor, to maintain the fuel cell working within the operating range. As shown in Fig. , the controller switches the power supply mode based on the voltage and current sensors [11].

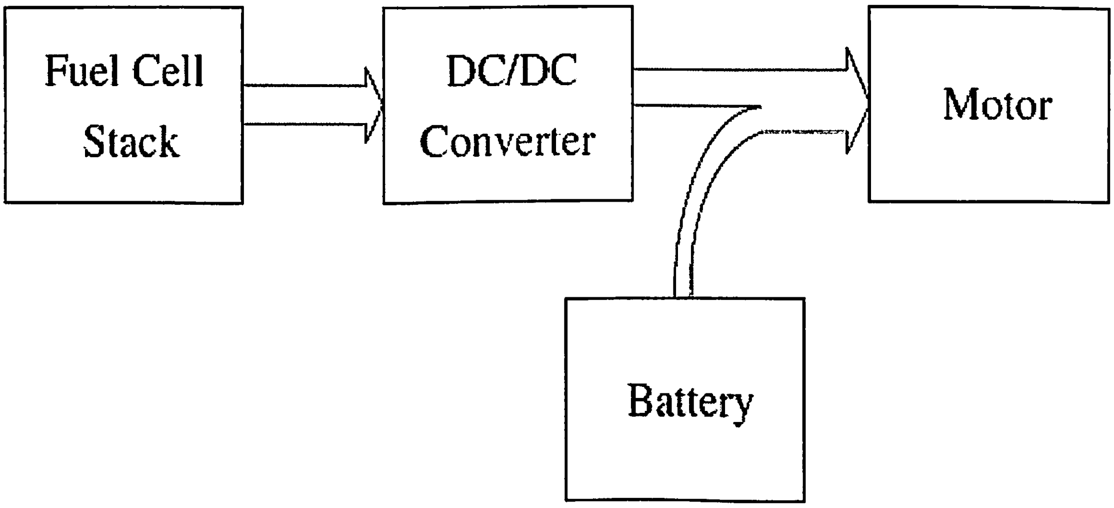


Figure 9.2: Energy flow in high power mode [Source: International Journal on H2 Energy 2012]

9.3 Low power mode [11]

If the power required in the system is low or approaches zero, the power is provided primarily from the fuel cell. During this period, if the battery SOC is lower than the pre-set value, the controller starts to charge the battery. Therefore, some of the fuel cell energy is used to charge the battery, as shown in Figure.

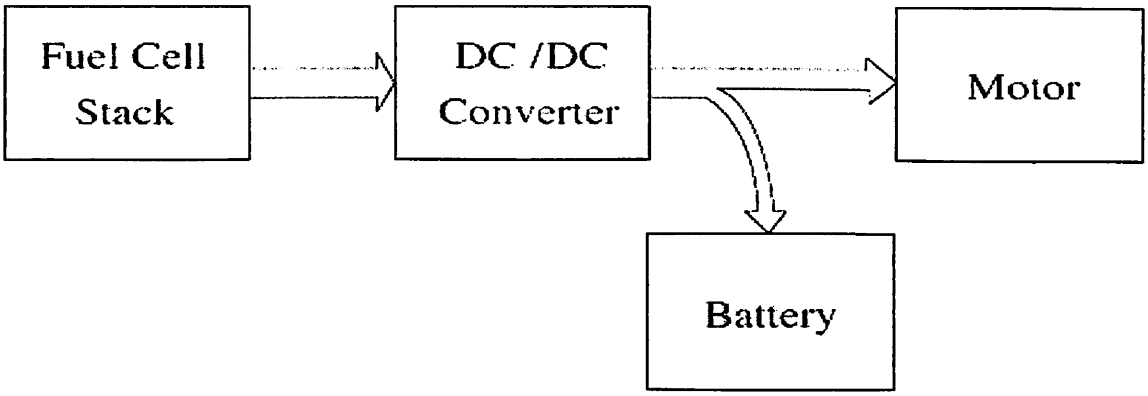


Figure 9.3: Energy flow in low power mode [Source: International Journal on H2 Energy 2012]

9.4 Standard power modes [11]

During the standard power mode, the power required falls within the operating range, and the battery SOC is maintained in state of high power. In this mode, power to the motor is fully provided by the fuel cell only, as shown in Figure.

