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Direct Methanol Fuel Cells towards Sustainable Future: An Indian Perspective

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Abstract: As we head towards a global depletion in traditional fossil fuels, the newly developed and sustainable fuel cells will be the rescue. This review paper briefly discusses the unpopular topic of Direct Methanol based Fuel Cells usage and production in India. This paper also highlights and explains their critical features by introducing the topic, starting with DMFC basics and how greener methanol is produced for the cell. We have clearly compared DMFC and other already existing fuel cells. As DMFC is a greener solution, its working principle is also stated. We discuss the various unique components that set DMFCs apart from other fuel cells and why we should surge the idea of replacing traditional fuel cells like Metal-ion based fuel cells and Hydrogen Fuel Cells. Concerning other fuel cells currently used in the market, DMFCs are predominantly cost-effective, adaptive to consumers' needs, and more efficient than other fuel cells. Alternate eco-friendly ways to produce methanol (bio-methanol) for DMFCs have not only benefited consumers to use DMFCs but have also resulted in more demand for the fuel cell. A global perspective of DMFCs regarding the demand by various countries importing and exporting components (electrode, membrane) and application-based result. Amongst all the nationwide competitors, North America has the largest market for DMFCs. Meanwhile, Asia Pacific is anticipated to take charge during 2021-2028, and the majority of demand is rising from China, Japan, Germany, and India. An Indian perspective gives credit to Niti Aayog's "Methanol Economy" program, which focuses on different parameters to produce fuel since the low cost of coal in India provides an opportunity to produce a range of products from coal such as methanol, olefins, DME, and others at a competitive price.
Keywords: Bio-methanol, Crude oil, Direct Methanol-based Fuel Cells, DME, DMFC, gasification, Hydrogen Fuel Cells, Metal-ion fuel cells, Methanol Economy, Niti Aayog, Production of methanol.

I. INTRODUCTION

Energy is necessary for our everyday life. The global depletion of fossil fuel resources such as oil, coal, and natural gas has led researchers to look for sustainable and efficient energy converters. The prospects for fuel cells as energy-efficient appliances have recently received much attention. William Grove first discovered fuel cell basics in 1839. Fuel cells directly convert the fuel's chemical energy into electrical energy by catalytic reaction.

The rapid growth of the total population and the stable growth of personal income are several factors that stimulate energy demand. By 2035, the world's population is expected to exceed 8.7 billion, which means that 1.6 billion more people will require energy.

The main problems are increasing energy demand, reducing the supply of fossil fuels, and applying traditional fossil fuels to human health. There is an urgent need to use green alternatives and sustainable energy to displace existing non-renewable fossil fuels. Approximately 80% of total energy consumption consists of combined heat and transportation. One of the world's most significant challenges today is finding efficient, renewable, and environmentally sustainable alternative energy sources. Mostly, these sources are still in the research and development stage. New energy options like solar, wind, and fuel cells offer viable alternatives to existing technologies.

Renewable energy production is increasing around the world. Literature studies indicate that approximately 1560 GW of renewable energy capacity was used by the end of 2013, almost double the 895 GW in early 2004. However, renewable power plants have many disadvantages. The main disadvantage is that renewable power plants are generally far from where they are needed, making it challenging to move renewable energy. Today's centralized power and distribution grids significantly impact grid stability due to the increasing number of distributed renewable energy power plants such as solar systems and wind power plants. Hence, pruning methods have been applied to solve these costly and growing problems. Besides energy storage technology, fuel cell technology is one of the new technologies that can quickly solve the above challenges.

Fuel Cell (FC) technology is one potential option in the hunt for a clean, effective energy source.

A *fuel cell* is an electrochemical device that generates energy by reacting with fuel and an oxidant. It transforms chemical energy into electrical energy.

DMFC is viewed as an energy generation and storage system for mobile devices. The PEM (Polymer Electrolyte Membrane) fuel cell sub-category of fuel cells includes the Direct Methanol Fuel Cell type. Methanol serves as the fuel for the natural process. With water and carbon dioxide as by-products, the DMFC makes it possible to convert chemical energy in liquid methanol fuel directly into electrical energy.

Integrated and sustainable decarbonized renewable energy systems must be developed to combat climate change. DMFCs are a promising energy source that quickly adapts to modern life and can improve humankind's environment. Due to its properties that make it ideal for portable devices, the DMFC is currently a significant focus of fuel cell development for portable applications.

Compared to the more popular hydrogen-fuelled PEM fuel cells, DMFCS offers several exciting benefits and a number of difficulties.

