FUEL CELL

Introduction

A **fuel cell** *is an electrochemical device in which the chemical energy of a conventional fuel is converted directly and efficiently into low voltage, direct current electrical energy.*

- Fuel cell systems generally *operate on pure hydrogen and air to produce electricity.*
- One of the chief advantages of such a device in that because the conversion, at least in theory, can be carried out *isothermally*, the *Carnot limitation on efficiency does not apply*.
- The essential *difference* between the primary/secondary cell and ***fuel cell*** is of *continuous energy input and output of fuel cell*. A fuel cell system requires continuous supply of a *fuel* and an *oxidizer* and generates D.C. electric power continuously.
- **A battery** has *stored* electrochemical energy within its container. After discharge it needs recharging or replacement. *Fuel cells do not need such recharging replacement*. A fuel cell is often described as a primary battery in which the fuel and oxidize are stored external to the battery and fed to it as needed.

Advantages, Disadvantages and Applications of Fuel Cells

Following are the *advantages*, *disadvantages* and *applications of fuel cells*:

Advantages:

1. Conversion efficiencies are high.
2. Require little attention and less maintenance.
3. Can be installed near the use point, thus reducing electrical transmission requirements and accompanying losses.
4. Fuel cell is odourless and does not make any noise.
5. A little time is needed to go into operation.
6. Space requirement considerably less in comparison to conventional power plants.
7. Simple and safe.
8. Pollution free.
9. No cooling water needed.
10. Capacity can be increased as the demand grows.
11. Long life.

Disadvantages:

1. High initial cost.
2. Low service life.
3. Problems for refilling in vehicles.

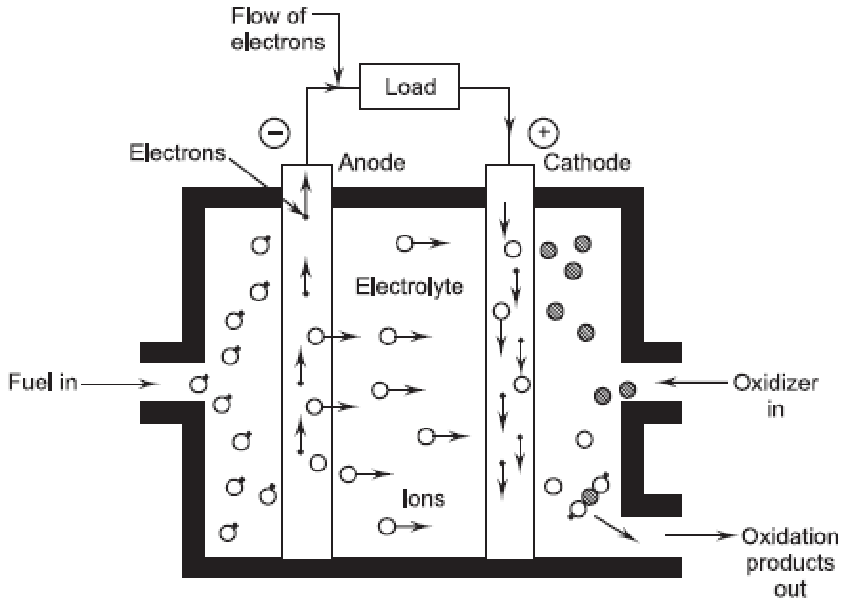
Components and Working Theory of a Fuel Cell

Components. The main components of a cell are:

1. Anode (Fuel electrode)
2. Cathode (oxidant electrode)
3. Electrolyte
4. Container
5. Separators
6. Sealings
7. Fuel supply
8. Oxidizer.

The '*fuel gas' diffuses through the anode and is oxidized, thus releasing electrons to the external circuit*.

