



## Microbial Fuel Cells as Source of Clean Energy - Potential and Pitfalls

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### ABSTRACT

Microbial fuel cell (MFC) is one among several other technologies which are being vigorously explored on the assumption that they can achieve pollution control with concomitant generation of 'clean' energy. In this study, the techno-economical problems associated with MFCs have been identified and catalogued in the context of the fuel cell technology in general and MFCs in particular. It is shown that even as the attention of the supporters of MFCs is riveted on the ability of MFCs to generate electricity directly from organic waste, the high costs and the pollution that the making, operation, decommissioning, and disposal of MFCs entails, is not taken into account. Once this is done, MFCs prove not only prohibitively costly but environmentally incompatible as well. In this respect MFCs are one among numerous other waste-to-wealth technologies whose promise was never fulfilled because the energy they generated might have been clean but the process of that generation was very unclean as well as expensive. The study underscores the harm caused by the expectations associated with MFCs and other similar, perpetually 'likely to succeed', technologies because in the vain hope that such options will one day enable 'clean' treatment of waste we keep generating ever larger quantities of waste instead of focusing on what is viable: waste reduction and conservation of resources.

### INTRODUCTION

From 1950 onwards, when the global population began to rise at a much faster rate than ever before, with concomitant increase in consumerism, the quantities of liquid, solid and gaseous waste generated across the world began to rise exponentially (Emmott 2013).

Then, from the 1990s onwards, the global production of goods began increasing at still faster rate with the increasing penetration of globalization. The generation of waste also increased in proportion (Abbasi 2018, Abbasi & Abbasi 2019). Additionally, the world also kept increasing the complexity of the waste it generated. For example, on to the increasing piles of municipal solid waste (MSW), the world began adding ever larger quantities of e-waste, especially discarded computers, cell phones and associated gadgets, which contains many toxic elements (Premalatha et al. 2012, 2014). Those elements are at high enough levels to cause harm to the environment yet not so concentrated that they can be recovered cleanly and economically. This no-win situation has given rise to the informal e-waste recycling sector wherein unskilled and untrained workers, often including children, try to recover valuables from the e-waste in a highly hazardous and grossly polluting manner (Premalatha et al. 2012, 2014). What is not recoverable is added to the municipal solid waste (MSW), making it hazardous (Bedi 2018).

The quantities of plastic waste and packaging material like thermocol and plastic foam peddling are also rising with the rise in e-commerce because numerous goods which earlier used to be bought across the counter are now ordered on-line, making it necessary for the supplier to use large quantities of paper, plastic foam, cellophane taps, etc. on the packaging of each good. Once we unwrap the purchase, we toss all the packaging material, much of which is nonbiodegradable, in the dustbin. It eventually gets dropped into one or the other solid waste pile, adding to its size and to the problems associated with its disposal. The still more recent trend of ordering food online, which is then delivered with an assortment of metal foils, plastic cutlery, and containers - all of which are trashed along with the unconsumed remains of the food - are adding to the rising piles of untreatable garbage.

Parallel to the global trend of increasing waste generation have run the research and developmental (R&D) efforts to utilize the waste (Abbasi 2018, Abbasi & Abbasi 2012, 2018). The hope always has been that if we can find ways to utilize a waste, we can then go on generating that waste *ad infinitum* without causing any harm.

Buoyed up with this hope, R&D efforts have been invested in the possible recovery/recycling/reuse of all types of wastes and their individual components. Some success has been achieved too, but the fraction of waste gainfully

processed has always been insignificant in comparison to the quantum of the waste generated (Abbasi & Abbasi 2012, Premalatha 2015). This is mainly because the processes developed for reuse/recycling of waste are almost always too expensive to be viable. Moreover, in several situations such processes generate problematic wastes themselves, besides only delaying the inevitable dumping of the wastes into the environment. For example, computers reassembled from e-waste eventually go back to the waste after having consumed energy and generated pollution in the process of their remaking and reuse.