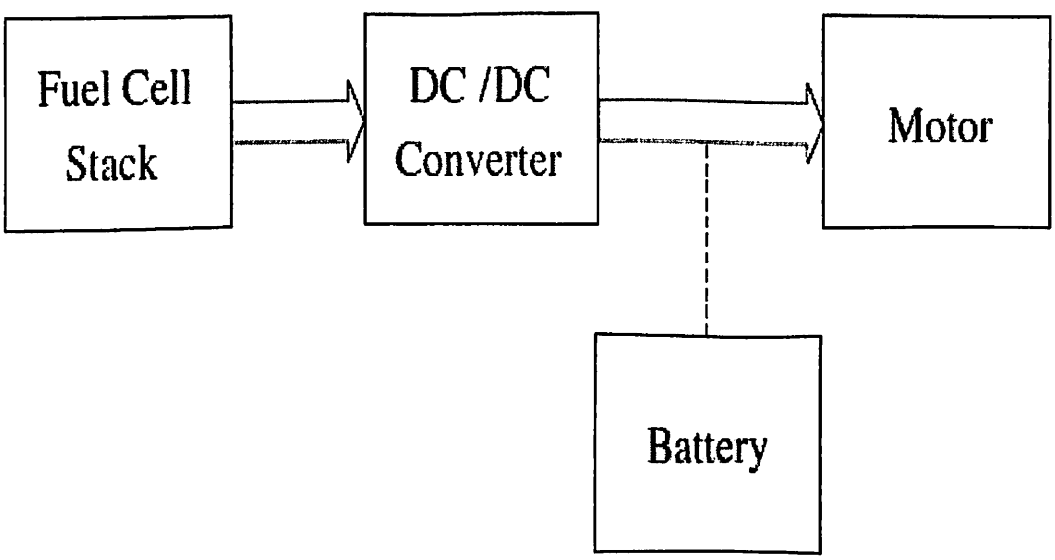


Figure 9.4: Energy flow in standard mode [Source: International Journal on H2 Energy 2012]

9.5 Charge mode [11]

If the vehicle stops moving and the motor do not require any power, the fuel cell starts to charge the battery once the battery SOC is lower than 80%. The energy flow in charge mode is shown in Figure.

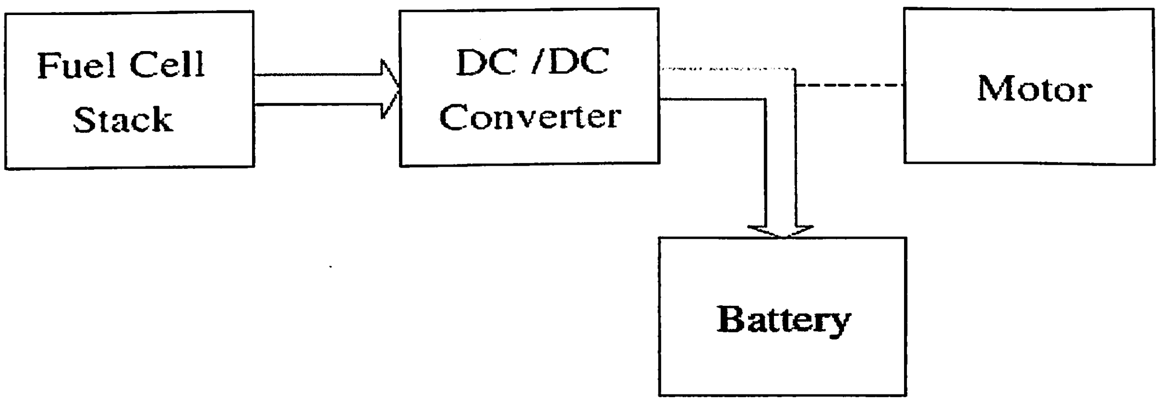


Figure 9.5: Energy flow in charge mode [Source: International Journal on H2 Energy 2012]

9.6 Model of the controller [11]

Both the energy input and output to the power management system were controlled. The input parameters included the charge power, battery power limit, drive torque, drive power, motor speed, and the voltage/current in the fuel cell. The output parameters comprised the motor torque reference and the fuel cell current reference. The power management system is shown in the figure.