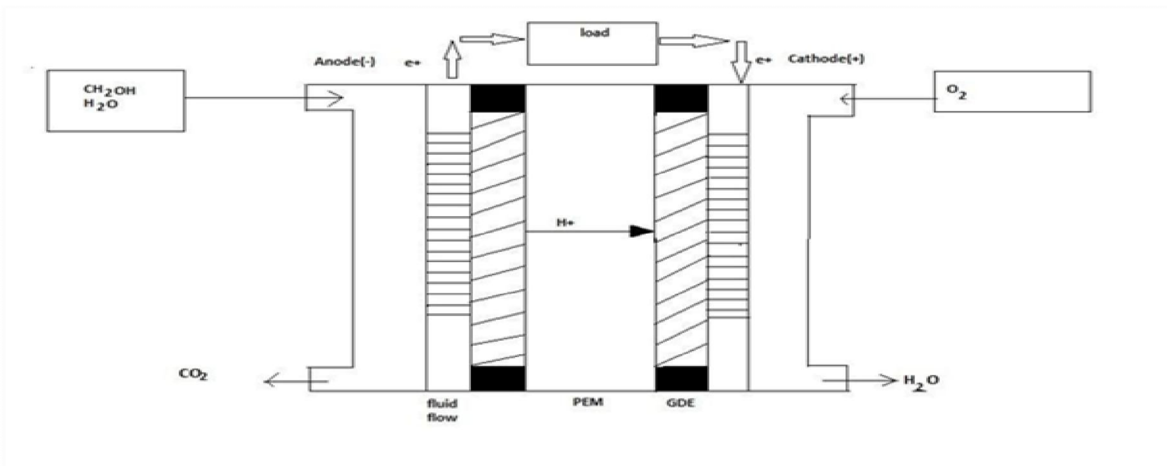

Figure 1. Direct Methanol-based Fuel Cell

Methanol can be used as a fuel either directly or in a blend with gasoline. The use of methanol in the fuel industry has increased rapidly since the mid-2000s. Direct use of methanol as a fuel has grown from less than 1% of the global methanol consumption in 2000 to more than 14% by 2021. Within the fuel cell family, DMFCs are undergoing rapid development. The reason is its structural simplicity, low pollution, high-speed operation, and high energy density. The Direct Methanol Fuel Cell uses methanol as the anode fuel and oxygen as the cathode fuel to generate electricity without a reformer or humidifier. Also, DMFCs promise energy for use in portable electronic devices such as laptops, mobile phones, and digital cameras. Spare cartridges store fuel and can be refilled in seconds by replacing or refilling the cartridge. The DMFC can be divided into active or passive based on the supply mode and liquid or vapor supply based on the state of the methanol supply. The energy density (i.e., the total energy stored in a space or substance) of a DMFC is 15 times that of a lithium-ion battery. Liquid fuels such as ethanol have the same energy density as methanol but cannot be used due to their slow electrochemical oxidation and low output.

DMFC is not only eco-friendly but also easily accessible and affordable. The DMFC has a higher power density than other fuel cells, so it competes with lithium-ion (Li-Ion) batteries for powering small portable electronic devices such as laptops. In this respect, DMFCs are superior to PEM fuel cells. DMFCs for portable applications are not expected to be as durable or cheap as Proton Exchange Membrane Fuel Cells for transport and fixed applications. Portable electronic devices use lithium-ion batteries almost everywhere today. Lithium-ion batteries are expensive and do not last long. It is commercially competitive as long as the DMFC lasts longer or is cheaper than a lithium-ion battery. However, PEMFCs face much tougher competition.

DMFCs for portable applications need to be more compact and lighter to compete with the other batteries. In addition, the recent decision to allow methanol cartridges on aircraft will facilitate the commercialization of DMFCs for portable applications. Methanol is toxic and flammable and is banned on airplanes. However, the Dangerous Goods Panel of the International Civil Aviation Organization will allow passengers to mount methanol fuel cartridges on aircraft and use them to power laptops and other consumer electronics in November 2005.

The Ministry of Transport made a similar decision on April 30. 2008. The decision helps passengers and crew to carry approved fuel cells with methanol cartridges installed. Especially in the military market, the demand for power supply systems for portable electronic devices is increasing. The applications of portable DMFCs and PEMFCs are expanding due to their quietness, high power/energy density, and weight reduction compared to current battery systems, increasing Base wearable devices. In addition, the military market is accepting higher prices due to the trade-off between performance and weight gain.

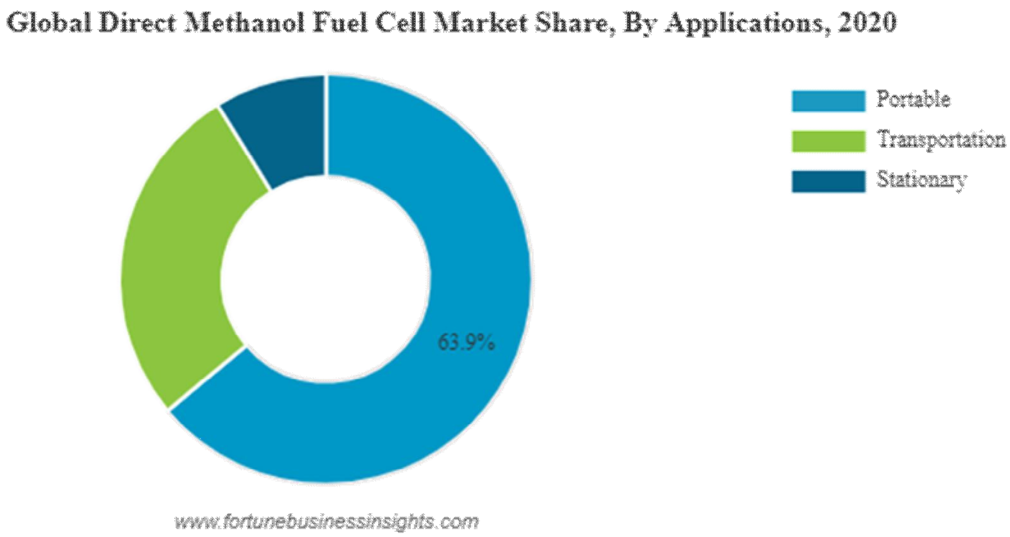

Figure 2. Global methanol fuel cell market (source: fortune business insights)