Microbial fuel cells (MFC) represent a technology on which enormous efforts and funds are being invested across the world in the hope of finding a way to treat waste which is not only clean but a source of energy as well. But how realistic are the prospects of MFC being any more capable of achieving this magic than scores of similar technologies, which have eventually proved too costly to be of any widespread use? This paper seeks to examine this question.

### Fuel Cells (FC) and Microbial fuel Cells (MFCs): A Brief History

The first-ever report on a fuel cell (called ‘a gaseous voltaic battery’ by its inventor) is credited to William Grove, a Welsh physicist. It was published in a December 1838 issue of *The London and Edinburgh Philosophical Magazine and Journal of Science*.

Grove’s was a device which had two platinum electrodes, each embedded in hollow glass tubes (Fig. 1), which were half inserted in a beaker containing diluted sulphuric acid. Hydrogen was sent to one of the electrodes and oxygen to the other. The gases were consumed at the electrodes; the resultant vacuum caused the sulphuric acid solution to rise and fill the electrodes. While this happened, a galvanometer detected a current flowing between the electrodes (Guaitolini & Fardin 2018).

Almost simultaneously Christian Friedrich Schönbein, a German physicist, also fabricated a similar device but the term ‘fuel cell’ was used for the first time 51 years later, in 1889, when Charles Langer and Ludwig Mond improved upon Grove’s invention and called it a ‘fuel cell’ (Grime 2000). Whereas in other forms of utilization of chemical energy for electricity generation there is an intermediate step in which chemical energy is first converted to heat by the burning of a fuel and the heat in turn is used to generate electricity, a fuel cell directly converts chemical energy into electrical energy. This makes it potentially more energy-efficient *vis a vis* conversion of a fuel into electricity. But the technological problems in the way of realizing this potential have been monumental, and yet to be solved in a cost-effective fashion.

Indeed, after the birth of the term ‘fuel cell’ another 49 years elapsed during which little advancement in the fuel cell technology occurred. Then, in 1939, which was the 100<sup>th</sup> anniversary year of Grove’s invention, Francis Bacon created the first fuel cell which had some limited commercial application. It was based on alkaline electrolyte and nickel electrodes. It generated electrical energy from hydrogen and oxygen in a utilizable manner, and found application for electrical power generation in certain niches applications, which included submarines during the Second World War. Later fuel cells were used in a limited way in the Apollo missions of NASA, USA (Ortiz-Rivera et al. 2007). It was also demonstrated that fuel cells can power tractors, vans, forklift trucks, and taxis but all remained demonstration pieces, and none of them could compete with their fossil fuel driven counterparts.

Even as conventional fuel cells were awaiting inventions during the early twentieth century, which could make them practicable, microbial fuel cell was invented by Potter in 1910 (Ieropoulos et al. 2005). In it Potter was able to generate electrical current by harnessing biochemical reactions caused by microorganisms *Escherichia coli* and *Saccharomyces* spp. (Potter 1912). But the current density that Potter obtained, was too low to be practicable. Only from the 1980s onwards inventions and modifications lifted MFCs from the position of a mere scientific curiosity to