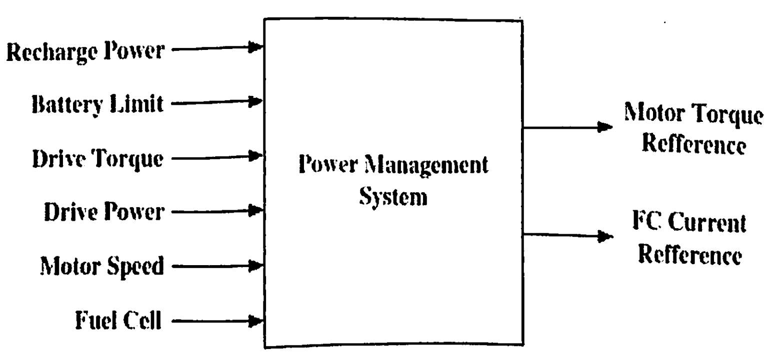


Figure 9.6: Power management system [Source: International Journal on H2 Energy 2012]

CHAPTER 10

PROPELLER DESIGN

10.1 High wing, twin push propeller

In this configuration the high wing assembled with a high visibility fuselage. The pilot and the passenger are situated right at the very front of the fuselage.

The aircraft is powered by two pusher propellers which are driven by electric motors, which do not interfere with the observer's vision, even when the observer is in the rear seats.

This option leaves a large amount of space available in the fuselage, to store hydrogen and also enables the aircraft to achieve better ranges. Fuel is also stored in the outer wings.

The converter and the stacks are located around the centre of gravity in the fuselage right in front of the auxiliary hydrogen tank.

The use of pusher propellers prevents the use of significant flaps so that this drawback would have to be balanced by a wing profile that is designed for low speed. Another option would be to accept the visibility penalties suffered from the propellers and then use tractor propellers, allowing for the use of flaps.

The advantage of this design is that it is fairly classical and therefore an easy handling could be appreciated by the private pilots. A common design also permits reduced manufacturing costs by using well known, cheap processes while risks due to innovative techniques are also reduced to a minimum. However noise and slow motion performances are lower than hat with some other designs.

10.2 Pusher propeller configuration

On an aircraft with pusher configuration, the propellers are mounted on the rear side of the respective engines. This enables the drive shaft to be in compression.

Figure 10.1: Push prop configuration [Source: Wikipedia]

10.3 Engine consideration

Specifically, the force provided by the propeller is pushing towards the engine, instead of away. To convert a tractor engine and propeller combination to pusher operation it's not enough to easily flip the engine and propeller spherical, since the propeller would still "pull" driving the craft to the rear. Forward the engine can't be run within the reverse direction; the "handedness" of the propeller should be reversed. the hundreds on the thrust race (bearings that stop fore and aft movement of the crankshaft) are reversed, as a result of the pusher propeller is pushing into the engine instead of actuation far from it as in an exceedingly tractor. Some trendy engines designed for lightweight craft are fitted with a thrust race appropriate for each "pushing" and "pulling", however others need a distinct half relying during which sense they're operating. Power-plant cooling design is far more complex than for the tractor configuration, in which the propeller forces air through the system.

10.4 Advantages

10.4.1 Practical requirements

Placing the cockpit forward of the wing to balance the load of the engine(s) aft improves visibility for the crew. Equally any front armament may be used a lot of simply.

The absence of front engine permits special instrumentality (radar, AUV cameras) to be expeditiously put in within the body nose.

Consequently, this configuration was wide used for early combat craft, and remains widespread nowadays among ultra light craft; remote-controlled aerial vehicles (UAV) and FPV guided planes.

Aircraft wherever the engine is carried by, or terribly near, the pilot (such as paramotors, powered parachutes, autogyros, and flex wing trikes) place the engine behind the pilot to minimise the danger to the pilot's arms and legs.

10.4.2 Aerodynamics

Placing the cockpit forward of the wing to balance the weight of the engine(s) aft improves visibility for the crew. Similarly any front armament can be used more easily.

The absence of front engine allows special equipment (radar, AUV cameras) to be efficiently installed in the fuselage nose.

Consequently, this configuration was widely used for early combat aircraft, and remains popular today among ultra light aircraft, unmanned aerial vehicles (UAV) and FPV radio-controlled planes.

Aircraft where the engine is carried by or very close to, the pilot (such as paramotors, powered parachutes, autogyros, and flex wing trikes) places the engine behind the pilot to minimise the danger to the pilot's arms and legs.

10.4.3 Safety

The engine is mounted behind the crew and rider compartments, therefore fuel doesn't need to flow past personnel; any leak can vent behind the craft, and any engine hearth are going to be directed behind the craft (however, this arrangement puts the tail at larger risk—if there's one—but this is often less of a problem if the fireplace happens at the time of, or as a consequence of, landing). Similarly, propeller failure is a smaller amount possible to directly endanger the crew.

Leaks of fuel, oil or fluid from the engine stream removed from the craft rather than changing into a risk to the pilot, alternative occupants, and any whole-aircraft parachute installation.