II. COMPONENTS OF DMFC AND ITS MECHANISM

Anode Reactions Electro-oxidation of methanol takes place at the anode. The creation of electron pair from either the carbonaceous species or H2O present in the surrounding (inside the cell). The oxidation reaction occurring at the platinum-ruthenium catalyst of the anode is given by:

A. $CH_3OH+H_2O\rightarrow CO_2+6H^{+}+6e^{-}$

In a DMFC, the methanol oxidation process is a crucial stage and a performance-limiting step. The intermediate carbon monoxide may constrain the anodic reaction rate. The substantial CO poisoning issue with platinum is why the 6908 International Journal of Hydrogen Energy 34 (2009) 6902-6916 emerged initially. Regarding practical use, platinum is one of the most effective catalysts for DMFC anodes. To solve this issue, a second catalyst, made of Pt and Ru, must be used to combine an active catalyst with a CO-poisoning-resistant catalyst. This solution came into use after a variety of catalysts were examined, such as pure platinum (Pt) and alloys of Pt with other elements, such as iridium (PtIr), palladium (PtPd), osmium, rhodium, tungsten (PtW), gallium (PtGa), ruthenium (PtRu), ruthenium-rhodium (PtRuSn). When the anode is at low voltage, it forms a more active electrocatalyst for the electrooxidation of methanol. Pt and Ru together create a bi-functional mechanism. The oxidation process at the Pt-Ru catalyst may involve some adsorbed species, including Pt(CO)ad, Ru(CO)ad, Ru(OH)ad, and Pt(OH)ad. The following are the specifics of the bi-functional mechanism: Adsorption of methanol CH3OH(sol)/(CO) and 4H 4e (4) (CO)ad indicates an adsorbed CO species either on Pt or on Ru is the initial step of the reaction. Pt and Ru both separate water to create adsorbed OH. Ru, H2O, (OH), and H 4e (5) Pt, H2O, (OH), and H 4e (6) Adsorbed CO and OH react to generate CO2 in the final phase of this mechanism.

Cathode reactions: Methanol transfers from the anode to the cathode, where oxygen (incorporated from the air) reduction reactions (ORR) take place. Overall performance may reduce the mixing potential caused by methanol in the cathode. The operating conditions for DMFC cathodes are more corrosive than anode since high water content is present, low pH (1), high temperatures (50–90 C), high potentials (0.6–1.2 V), and operating oxygen partial pressures. The most frequent cathode catalyst is platinum (Pt). The maximum Pt loading should be around 6.2 mg/cm2, and other studies have demonstrated that Pt loading above 4 mg/cm2 does not significantly improve performance.

The reduction reaction occurring in the cathode is

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$3/2O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$

Bipolar plate: The bipolar plate is a polymer plate device that has an anode and cathode flow fields on each side used for dispersing reactants, and under specific circumstances, it can also gather and disperse current. A good bipolar plate must meet the following requirements: it must be mechanically sturdy, have good conductivity, and be capable of withstanding acid-base environments. Although plastic and ceramic were used in some tests. Metal, graphite, or other composite materials are more frequently used as bipolar plates.

The current generated in the MEA is collected by the current collector in a DMFC system. The current collector requires high electric conductivity, superior mechanical strength, and a uniform transport area. Certain current collectors with low effective thermal conductivity can prevent heat loss and support temperature stabilization. The end plates hold the other DMFC components, working with bolts to support and preserve the system's compactness.

Polymer Electrolyte Membrane: The PEM separates the anode and cathode of the DMFC, conducts protons, and restricts the flow of electrons. PEMs must have high proton conductivity, high electron resistance, low methanol and water permeability, high chemical stability, high durability, and low cost. Per fluorinated membranes are the most commonly used PEMs and are commercially available as Nafion (Dupont), Flemion (Asahi Glass), Aciphex (Asahi Kasei Chemicals), Fumapen (Fumatech), and Gore-select (W.L. Gore & Associates). These PEMs are available in a variety of thicknesses.

For example, Nafion membranes are indicated by the letter "N" followed by a three- or four-digit number. N-112, N-115, N-117, N-1110, etc. Multiply the first two digits by 100 gives the equivalent weight (EW) in grams/equivalent (g eq1), and the last digit gives the thickness of the film expressed in mills (1 mill = 25.4 mm). The thickness of the membrane affects the performance of the DMFC. The thicker the membrane, the lower the MCO (methanol crossover) and the lower the proton conductivity. It has been found that thicker films give better cell performance at relatively low current densities and thinner films at relatively high current densities; for example, the EW of N-115 is 1100 g eq1, and the thickness is five mils. The thin F-1850 membrane, characterized by an equivalent weight of 1800, performs much better than the F-18120, characterized by the same EW but has a larger thickness (50 µm vs. 120 µm).