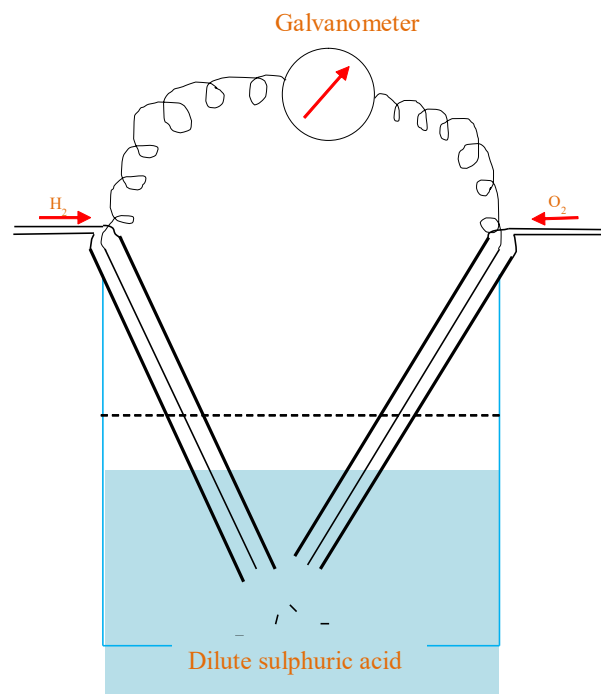


Fig. 1: Schematic of the first-ever fuel cell invented by William Grove in 1839.

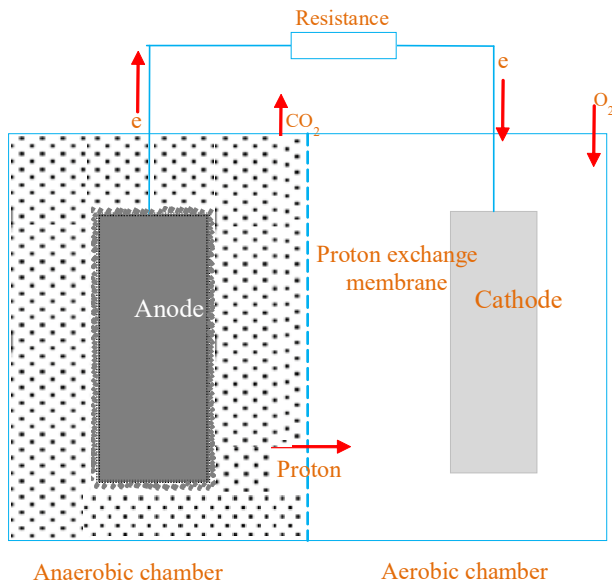


Fig. 2: Schematic of a typical MFC.

something that had a promise of utility in future.

The basic MFC design is shown in Fig. 2. Similar to other FCs, an MFC consists of anodic and cathodic chambers connected by an external circuit for transporting the electrons generated at the cathode to the anode. A proton-exchange membrane (PEM) allows protons to pass through from the anodic chamber of the MFC to its cathode but prevents the oxygen from the cathode to permeate into the anodic chamber. This is essential for maintaining strictly anaerobic conditions at the anode because it is at the anode that the 'fuel' is oxidized by anaerobic microbes, thereby releasing electrons that generate the desired MFC product: an electrical current. Unlike in the FCs, the 'fuel' in the MFCs is not hydrogen but an organic compound (or a mixture of organic compounds as in sewage or other biowaste) which are acted upon by microorganisms to release electrons, protons and  $\text{CO}_2$ . Use of salt bridge can also be done to interface the electrodes in an MFC.

### THE ENCHANTING PROSPECTS

The prospect of turning any waste into a resource has been deeply enchanting, and continues to be so. It is because if we can profitably recycle or reuse any waste, then we can freely generate that waste, without fear of any disposal problem. And organic waste, which includes all forms of biomass, is the largest quantity of waste that the world generates in liquid, semi-solid and solid forms (Abbasi et al. 2012, Abbasi 2018). The energy potentially contained in organic waste is enormous. Its solid form can be directly used as a fuel or can be a raw material for producing so-called 'clean' liquid

fuels such as methanol and ethanol. Its liquid form can yield methane and hydrogen.

Theoretically, each gram of carbohydrate incorporates 1.06 g of chemical oxygen demand (COD). If fully converted to energy, each kg of carbohydrate would yield 4.41 kWh worth of power. But at present, and despite very extensive efforts across the world, only about 23% of this potential is realizable (Pham et al. 2006). Worse, the process of production of the carbohydrate needed to generate this energy itself consumes more energy than it generates; with enormous collateral pollution (Tilman et al. 2009, Abbasi & Abbasi 2010 a, 2010b). Even though it is a small wonder, the prospect of biomass to be a source of clean and affordable energy in future is regarded as very slim (Davis et al. 2018). Where FCs or MFCs provide a glimmer of hope, and induce R&D efforts, is their ability to convert chemical energy directly to electrical energy. That raises the prospect of MFCs converting biomass to electrical power more efficiently than other routes do. But, as brought out in this review, numerous factors make MFC-based energy even more expensive and unclean than the production of gaseous or liquid fuels from biomass entails.