In case of a crash or crash-landing, fuel and oil within the aft engine space square measure less possible to be a fireplace hazard and high-energy propeller fragments square measure less possible to enter the cabin space.

At the time once several military craft were pushers, the engine afforded some rear protection to the pilot.

A pusher ducted fan system offers a supplementary characteristic attributed to intromission the rotating fan within the duct, thus creating it a horny possibility for numerous advanced unmanned air vehicle configurations or for small/personal air vehicles or for craft models.

10.5 Disadvantages

10.5.1 Structural and weight considerations

A pusher style with a tail behind the propeller is structurally a lot of complicated than an identical tractor kind. The enhanced weight and drag degrades performance compared with an identical tractor kind. Trendy mechanics data and construction strategies might cut back however ne'er eliminate the distinction.

A remote (buried) engine needs a drive shaft and its associated bearings and supports, special devices for torsional vibration management, increasing mechanical needs, weight and quality.

10.5.2 Centre of gravity and landing gear considerations

To maintain an executable CG position, there's a limit as however way aft associate engine may be put in. The forward location of the crew might balance the engine weight and can facilitate verify the CG. Because the CG location should be unbroken at intervals outlined limits for safe operation load distribution should evaluated before every flight.

Due to a usually high thrust line (needed for mechanical device ground clearance), negative (down) pitching moment and generally absence of prop-wash over the tail, higher speed and longer roll is needed for takeoff compared to tractor craft. Main gear situated too way aft (aft of empty craft c.g.) might need higher takeoff rotation speed or perhaps stop the rotation. The Rutan answer to the current downside is to lower the nose of the craft at rest such the empty c.g. is then before the most wheels.

Due to the middle of gravity usually being any back on the longitudinal axis than on most tractor airplanes, pushers may be additional liable to flat spins, particularly if loaded improperly

10.5.3 Aerodynamic considerations

Due to the widely high thrust line (aft propeller/ ground clearance), a coffee wing pusher layout might suffer pitch changes with power variation (pitch/power coupling). Pusher seaplanes with particularly high thrust lines and tail wheels might notice the surface disguised from the flowing, severely reducing management at low speeds, like once taxiing.

The absence of prop-wash over the wing reduces the raise and will increase takeoff roll length.

Pusher engines mounted on the wing might hinder sections of the wing edge, reducing the entire dimension accessible for management surfaces like flaps and ailerons.

When a mechanical device is mounted before of the tail changes in engine power alter the flowing over the tail and may offer sturdy pitch or yaw changes.

10.5.4 Propeller ground clearance and foreign object damage

Because of pitch rotation at kick off, propeller diameter might ought to be reduced (with a loss of efficiency and/or undercarriage created longer and heavier. several pushers have ventral fins or skids below the propeller to stop the propeller from hanging the bottom at another price in drag and weight.

On acaudal pushers like the Rutan Long-EZ the propeller arc is extremely near the bottom whereas flying nose-high throughout takeoff or landing. Objects on the bottom kicked up by the wheels will taste the propeller disc, inflicting injury or accelerated wear to the blades, or in extreme cases, the blades might strike the bottom.

When a heavier-than-air craft flies in icing conditions, ice will accumulate on the wings. If a heavier-than-air craft with wing-mounted pusher engines experiences icing the props can ingest shredded chunks of ice, endangering the propeller blades and elements of the framing that may be affected by ice violently redirected by the props.

In early pusher combat craft, spent ammunition casings caused similar issues and devices for grouping them had to be devised.

10.5.5 Propeller efficiency and noise

Because of pitch rotation at kick off, propeller diameter might ought to be reduced (with a loss of efficiency and/or undercarriage created longer and heavier. several pushers have ventral fins or skids below the propeller to stop the propeller from hanging the bottom at another price in drag and weight.

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In early pusher combat craft, spent ammunition casings caused similar issues and devices for grouping them had to be devised.

10.5.6 Engine cooling and exhaust

In pusher configuration, the propeller doesn't contribute flow of air over the engine or radiator. Some aviation engines have full-fledged cooling issues once used as pushers. To counter this, auxiliary fans is also put in, adding extra weight.

The engine of a pusher exhausts forward of the propeller, and during this case the exhaust might contribute to corrosion or different harm to the propeller. This is often sometimes minimal, and should be chiefly visible within the kind of soot stains on the blades.

10.5.7 Propeller and safety

In case of propeller/tail proximity, a blade break will hit the tail or turn out damaging vibrations resulting in a loss of management.

Crew members risk hanging the propeller, while making an attempt to bail out of a single-engine plane with a pusher prop. A minimum of one early seat was designed specifically to counter this risk. Some trendy light-weight craft, embrace a parachute system that saves the whole craft, so averting the necessity to bail out.