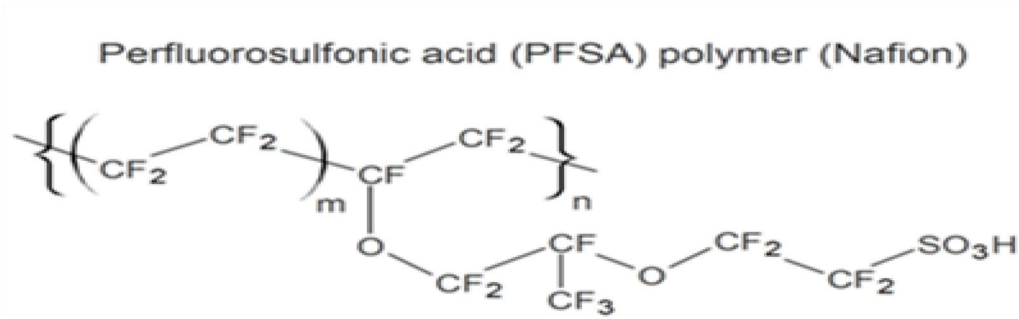

Figure 3. PFSA polymer

Figure 3 shows the chemical structure of a typical PFSA-PTFE film (per fluorinated film).

The strong bond between carbon and fluorine in the PTFE copolymer resists chemical attack and makes it hydrophobic. The sulfonic acid (HSO3) side chain is covalently attached to the PTFE structure and can be hydrophilic or absorb large amounts of water. H ions are weakly bound to SO3 groups and can move freely in a fully hydrated membrane, resulting in a conductive membrane. EW (equivalent polymer weight), water absorption, proton conductivity, and mechanical strength are important membrane properties. EW is a measure of the ionic concentration of the membrane and is defined as the molecular weight of the dry membrane per mole of sulfonic acid groups. The typical EW value for membranes is 1100 geq1. Water uptake is expressed as the number of hydrates defined as the number of water molecules per conductive functional group. The typical water absorption value of the membrane comes to 22. The proton conductivity relates to water content, temperature, chemical structure, and membrane morphology. The proton conductivity of a fully hydrated membrane is approximately 0.1 Scm1. A tensile test determines the mechanical strength of the membrane. Creep testing is used to determine the time-dependent behaviour of the membrane. Direct methanol fuel cells (DMFCs) are considered one of the most promising alternative energy supply systems due to their high energy efficiency and simple design and operation. The Polymer Electrolyte Membrane (PEM), an essential part of a fuel cell, is the polymer membrane. The polymer membrane has the essential function of a proton conductive medium and a barrier that prevents direct contact between the fuel and the oxidant.

One of the challenges in current DMFC research is the development of new proton conductive membranes to improve DMFC performance. At the same time, the polymer membrane must maintain high proton conductivity and have sufficient chemical, thermal and mechanical stability; low permeability to reactants; inexpensive; readily available.

III. METHANOL MANUFACTURE

Methanol manufacturing is through various natural gas, coal, and biomass. The common root source of methanol is coal, India's most fuel-efficient option. India holds abundant coal reserves, proportionally more economically than natural gas (55%) and crude oil (85%) on import. Sustainable biomass can is necessary to create bio-methanol. The biomass used here has low carbon or carbon dioxide levels, and hydrogen is combined to create renewable methanol using renewable electricity (e-methanol).

Feedstocks, including forestry and agricultural waste and items like biogas from landfills and sewage, are used to make bio-methanol. By utilizing CO2 extracted from renewable sources, e-methanol is generated. There are three primary methods for manufacturing bio-methanol: gasification, reformer-based (from biogas), and pulping cycle in pulp mills. There are several similarities between the manufacture of non-renewable methanol and the gasification and reformer-based generation of bio-methanol. The steps of methanol synthesis for these two routes are as follows:

1) Synthesis gas production
2) Methanol synthesis
3) Product purification

The synthesis gas is produced from a variety of sources and is a mixture of hydrogen (H2), carbon monoxide (CO), and carbon dioxide (CO2).

Methanol production from biomass for large-scale production is through gasification, which includes partial oxidation by steam and air. Large-scale production through biomass gasification is alluring for achieving methanol synthesis. However, the process is very complex, involving multiple components, polyphase (solid, liquid, and gas), and multiscale properties. In addition, the gasification process results from a series of steps in which biomass particles are gradually converted to biosynthetic gas and then to methanol by catalytic synthesis.

Biomass particles are sent to the gasifier. The particles are partially dried, and the hot gas removes the main moisture from the underlying biomass layer in the first step. The particles are then pyrolyzed and gasified before entering the charcoal combustion zone, where a specified (stoichiometrically inadequate) amount of oxygen/air is introduced. The heat generated by this step can energetically maintain the endotherm of the gasification step.

Finally, heat is transferred from the ash to the inlet gas stream and discharged from the gasifier in the ash zone.

A. Greener Methanol Production Reactions

(Biomass gasification to produce CO2)

$$CO_{2\,(g)} + 3H_{2(g)} \rightleftarrows CH_3OH_{(l)} + H_20_{(l)}$$

$$\Delta H^\circ_{298K} = -49.5\ kJ/mol$$

$$CO_{2(g)} + H_{2(g)} \rightleftarrows CO_{(g)} + H_2O_{(l)}$$

$$\Delta H^\circ_{298K} = 41.2 kJ/mol$$

IV. ADVANTAGES OF DMFC OVER OTHER FUEL CELLS:

A. Hydrogen Fuel Cells

A chemical reaction is used to produce electricity in hydrogen fuel cells. Each fuel cell has two electrodes: a positive cathode and a negative anode. By a reaction occurring at these electrodes, an electrolyte conveying electrically charged particles between them, as well as a catalyst to quicken the reactions, electricity is generated. In this instance, hydrogen serves as the primary fuel in a hydrogen fuel cell, but the cell also needs oxygen to function.