### THE PITFALLS

Very similar to the promises that were seen in the other purportedly 'clean' sources of power - wave/tidal/ocean thermal/solar/ wind/hydrogen energy (Abbasi & Abbasi 2012, Premalatha et al. 2014) - MFCs had appeared infallible when they were in the proof-of-concept stage. So attractive they had appeared that it was hoped that soon MFCs will transform wastewater treatment plants into power-houses. MFCs were also expected to play a pivotal role in the then believed to be inevitable transition from fossil-fuel based energy to hydrogen energy. But hydrogen energy is becoming an increasingly elusive dream; the prospect of it replacing fossil fuels in a big way is becoming more and more remote with every new realization of the problems and the costs associated with hydrogen energy (Abbasi & Abbasi 2011a, 2011b). Much as has happened with hydrogen energy and most other renewable/alternative energy sources (Abbasi & Abbasi 2012, Tabassum-Abbasi et al. 2014, 2016); one pitfall after another was experienced when attempts were made to put the MFC concept into practice and move from small-scale demonstration units to scales comparable with that of conventional energy sources.

Theoretically, an MFC can yield 2.2 kWh/m<sup>3</sup> of reactor size or 2.0 kWh/kg of COD independent of the reactor size (Ge et al. 2013, Zou & He 2018). However, the power actually realized is 20 times lesser than the theoretical potential: less than 0.1 kWh/m<sup>3</sup> or 0.1kWh/kg of COD (Ge et al. 2015).

This is due to multiple reasons, which influence the equation:

$$V_{FC} = V - V_{act} - V_{con} - V_{Ohm}$$

Of these  $V_{FC}$  is the net voltage attained in an MFC (and which is indicative of the cell's energy output),  $V$  is the voltage theoretically possible,  $V_{act}$ ,  $V_{con}$  and  $V_{ohm}$  are voltage losses on account of activation, concentration and Ohmic polarizations, respectively. The combined effect of the three forms of polarization dramatically brings down the MFC energy yield (Guaitolini et al. 2018).

Equally grave is the fact that the energy used to operate the MFCs is more than the energy they generate, leading to a mostly negative energy balance (Zou & He 2018). If life-cycle energy costs were to be computed, including the costs involved in the decommissioning and disposal of the spent MFCs, the energy balance would tilt further to the negative side. Even at small scale of operation, MFCs are besieged with the problems described below; most of these get magnified when scaling up is attempted and the magnification is often greater in proportion to the extent of the scale-up (Goswami & Mishra 2017, Beyene et al. 2018, Yang et al. 2019).

**Cost of the electrode materials and proton exchange membranes (PEM):** Electrodes are among the most influential of the MFC constituents (Palanisamy et al. 2019). They must support bacterial adhesion, electron transfer, and have good electrochemical efficiency. To acquire these virtues the material of an MFC anode should have, (a) low resistance but high electrical conductivity; (b) biocompatibility; (c) corrosion resistance and other forms of chemical stability; (d) large surface area, and (e) adequate mechanical strength. Carbon cloth, carbon paper, carbon felt, graphite rods/plates and graphite fibre brush are among hundreds of materials explored for MFC anodes. As for MFC cathodes, they should be able to capture protons easily and have a high redox potential. Apart from the materials used for anodes platinum (Pt) is suitable but due to the high cost of Pt, and other noble metal catalysts (Goswami & Mishra 2017, Zou & He 2018), substitutes such as iron phthalocyanine have been tried (Cheng et al. 2006). But what fits into the above mentioned requirements is prohibitively expensive while that which is affordable is not suitable for one or more reasons (Goswami & Mishra 2017, Do et al. 2018).