The '*oxidizer' diffuses through the cathode and is reduced by the electrons that have come from the anode by way of the external circuit.*



— The *fuel cell is a device that keeps the fuel molecules from mixing with the oxidizer molecules, permitting,* however, *the transfer of electrons by a metallic path that may contain a load.*

Classification Fuel Cells

Fuel cells may be *classified* as follows:

A. Based on the type of electrolyte:

1. Alkaline fuel cell (AFC).
2. Phosphoric acid fuel cell (PAFC).
3. Polymer electrolytic membrane fuel cell (PEMFC).
4. Molten carbonate fuel cell (MCFC).
5. Solid oxide fuel cell (SOFC).

B. Based on operating temperature:

1. Low temperature fuel cell 25–100°C.
2. Medium temperature fuel cell (below 100–500°C).
3. High temperature fuel cell (500–1000°C).
4. Very high temperature fuel cell (Above 1100°C).

C. Based on the types of fuel and oxidant:

1. Hydrogen-oxygen fuel cell.
2. Hydrogen - air fuel cell.
3. Hydrazine-oxygen fuel cell.
4. Ammonia-air fuel cell.
5. Synthesis gas-air fuel cell.
6. Hydrocarbon (gas) - air fuel cell.
7. Hydrocarbon (liquid) - air fuel cell.

Types of fuels used in fuel cells:

The following fuels are mostly used in fuel cells:

1. Hydrogen (H2).
2. Hydrocarbon fuels.
3. Fossil fuel.
4. Alcohol fuel.
5. Hydrazine (N2H4) fuel.

Requirements of Electrolyte and Electrode

Following are the *requirements* of electrolyte and electrode:

Electrolyte:

1. It should be *conductive to ions.*
2. It should be *electrically non-conductive*.
3. *Ions should be free to move through the electrolyte.*
4. The composition of electrolyte should *not get changed during operation.*

Electrode:

1. It should be electrically *conductive*.
2. It should *not react with electrolyte* to prevent corrosion.
3. It should be *able to withstand high temperature.*
4. It should also *act as a catalyst* to convert hydrogen and oxygen molecules into their ions.

Desirable Characteristics of a Fuel Cell

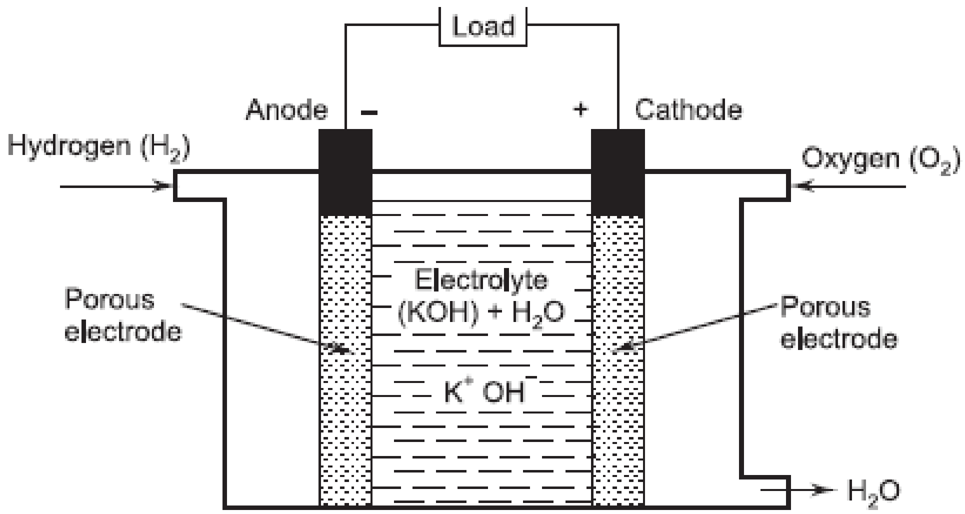
The *fuel cell* should have the following *characteristics*:

1. It should have high *energy conversion efficiency.*
2. It should produce *low chemical pollution.*
3. It should be *flexible to choose any fuel.*
4. It should have cogeneration capability and *rapid load response*.