Since water is produced as a by-product of the reaction between the hydrogen and oxygen required to generate energy, one of the most significant benefits of hydrogen fuel cells is that they produce electricity with little pollution when compared to DMFC. Pure hydrogen is used as fuel in carbon-free cells. As opposed to fossil fuel sources, they do not produce greenhouse gas emissions, which lowers pollution and improves air quality. These fuel cells have nearly no emissions. Therefore, they do not emit greenhouse gases while in use, negating their carbon impact. Technological advancements allow fuel cells to supply power for various mobile and stationary applications. Hydrogen fuel cells are more expensive than DMFCs per unit of power. This may change as technology develops, as hydrogen is now less expensive but less widely used despite being more effective.

Hydrogen storage and transportation are more complex than DMFC. This suggests that additional expenditures for hydrogen fuel cells will be taken into account. Being a highly combustible fuel source, hydrogen raises understandable safety concerns. Hydrogen burns in the air at concentrations ranging from 4 to 75%. Additionally, there are obstacles, such as regulatory concerns implied by the framework defining commercial deployment models. With it, commercial projects may find it easier to reach a financial investment decision.

B. Lithium Fuel Cells

Anode, cathode, separator, electrolyte, and two current collectors make up a battery (positive and negative). Positively charged lithium ions are transported through the separator by the electrolyte from the anode to the cathode and vice versa. A charge is produced at the positive current collector by the movement of the lithium ions, which releases free electrons in the anode. The electrical current then travels from the positive current collector to the negative current collector after passing via a powered device (such as a computer or cell phone). The separator prevents electrons from moving freely inside the battery.

The lithium-ion battery's power density is high compared to DMFC, mainly caused by the high volume of the fuel cell at high power output. The number of components and production cost of fuel cell systems is generally higher than 'easy' to produce lithium-ion batteries. For lithium-ion batteries, a protection circuit is needed to maintain the voltage. The transportation of large amounts of lithium-ion batteries comes under regulatory provisions that lead to transportation restrictions. The manufacturing of lithium-ion batteries is costlier than DMFC. Lithium-ion batteries suffer the issue of aging and are also considered to be an immature technology. The energy density of the DMFC system is much higher than that of the lithium battery. DMFC system is smaller than the lithium-ion battery system.

V. GLOBAL SCENARIO OF DMFCs

A demand-specific perspective is determined by the countries importing and exporting manufacturing components *(electrode, membrane)* and their application-based result.

The global regions with continuous demand for direct methanol fuel cells include *North America, Europe, and Asia Pacific*. Region-wise, Asia-Pacific leads the market for DMFC, precisely *Japan, South Korea, and China,* and then come in queue *USA, UK, and Germany*. Many government-led initiatives were taken in Japan and South Korea to minimize dependence on nuclear and fossil fuels and make a future towards renewable energy. Other countries, such as Singapore, India, Indonesia, and Malaysia, have started exclusive programs to promote fuel cells in regional markets. These countries primarily aim for backup power, which is the stationary application of fuel cells. Moreover, India expects to invest in fuel cell systems to provide backup power for telecommunication towers. More than 14 countries plan to ban the sale of internal combustion engine (ICE) vehicles by 2035.

Additionally, the increasing awareness of clean energy and the demand for zero-emission energy sources drive the demand for DMFC. Amongst all the nationwide competitors, North America has the largest market for DMFCs. Meanwhile, Asia Pacific anticipates taking charge during 2021-2028, and the majority of demand is rising from China, Japan, Germany, and India.

Source: MarketsandMarkets Analysis

Figure 4. Global market size (source: markets and markets analysis)

The leading companies in the DMFC market include Treadstone Technologies *(U.S.)*, Oorja Photonics Inc. *(U.S.)*, MeOH Power *(U.S.)*, Viaspace *(U.S.)*, SFS Energy AG (Germany), Blue World Technologies (Denmark), Roland Gumpert *(Germany)*, Fujikura Limited *(Japan)*, Antig Technology *(Taiwan)*, Horizon Fuel Cell Technologies *(Singapore)* and many more. These companies have acquired growth strategies such as new product launches, contracts & agreements, mergers & acquisitions, and expansions to capture a larger share of the DMFC market.

VI. INITIATIVES BY GOVERNMENT FOR PROMOTING DMFC USAGE

NITI Aayog's 'Methanol Economy' program aims to reduce India's oil import bill and greenhouse gas (GHG) emissions and convert coal reserves and municipal solid waste into methanol. The Indian govt is trying to create close to 5 million jobs through methanol production distribution services. On 5 October 2018, Assam Petrochemicals launched Asia's first canister-based methanol cooking fuel program. India primarily targets Rs 6000 crore to be saved annually by blending 20% DME (Di-methyl Ether, a methanol derivative) in LPG. It will help the consumer save between Rs 50-100 per cylinder.