Very similar has been the experience with the other key MFC component: the proton exchange membrane (PEM). What is suitable is prohibitively expensive while the cheaper alternatives have one or more disadvantages that suppress the MFC performance. A PEM in a MFC is required to (a) separate, and act as interface between anode and cathode; (b) minimize substrate flux from the anode to

the cathode while preventing back diffusion of oxygen to the anodic chamber; (c) increase the Coulombic efficiency (CE), and (e) be durable.

A good PEM can reduce internal resistance as also concentration polarization. The Nafion membrane meets with most of these requirements (Hernandez-Flores et al. 2015) but is very expensive. Feverish efforts to find alternatives to Nafion have led to the exploration of ultrafiltration membranes, sulphonated polyether ether ketone membranes, anion and cation exchange membranes, bipolar membranes, forward osmosis membranes, etc. (Rozendal et al. 2006). But none matches Nafion. Salt bridges have also been tried. They are much less expensive but have high internal resistance.

**The problem of internal resistance:** As the size of an MFC is increased, so does the size of its electrodes and the path that electrons have to traverse in it from electrode to electrode. The resistance in the path of the electrons increases in proportion, reducing the power output, too, in proportion. Given that the electrical resistivity of graphite is high at  $1375 \mu \Omega \text{cm}$ , the factor which becomes a major challenge in scaling MFCs (Doherty et al. 2015). Whereas in other waste treatment or energy generation processes, the cost per unit waste treated or per watt of energy generated reduces with increases in scale, reverse happens with MFCs (Yang et al. 2019, Mian et al. 2019).

**The need for a better electron acceptor than oxygen:** Being abundantly and readily available in air, oxygen has been a natural choice as an electron acceptor. Enduring, too. But continuous aeration of the cathode can effect the anaerobic microflora around the anode when an MFC is continuously operated - as it would be in any real-life applications - because cathodic oxygen tends to diffuse through the PEM to the anodic zone (Kumar et al. 2018). Potassium permanganate and ferricyanide have been tried (Yoshizawa et al. 2014) but have not been found practicable. Use of such materials will also increase the waste disposal problems associated with the MFCs. The problem of finding catalysts, which can increase the oxygen reduction rate (ORR), thereby reducing the extent of aeration otherwise done, leads to platinum which is used most commonly for increasingly the ORR. But platinum is exceedingly expensive, and even for a tiny 250 mL MFC, carbon paper containing 20% platinum costs around US \$ 250. And if the MFC is intended to be used for wastewater treatment, there is a serious risk of platinum forming toxic chemicals by reacting with sulfide and other radicals present in the wastewater (Kumar et al. 2018).

**Costs increasing incrementally with design improvements:** As exemplified above by the options that improve

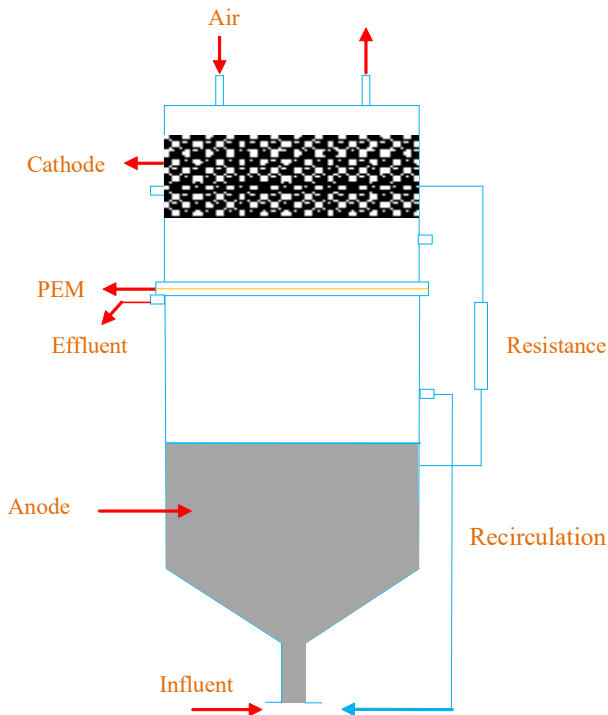


Fig. 3: An upflow MFC.