Hydrogen-Oxygen Fuel Cell (Hydrox Cell)-Alkaline Fuel Cell (AFC)

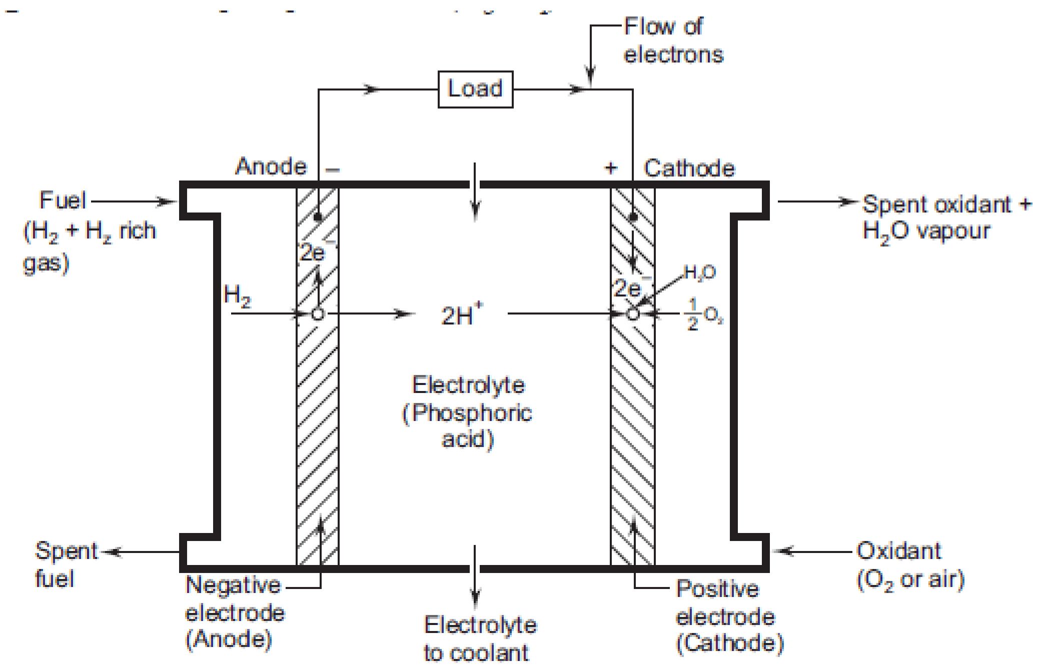
In this cell **hydrogen** and **oxygen** are used as the ‘*fuel*‘ and ‘*oxidant*‘ respectively as these elements are most *reactive with least complications*. The *‘electrolyte‘ is potassium hydroxide* (20 to 40% concentration) which has *high electrical conductivity* and is less *corrosive than acids*.

Structure of a hydrox cell (alkaline cell).



Construction. It has three chambers separated by two porous nickel electrodes, the *anode* and *cathode*. The middle chamber between the electrodes is filled with a strong solution of potassium hydroxide (KOH). The surfaces of the electrodes are chemically treated to repel the electrolyte, so that there is minimum leakage of potassium hydroxide into the outer chamber.

Phosphoric Acid Fuel Cell (PAFC)



The phosphoric acid cell consists of *two electrodes* of porous conducting material (*e.g. nickel*) *to collect charge and, 'phosphoric acid' used as electrolyte.*

At anode, hydrogen molecule is split into *hydrogen ions* (protons) and *electrons*. The electrons flow through external circuit and produce electric power while protons travel through electrolyte and combine with oxygen, usually from air, at the *cathode* to form water. The electrochemical reaction is very slow, so a *catalyst* is required in the electrode to accelerate the reaction. The catalysts used are platinum, nickel (for anode) and silver (for cathode). *Platinum is the best catalyst for both electrodes*.