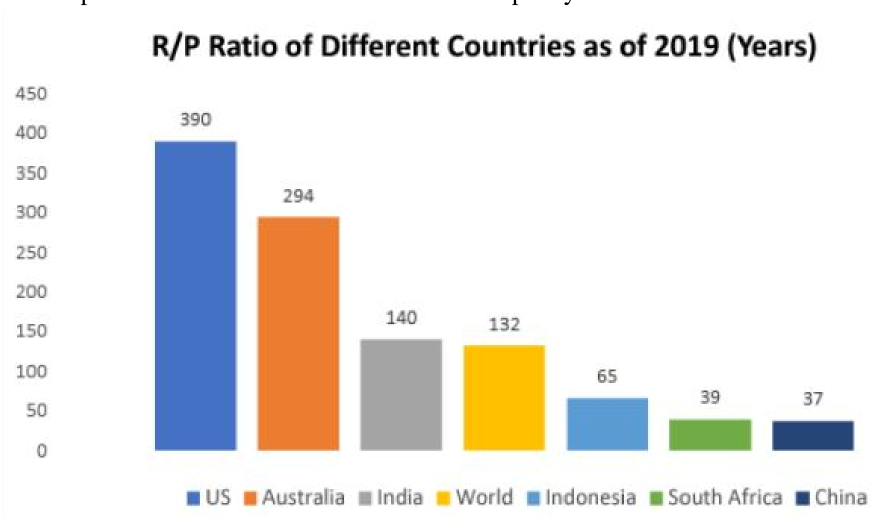

Figure 5. R/P ratio of different countries (source: BP Statistics)

As India moves towards a low-carbon economy, the share of coal in India's energy mix is expected to decline by 46% to 40% by 2040. That leads to stricter sanctions on the coal sector worldwide. Therefore, using domestic reserves of coal sustainably, gasifying it along with using Carbon Capture and Storage (CCS) provides an opportunity for India to use its natural resource at a relative discount to other fuels such as oil or natural gas. Coal gasification produces 31% less CO2 emissions, 98% fewer SOx emissions, and 84% fewer NOx emissions than a coal plant. Moreover, if CCS is used, emissions can be virtually eliminated. Therefore, developing coal to chemicals industry in a sustainable fashion is much in the interest of India. The low cost of coal in India provides an opportunity to produce a range of products from coal, such as methanol, olefins, DME, and others, at a competitive price.

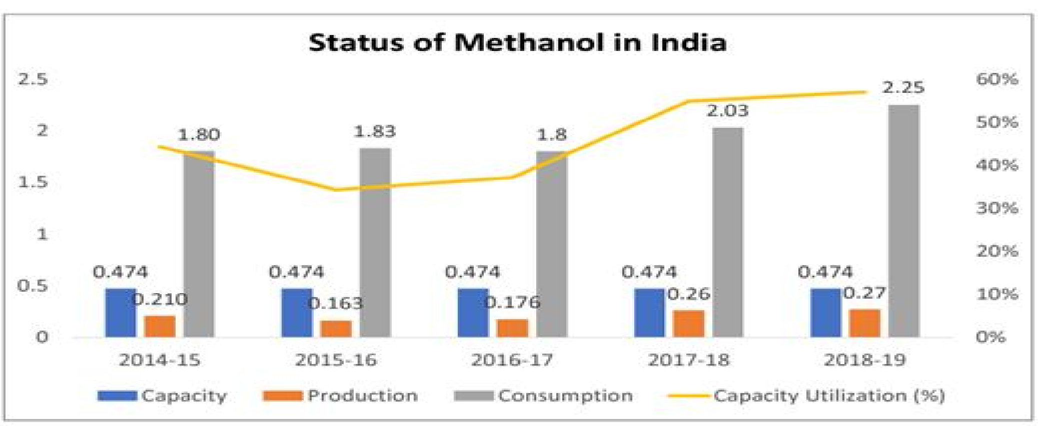

Figure 6. Methanol Status in India (source: Niti Ayog)

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From the above graph, it is clear that 90% of the methanol demand in India is met through imports, whereas the capacity utilization of domestic plants in India hovers around 45-50%. The reason is that the domestically produced methanol (from natural gas) is not competitive with the imported methanol, mainly from the gulf, where natural gas is abundantly available at meager prices. Methanol consumption has increased at a CAGR of 7% during the past five years. There is a high latent demand for methanol in India.

If India were to produce methanol from coal at a competitive price, methanol could be readily consumed in the chemical and petrochemical sector.

Methanol imports have grown at a CAGR of 5.4%, and the import value is to the tune of $700 Million in 2018-19.

Therefore, domestic production of methanol derived from coal will be an opportunity for India to substitute methanol imports.

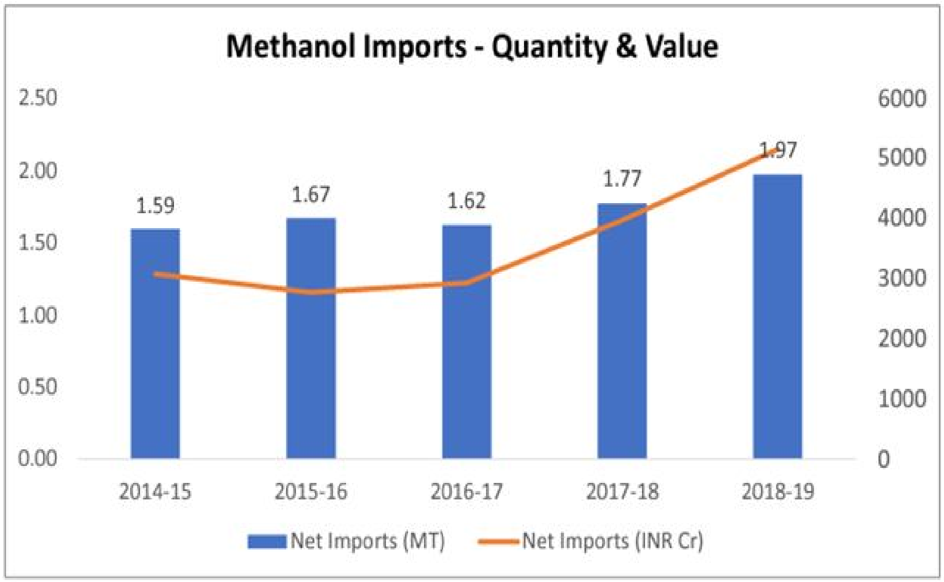

Figure 7- Methanol Imports - Quantity & Value (source: Niti Ayog)