ORR, most design improvements in the MFCs end up making them even more costly and less practicable than before. For example, the problem of internal resistance mentioned above, can be reduced by employing metal current collectors. But, that would jack up the costs.

Enormous research has been done and is continuing to be done to solve these problems. It includes sweeping changes from the core MFC design (Fig. 2). Two of the many such modifications are shown in Figs. 3 and 4 by way of examples. The experience has been that with every design change if one problem gets attenuated, one or more other problems get exacerbated (ElMekawy et al. 2017, Kumar et al. 2018, Sekoai et al. 2017, Grattieri & Minteer 2018, Guaitolini et al. 2018).

As a means to inexpensively try various possible design modifications, microfluidic microbial fuel cells (MMFCs) have been introduced (Mu et al. 2006, Goel 2018), which are miniaturized systems hence need much lesser material to fabricate (Sackmann et al. 2014). But the physics governing microfluidics is dominated by the concepts of surface and interfacial tension, capillary action and laminar flow. None of these play any significant part in even small, lab-scale, MFCs, let alone higher-scale systems. That designs based on experiments with microfluidic MFCs will work at scale-up better than design based on lab-scale, bench-scale, and pilot plant trials is hard to accept.

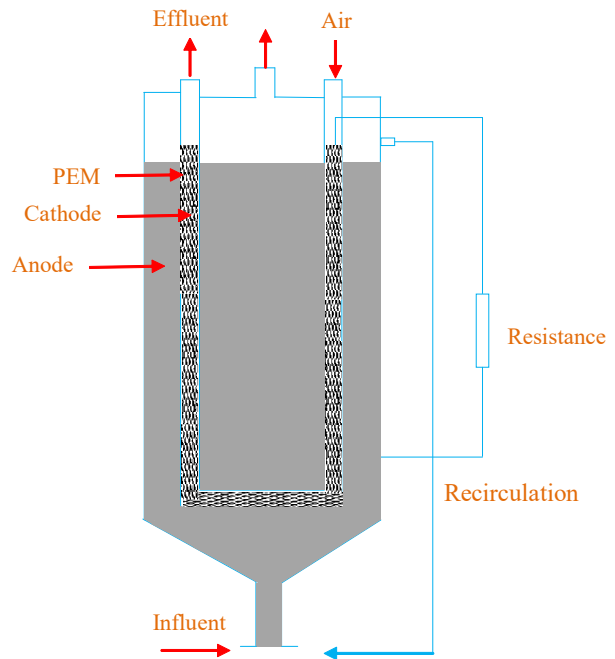


Fig. 4: An MFC with U-shaped cathode.

#### Unviability of attempts at coupling MFCs with constructed wetlands:

Even as the world is yet to see a single real-life waste treatment plant running on MFCs, attempts to somehow find value addition to a technology proving increasingly unviable continue to be made. One such attempt is to integrate fuel cells with constructed wetlands (Yadav et al. 2012, Liu et al. 2013, 2014, Doherty et al. 2015, Guadarrama-Perez et al. 2019). But, the constructed wetland technology (CWT) is itself struggling to final application where it is needed the most, developing countries who can not afford more expensive conventional technologies. Larger land areas required per unit volume of wastewater treated is the single biggest impediment in the use of CWT in these regions.