10.5.8 Engine and safety

Engine location within the pusher configuration may endanger the aircraft's occupants in a very crash or crash-landing within which engine momentum comes through the cabin. For instance, with the engine placed directly behind the cabin, throughout a nose-on impact the engine momentum might carry the engine through the firewall and cabin, and may injure some cabin inhabitants.

CHAPTER 11

RESULTS AND DISCUSSIONS

1. The mission requirement was 123.44KW power so as the fuel cell used in this particular project has an efficiency 71% so on calculating the power required was found to be 173.86 KW.
2. A most probable fuel cell was selected (FC VELOCITY 9SSL) which is very commonly used in the transport industry in both aviation and automobile sector.
3. FC VELOCITY was chosen because it has high efficiency, weight distribution is even throughout as it has multiple stacks. Gross power of fuel cell is 19.3 kW thus the number of fuel cells selected were 10 so that required energy of 173.86KW is produced. On dividing 173.86 by 19.1 we get 9.1 so we found appropriate to take 10 cells so all the power required conditions are fulfilled.
4. Hydrogen consumed was calculated to be 23.72 kg per hour as the efficiency is 80% so the hydrogen needed is 29.65 kg per hour. Accordingly the fuel storage was proposed in it.
5. For the motor of the aircraft, there were two motors required as it is a twin prop aircraft. So as we need 123 KW power so we needed two motors of around 60-70KW power so that the aircraft may fly.
6. The most suitable choice for the motor requirement was HVH250-115-SOC3 high torque winding configuration. As the power output of the motor matches the power required of about 60-65 KW power plant.
7. The hydrogen to be used in the fuel cells is kept in tanks which are stored in wing. The temperature has to be maintained about -253 degree Celsius to keep it in liquid state. Mass of liquid hydrogen (D= 70g/l) for 90 litres volume = 70*90 =6.3 Kg Mass availability for liquid Hydrogen with volume 90 L in a unit container = 6.3 Kg Storage kit weight for liquid Hydrogen = 40 Kg Total weight with fuel = 40+ 6.3 Kg = 46.3 Kg
8. Volume of container with dimensions 22 inches by 20 inches standard size = 3.14*25.4*25.4*55.88 c.c. =110 Litres per kit with 6.3 Kg fuel Thus required volume in the wings/fuselage of the aircraft can be calculated, depending on the power and fuel supply. From Fuel cell we have calculated that the required amount of 9.34 kg $_{H2}$ per hour. Fuel flow rate is 29.65 at 80 % efficiency.

9. The aircraft is designed to carry four people including the pilot also the aircraft is to be used as a sightseeing aircraft so the propellers are a push configuration type this makes the aircraft having a twin engine push configuration propeller type.

CHAPTER 12

CONCLUSION AND FUTURE WORK

The team worked on this project thesis for around six months. A very through literature study was done in the field of fuel cells. Fuel cells used in aviation were well studied and their performance, their working principles were studied and explained as well. Although our project dealt with the entire fuel cell technology our main focus was on proposing a propulsion system for a fuel cell aircraft. Also a study was done on the propeller system which is to be used in the aircraft A detailed study was done on the production techniques of hydrogen and problems faced by various other types of fuel cells also a detailed comparison was done between various types of fuel cells their usage. Also few existing working projects were studied in order to understand the project problem and current scenario of the fuel cell technology

The detailed data of the aircraft was given by other team which was then used to calculate further data used in the aircraft. The required power by the aircraft was 123.4 KW as per its shape and mission profile. It was calculated that the hydrogen needed was around 9kg per hour. And accordingly a fuel cell Ballard FC Velocity 9SSL was chosen as the production fuel cell variant to be used in the aircraft and its stacking configuration and cooling was studied thoroughly. Using various available data of this fuel cell the number of fuel stacks was calculated

Moving further a motor was also selected which were two in number as this aircraft is a twin engine aircraft. The motor was selected on the basis of its power usage and output data. Also a detailed study about the storage was done. It was calculated that how much of the space is needed and the tank sizes and their efficiencies as well to store the hydrogen which was going to be used as fuel.

The projects concludes that a proper propulsion system was proposed for the given aircraft data on the availability of current technologies and the challenges faced by the latest fuel cell technology

Hydrogen cell technology is itself a futuristic approach towards non-conventional energy sources. A lot of research is needed in this area and there is a huge scope for future work as this area is still untapped completely. There are no practical or we can say any commercial