VII. FUTURE PROJECTIONS OF DMFCs IN INDIA

Fuel cells are electrochemical devices that efficiently and cleanly convert a fuel, such as methanol, into electricity without burning. The fuel cells are permanently built into a notebook computer in the space where the battery is now. A small disposable fuel cartridge is inserted into the computer, which provides the fuel for the fuel cell.

The advantages of a fuel cell are longer-lasting power compared to a rechargeable battery, quick recharging by simply replacing the disposable fuel cartridge, non-toxic disposal, and lightweight. As a result, methanol fuel cells are in the process of development by many companies as a new, clean alternative power source for portable electronic devices. Fuel cells offer freedom from the electrical grid, which is essential for many business and professional applications.

Methanol fuel cells and fuel cartridges are efficient, clean, and safe. The US Department of Transportation and The International Civil Aviation Organization have approved to be carried on airplanes. These approvals are expected to encourage faster and more widespread adoption of fuel cells for portable electronic devices.

A. Patented Clean Energy Technology

DMFCC has licensed an extensive portfolio of direct methanol fuel cell patents from the Pasadena-based California Institute of Technology (Caltech) and the University of Southern California (USC). Caltech manages NASA's Jet Propulsion Laboratory (JPL), where the direct methanol fuel cell was invented in collaboration with professors at USC. There have been 65 issued patents and 33 pending patents. These include direct liquid hydrocarbon fuel cells (including direct methanol fuel cells), electrode construction, membrane electrode assemblies (MEAs), fuel cell systems, methanol sensors and filters, water recovery, monopolar geometry, and electrolysis of methanol to form hydrogen. Access to these patents is needed for companies making, using, or selling direct methanol fuel cells. DMFC also has several patent applications pending on disposable fuel cartridges, valves, and connectors to fuel cells.

B. Business Partners

The development of the global production infrastructure, distribution, and filling of disposable methanol fuel cartridges are all priorities for the Direct Methanol Fuel Cell Corporation and its collaborators. The general use of fuel cell-powered products depends on this global capability. The manufacturers of DMFCC's cartridges are reputable, experienced providers to many different industries, including electronics OEMs. DMFCC may provide patent protection for OEMs and producers of direct methanol fuel cells and other liquid hydrocarbon fuel cells. DMFCC will collaborate with electronics and fuel cell producers worldwide to sell their fuel cell products within budgetary constraints.

1) DMFCC has partnered with Samsung and many other companies engaged in fuel cell development and its applications. DMFCC is forming a worldwide supply infrastructure of cartridge manufacturing, methanol filling, and distribution to support the ongoing needs of our customers, including the commercial introduction of liquid fuel cells as an economical and environmentally friendly alternative to traditional batteries. With state-of-the-art proprietary products, a global network of manufacturing partners, and a comprehensive suite of fundamental fuel cell patents, DMFCC has a mechanism to commercialize this exciting new technology. Since the cartridges are a disposable consumable item, they are analogous to razor blades and printer cartridges and, as such, represent a significant ongoing recurring revenue stream. According to Frost & Sullivan, the market for commercial fuel cells is expected to reach more than $600 million by 2013.
2) One of the top suppliers of direct methanol and hydrogen fuel cells for stationary and mobile hybrid power solutions is SFC Energy AG. It is a thriving, sustainably produced fuel cell manufacturer with its Clean Energy and Clean Power Management business sectors. In the market for fuel cell technology, SFC Energy AG has established itself as a pioneer and significant innovation driver. With its direct methanol fuel cells, it best meets the demanding needs of its clients. The company has sold over 55,000 fuel cells and distributes its award-winning goods globally. The power output range of the power units is 25 W to 1.5 kW.
3) The sole manufacturer of big, scalable Direct Methanol Fuel Cells (DMFCs) with trustworthy fifth-generation products is Oorja:

a) Oorja has been creating high-performance DMFC stacks and fuel cell solutions for more than eight years.
b) In terms of cost, availability, storage weight, safety, and transportation, methanol has numerous benefits over hydrogen. Oorja sells to numerous markets worth several billion dollars where there is a high demand from consumers:
c) Wireless telecom: Supplying cellular base stations with clean, silent backup power
d) Material handling: Extending the battery life of aviation scissor lifts and forklifts.
e) Security, surveillance, and the military all require backup power.
f) Oil and Gas: Instrumentation for pipeline operations.
g) Emergencies, residential and consumer (lights, structures, shelters), microgrids, and distributed energy generation are the future markets.

VIII. CONCLUSION

As we approach the future associated with climate change and building a more sustainable world to live in, DMFCs are one of the technologies that can tackle important issues we are facing right now. Given a chance, DMFCs can equally challenge hydrogen fuel cells and other fuel cells that have gained more demand and popularity in India. Among the fuel cell types, the direct methanol fuel cell (DMFC) is the best candidate than a lithium-ion battery as a power source for future portable applications and is currently being rapidly developed.