The situation on the ground is such that even activated sludge process, which is used all over the world for sewage treatment, including in developing countries, and which is 10 times cheaper than MFCs, is unaffordable to the majority of the world's population (Abbasi & Tauseef 2018, Abbasi et al. 2019). Nor has the CWT, with its excessive land area requirement, made any inroads. As a result over 70% of sewage generated in India and other developing countries is being discharged untreated (Sengupta 2018). It is playing havoc with our environment. Even the mighty River Ganga, which till the recent past has been carrying water that had the ability of healing and purifying, has been rendered unfit even for bathing at most of its stretches. Most of Indian rivers, lakes, ponds and coastal areas are being

increasingly polluted by sewage simply because the country can not afford the cost of sewage treatment.

Despite having been around since over 50 years, CWT has not been able to make any impact in India and the rest of the developing world due to its inherent slowness and large land area requirements. Putting MFCs in constructed wetlands will further increase the costs of the CWT systems, making them even less viable than they already are.

The findings of Corbella et al. (2017) confirm this; if coupling a constructed wetland (CW) system with a graphite anode MFC reduces the footprint of the CW by 20%, the cost of achieving it is 50% higher than the cost of CW. If a gravel anode MFC is used, the environmental footprint is twice as adverse as that of conventional CW.

Hence, from the viewpoints of environmental footprints as well as monetary inputs, use of MFCs in CWs only jeopardizes the latter's viability. Moreover, these and most other life cycle assessments do not incorporate the costs of decommissioning/disposal of spent MFCs. Once they are factored in, the MFCs, and most other purportedly 'clean' technologies come out much less clean (Tabassum-Abbasi et al. 2014, 2016). In summary the so-called backward and forward, upstream or downstream, integration of essentially inefficient technologies like MFC and CWT will only worsen each other's unviability.

**Anaerobic digestion is a much more viable alternative:**

There is a similarity between anaerobic digestion (AD) and MFCs but the former is a much more simple and mature technology (Tauseef et al. 2013). Wastewater varying in strength by several orders of magnitude can be treated with anaerobic digestion, with concomitant generation of energy. In contrast MFCs can handle only low-COD wastewater. Moreover, as estimated by Rabaey & Verstraete (2005), the costs of 1kW power per m<sup>3</sup> of anode surface achievable by MFCs is about 10 times greater than equivalent power obtained by conventional processes. For anaerobic digestion, this factor is close to 1. When it comes to the anaerobic digestion of MSW, even the present AD technology is not cost-effective (Abbasi 2018). Yet, and on a selective, lopsided, presumption of cleanness, enormous funds and efforts are being invested (Zheng et al. 2017, Khudzari et al. 2018) on hard-to-succeed technologies like the MFCs that can be more gainfully used in taking the near-viable technologies like solid waste anaerobic digestion to viable stage, and in finding ways to conserve resources.

**THE BASIC FLOW IN THE APPROACH TO ALTERNATIVE TECHNOLOGIES**

**The example of hydrogen energy: How the dream of shifting to a 'hydrogen economy' lies shattered now:** When

hydrogen was promoted as an alternative to fossil fuels, and a hydrogen-based economy was touted to solve the problem of global warming and several other forms of pollution, it was done on the basis of the well-known fact that upon oxidation H<sub>2</sub> provides a benign product water, in contrast to CO<sub>2</sub> and other harmful compounds that are emitted in the use of fossil fuels. The knowledge that generation of hydrogen itself needs fossil fuels, and that the cost of producing, storing, and using hydrogen is several times more than the cost of using fossil fuels of corresponding fuel value, was pushed to the background. It was just assumed, without any basis, that in due course one or other invention will be made, which will enable hydrogen to be generated and used at a cost lesser than that which is associated with the mining and use of fossil fuels. No thoughts were spared for the prospects that hydrogen may pose many other problems besides cost.