Reactions in this fuel cell produce electricity and by-product heat. The *reactions* are given below:

Anode: $$H_2 \longrightarrow 2H^+ + 2e^-$$

Cathode: $$\frac{1}{2}O_2 + 2H^+ + 2e^- \longrightarrow 2H_2O$$

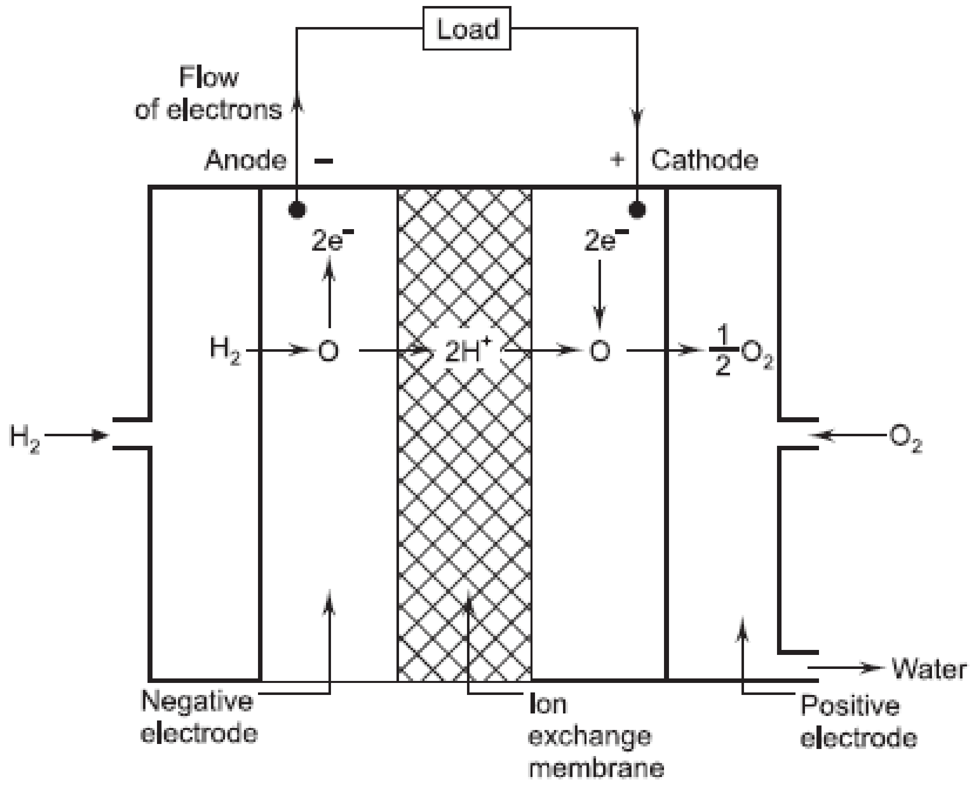
Overall cell reaction:

$$2H_2 + O_2 \longrightarrow 2H_2O + \text{Electrical energy}$$

- At atmospheric pressure PAFC produces an ideal emf of 1. 23V at 25°C which reduces to 1.15 V at operating temperature between 150 to 200°C.

Application. These cells are *used commercially having the plant capacity in the range of 50 kW to 200 kW.*

Polymer Electrolyte Membrane Fuel Cell (PEMFC)



In PEMFC cell, *electrolyte* is a *solid polymer membrane of an organic material* such as polystyrene sulphonic acid and this is *permeable* to protons (H^+) when it is saturated with water but it does not conduct electrons.

The fuel is *hydrogen* and charge carriers are hydrogen ions (protons). At the *anode*, the hydrogen molecule is split into hydrogen ions and electrons. The hydrogen ions permeate across the electrolyte to *cathode* while the electrons flow through an external circuit and produce electric power. *Oxygen* is supplied to the *cathode* and combines with electrons and hydrogen ions to produce water.

The *reactions* at anode and cathode are given below:

Anode: $$H_2 \longrightarrow 2H^+ + 2e^-$$

Cathode: $$\frac{1}{2}O_2 + 2H^+ + 2e^- \longrightarrow H_2O$$

Overall reaction: $$2H_2 + O_2 \longrightarrow 2H_2O + \text{Electrical energy}$$

The membrane is coated on both sides with finely powdered platinum which acts as a *catalyst*.