The main challenges for society and the economy in the 21st century is adapting to the changes in energy and material resources and lowering carbon dioxide emissions. Concerning the matter, fuel cell technology is discussed due to its high efficiency of energy conversion and its low to zero exhaust emission. For mobile applications, hydrogen-fed fuel cells entail major problems with hydrogen production, storage, transportation, and the fuel network.

A lot of development work still needs to be conducted for DMFCs to be viable for commercial applications.

The parts of the system that require further development are

1) The methanol feed subsystem,
2) New materials to construct a compact and inexpensive fuel cell stack, and
3) Optimization of processes for a more efficient system.

Successful development of the direct methanol fuel cell system would lead to small, portable, low-cost power sources for the military. This is mainly due to its high energy density, simple structure, and high-speed operation. However, the DMFC's widespread application has some significant obstacles that must be addressed.

Methanol crossover (MCO) through the membrane is one of the most prominent technical hurdles, significantly reducing cell performance. MCO is a function of membrane structure and thickness, concentration of methanol supplied, and cell operating conditions. A dilute methanol solution and high current density can effectively reduce MCO. Durability, stability, and cost are also significant factors influencing commercialization.

By using a significant amount of platinum catalyst on both electrodes for more good electrochemical activity, the commercialization of DMFC is not far away. Further investigation into these critical issues is required to achieve reliable DMFC technology in many applications. Improving the proton conductivity through the membrane would help advance the applications for DMFCs.

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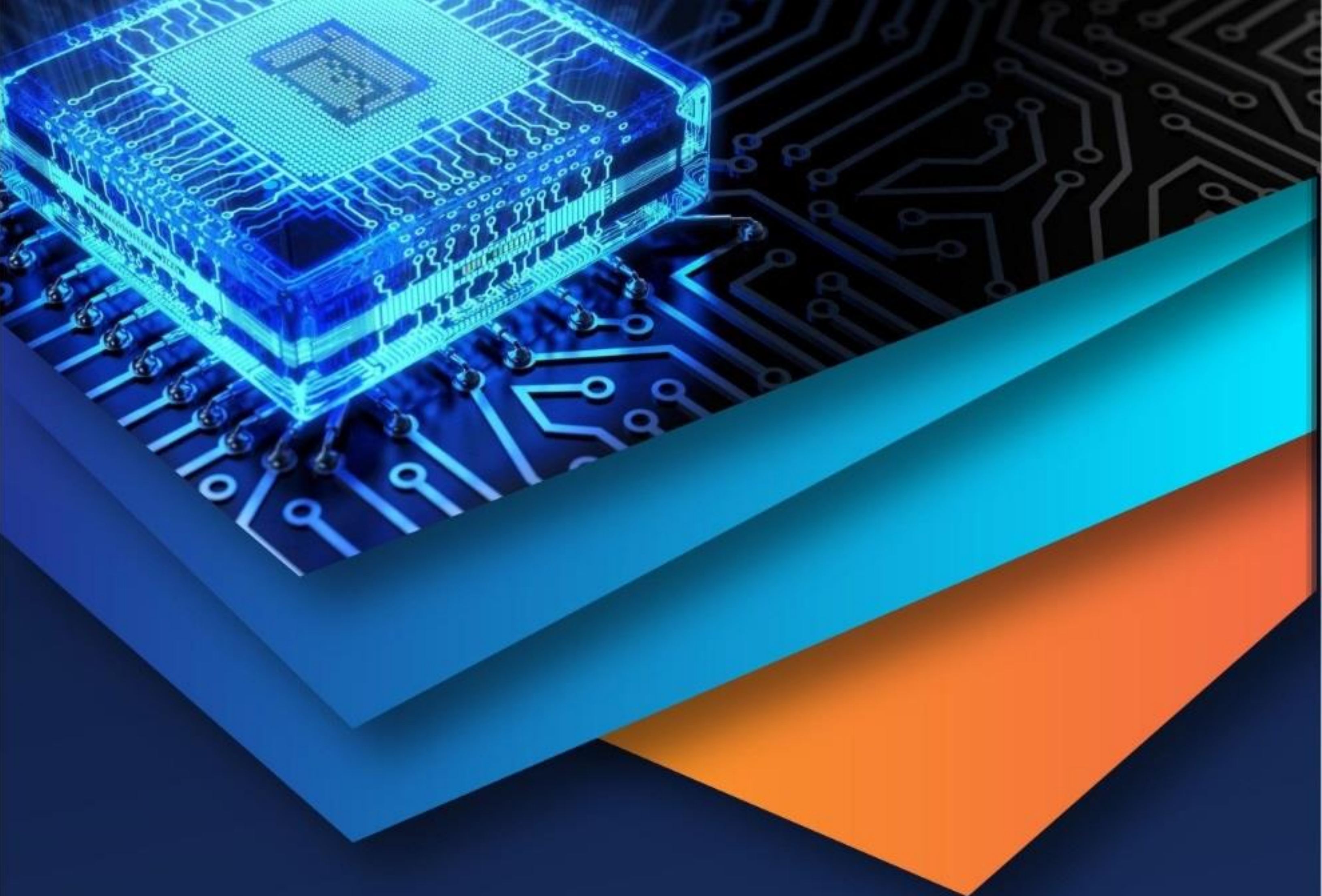

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