Only now, when replacement of fossil fuels with hydrogen is becoming a fast-receding dream, it is being increasingly admitted as to how daunting are the problems of hydrogen's low energy density and very low boiling point. To provide the same total energy as 1 litre of diesel, as much as 8 litre of hydrogen is needed and the container to store it has to be six times heavier than the container needed for diesel (Rigas & Amyotee 2013, Satyapal 2017). A motor-bike running on hydrogen energy will require a fuel tank larger and heavier than the fuel tank of a truck. For the flying of aeroplanes, such large volumes of hydrogen will be needed, and so much weight its containers will add that the planes will have little balance load to carry. There are many other problems that are surfacing, associated with numerous physical and chemical properties of hydrogen, that are unfavourable for its widespread use as an energy carrier (Abbasi & Abbasi 2011a, 2011b, Mukhim et al. 2018). Technology can surmount these problems but each step towards doing so will make hydrogen energy that much out of reach vis-a-vis costs.

**The core problem with FC technology:** The interest in FC technology was boosted due to the 'oil shocks' of 1973 and 1979, which had also rekindled great interest in renewable energy (Abbasi & Abbasi 2000). It was hoped that the ability of FCs to convert hydrogen directly to electricity (something that is not possible with the present manner of use of fossil fuels for electricity generation) will be a great boon to the 'hydrogen economy'. Likewise great effort was put in 'dark fermentation' and other routes of hydrogen production, all the while neglecting the facts that (a) the machines and materials needed in such processes are made with fossil fuels, so it is not really contributing to reduction of fossil fuel use; (b) the production and use of those materials and

machines causes pollution, (c) upon completing their useful life those materials and machines cause disposal problems, and (d) the overall cost of the so-called 'clean energy' is prohibitively high in comparison to the costs of conventional energy. The refrain was limited to the 'cleanness of hydrogen' or the 'prospect of clean energy', ignoring the reality that to produce a small quantity of the so-called 'clean' energy that is generated by technologies like MFC, much greater quantity of unclean energy is needed and much more net pollution is generated. But, sadly, we continue to witness more and more of this hype (Rusli et al. 2018, Bhatia et al. 2018, Shukla et al. 2018, Hua et al. 2019).

**The serious harm inherent in pursuing bioelectrical technologies like the MFCs:** FCs, including MFCs, do generate 'clean energy' in the form of electricity but to produce the electrodes, PEMs, and other fittings much more 'unclean' energy in the form of fossil fuels gets used. After a few years of productive life they generate hazardous waste such as platinum-embedded electrodes which will need further unclean energy to recycle/reuse and, eventually, to dispose. Overall, they cause the use of much more unclean energy than the clean energy they generate. In other words they represent a cure that is worse than the disease.

The most harmful fall-out of the unreasonable expectations attached with technologies like FC, MFC, biofuels, and the like is that the world continues with its wasteful style of living and an economy, which is based on consumption rather than conservation, on the false hope that soon technology will provide a way by which we can continue generating waste and yet not suffer from pollution.

## SUMMARY AND CONCLUSION

In this review-cum-opinion paper, the history of the invention and development of a technology, which is being hotly pursued at present – microbial fuels cells (MFCs) – has been traced along with the changing times which had made MFCs and other variants of fuel cells (FCs) attractive prospects after the oil shocks of 1973 and 1979. In the context of their core design and the attempts of improving those designs, the technical and cost-related problems associated with them are described.

It is brought out that neither FCs nor MFCs are capable of providing 'clean energy' at a cost even remotely comparable with that of conventionally generated energy. They will remain limited to a few niche applications, generating but a tiny fraction of the global energy output. The hope that integrating with other similarly unviable technologies like constructed wetlands will somehow make MFCs viable has no basis on the ground. The paper also emphasizes the fact that unreasonable expectation and effort vested in

these types of technologies is diverting attention from the real global priority that of drastically reducing wasteful consumption of resources as the only viable option which can halt the terminal decline of the Earth's ecosystem.

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## LIST OF ABBREVIATIONS

AD:	Anaerobic Digestion
FC:	Fuel Cell
MFC:	Microbial Fuel Cell
ORR:	Oxygen Reduction Rate
PEM:	Proton Exchange Membrane

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