This cell are also called "*Ion-exchange membrane cell*".

The desired properties of the electrolyte of an ideal ion-exchange membrane cell:

(*i*) Low permeability of fuel and oxidants.

(*ii*) High ionic conductivity.

(*iii*) Zero electronic conductivity.

(*iv*) Low degree of electro-osmosis.

(*v*) Mechanical stability.

(*vi*) High resistance to hydration.

(*vii*) High resistance to the oxidation or hydrolysis.

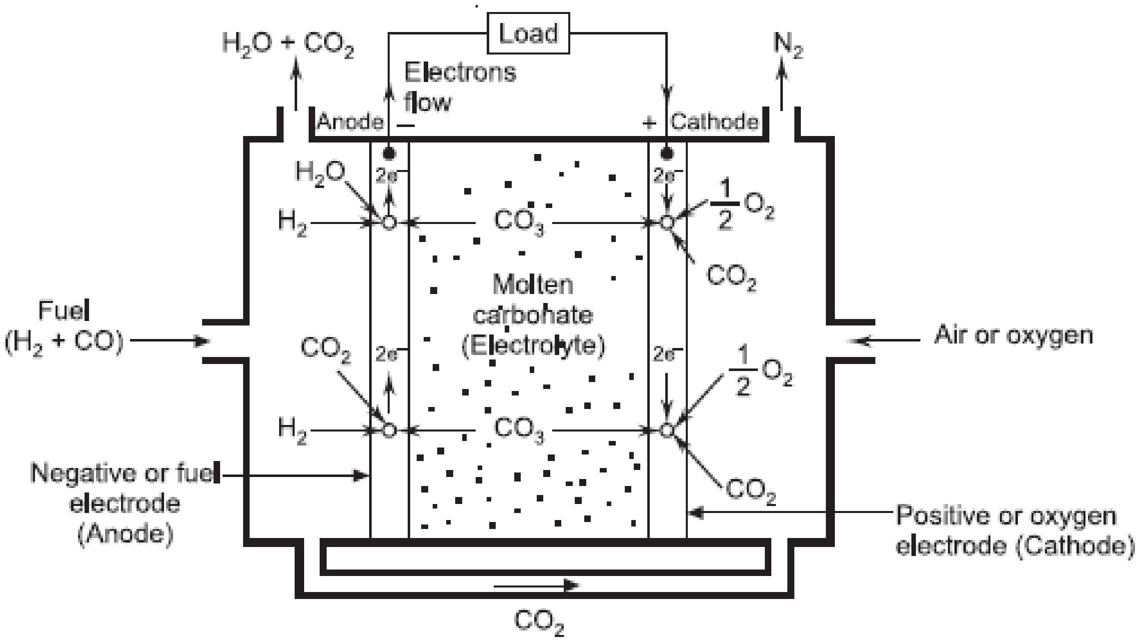
Applications. Residential, portable laptops, cellular phones, video cameras, buses, cars, railway locomotives.

Molten Carbonate Fuel Cell (MCFC)

This type of cell uses an *electrolyte*, which is a *molten mixture of carbonate salts*. Two mixtures commonly used are:

(i) Lithium carbonate and potassium carbonate, and (*ii*) Lithium carbonate and sodium carbonate. Since these salts can act as electrolytes only in *liquid phase*, the operating temperature should as high as 650°C.

MCFC in which porous nickel is used as electrodes and electrolyte is held in a spong like ceramic matrix.



A hydrocarbon fuel, such as methane or kerosene, is used. The fuel is reacted inside the cell to produce H_2O and CO. At the *fuel electrode* (anode) H_2O and CO react with CO_3 ions in the electrolyte, releasing electrons to the electrode, and forming H_2O and CO_2. At the *oxygen electrode* O_2 reacts with the returning electrons and CO_2 diverted from the fuel electrode to form CO_3 ions. These CO_3 ions then migrate through the electrolyte to the fuel rod.

The *reactions* are given below:

Anode: $H_2 + CO_3^{--} = H_2O + CO_2 + 2e^-$

$$CO + CO_3^{--} = CO_2 + 2e^-$$

These released electrons circulate through external resistance (load), forming load current and reach at oxygen electrode (cathode).

Cathode: $CO_2 + \frac{1}{2}O_2 + 2e^- = CO_3^{--}$

The CO_3^{--} ions are responsible for transportation of charge from cathode to anode within the electrolyte.

Overall reaction:

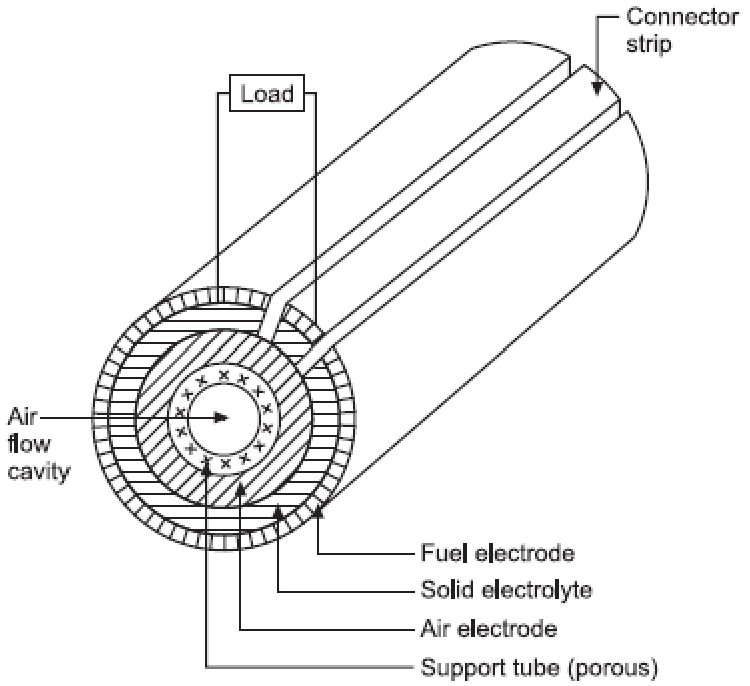
$$H_2 + CO + O_2 \longrightarrow H_2O + CO_2 + \text{Electrical energy}$$

- The theoretical *e.m.f.* produced by each cell is 1 V and actual e.m.f. being *0.8 V at 700° C*. The expected *efficiency is about 60%.*

Applications. *Dispersed power and utility power.*

Solid Oxide Fuel Cell (SOFC)

A solid oxide fuel cell (tubular shape)



This cell is based on a *solid metal oxide ‘electrolyte‘* (zirconium dioxide) called *zirconia*. It allows ionic Conductivity of oxygen ions from cathode to anode. The *electrodes* are electric conductors with a *high porosity*. The operating temperature (800–1000°C) is *high enough for internal reforming of natural gas* in the anode chamber. The water gas shift reaction takes place at the anode, thus enabling H2 and CO mixtures to be used as fuel feedstock.

— The construction materials used are *metal oxides* and *ceramics*. The central hollow space is for *air flow that acts as an oxidant*. Its operation is efficient at 1000°C and 1 atmospheric pressure.

Fuel gas flows through the outermost layer of the fuel electrode. Next to it is the *electrolyte layer*. The *fuel gas* permeates through the porous electrodes and is *oxidized by air containing oxygen*. The *air electrode* is next to electrolyte and air *flows axially through the central hollow space*.

— *Both fuel gas and oxidant are fed into the cell continuously which get consumed and the cell delivers electrical energy.*

- The solid oxide fuel cell fueled by *natural gas* can attain a high electrical efficiency upto 55 percent. Each cell delivers 25 A current at 0.7V and a pack of 50 fuel cells give an output of 1 kW.

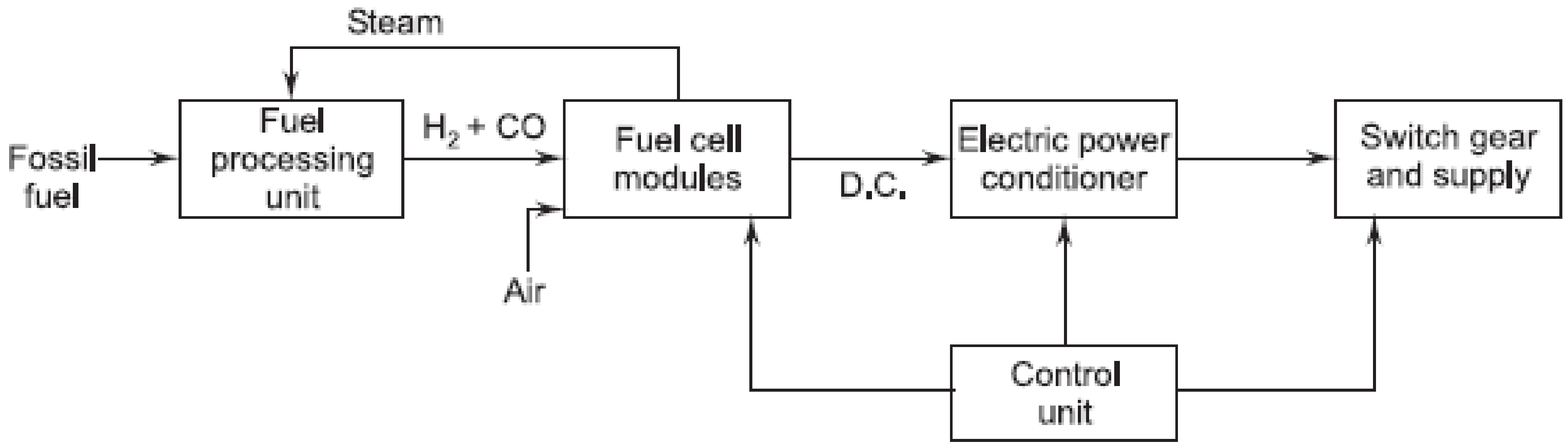
These cells promise a vast potential in utilisation of low grade high ash, graded coals through Fluidized Bed Gasification.

Applications. *Domestic and commercial utility power; mobile applications for railways.*

Fuel Cell Power Plant

The *primary fossil fuels* are used to *generate electrical energy in fuel cell power plant.*

The schematic of fuel cell based electrical power generation scheme:



— The fossil fuel is supplied to the '*fuel processing unit*', where fuel is purified and then supplied to '*fuel cell modules'.*

— The fuel cell modules convert fuel energy electrochemically into D.C. power.

— A number of fuel cells are stacked to form a module and several modules are interconnected to form a *power producing unit*.

— The *power conditioning unit* converts D.C. output to A.C output using *'inverter';* and the standard rated supply being 3-phase, 400 V, 50 Hz/60 Hz or single phase, 230 V/110 V, 50 Hz/60Hz.

Advantages of Fuel cell Power Plants

Following are the *advantages of fuel cell power plants*:

1. Besides *electric power*, fuel cell plants also supply *hot water*, *space heat* and *steam*.

2. These plants are *eco-friendly* and *noiseless* (since they don't have rotating parts.)

3. Fuel cell plants can attain *high efficiency upto 55%*, whereas conventional thermal plants operate at around 30% efficiency.

4. These plants have *cogeneration capabilities*.

5. A large degree of modularity is available with capacity ranging from *5 kW to 25 MW*.

6. There is a *wide choice of fuels* for fuel cells.

7. It is a *decentralised plant*, can be operated in isolation for military installations and hospitals where noise and smoke are prohibited.

Thanks