EC MICROBIOLOGY
Editorial

Use of Microorganisms as Catalyst- Bioelectrochemical Devices

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Microbial fuel cells

Microbial fuel cells (MFC) are bioelectrochemical devices that utilize microbes as catalysts for converting chemical energy in organic feedstock directly into electricity [1]. The utilization of MFCS offer a number of potential benefits that can result in eco-friendly fuel alternatives/supplementation, waste management, bioremediation, biosensors, etc [2]. Despite a multitude of promising studies, MFC development advancement is limited by low power generation, expensive electrode materials, and the inability to scale up MFCs to industrially relevant capacities [3]. Additionally, many factors impact the performances and power generation of MFCs, including electrode material, anode/cathode chamber materials, proton exchange system (PES) properties, pH, temperature and the MFC configuration [4]. Finding a balance between efficiency, cost, and application has resulted in the creation of several different types of MFCs.

There are 2 main classifications of MFCs: mediator types that utilize chemical exogenous electron carriers that transfer elections to the anode, and mediator-less types, that use electrochemically active bacteria [4]. The latter type relies on metal-reducing bacteria that can transfer electrons to the electrode using long appendages called nanowires. Recently, only several species of bacteria have been found to have this ability, including Shewanella and Geobacter [5]. In addition to these types, MFCs can be further classified depending on their configurations or applications. This includes double-chamber, single-chamber, upflow, stacked, soil- based, and phototrophic MFCs [6]. Each one has different limitations, such as high costs, toxicity, bacterial availability, the need for perfect operating conditions, specific applicability, etc. When MFCs are coupled in series or in parallel, the power output generally increases [6]. Additionally, double-chamber MFCS usually have lower power generation than single-chamber MFCs due to their complex design and greater internal resistance, but can be modified as a microbial electrolysis cell (MEC) to produce hydrogen as an alternative fuel source [4]. The MEC produces the most energy and electricity in the United States and will be discuses more in detail later in this paper.

To emphasize the potential advantage of utilizing MFCs, a quantitative breakdown of the energy use in New York State was evaluated. Below are figures taken from the U.S. Energy Information Administration outlining 1) the overall energy consumption estimates in 2019 in trillion Btu and 2) electricity generation by source in April 2021 [7]. By observing the energy consumption breakdown, it is evident that multiple energy sources are utilized throughout the state (Figure 1 and 2). New York State's top consumption source was fossil fuels, and the primary energy consumption source in 2020 in the United States was also fossil fuels (petroleum - 35%, natural gas - 34%, coal - 10%) [7].

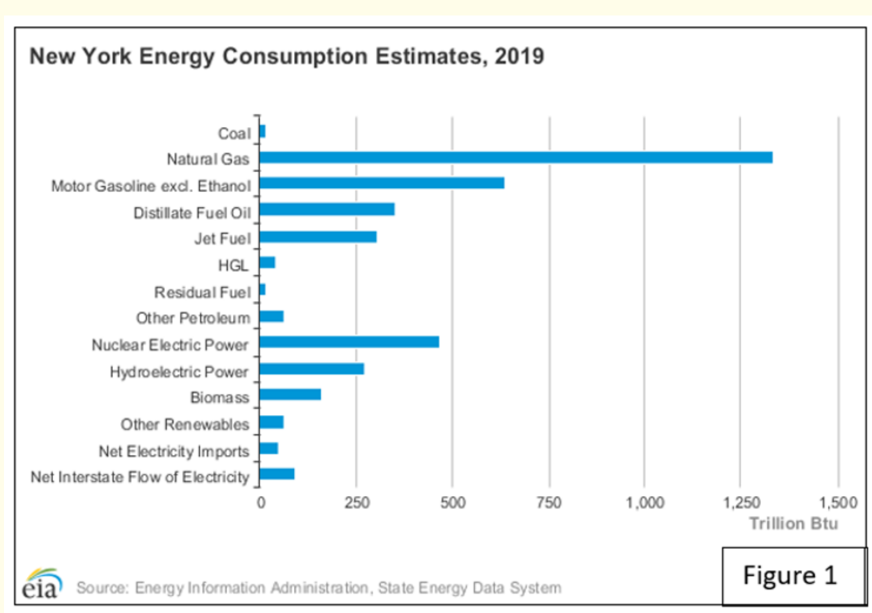

Figure 1

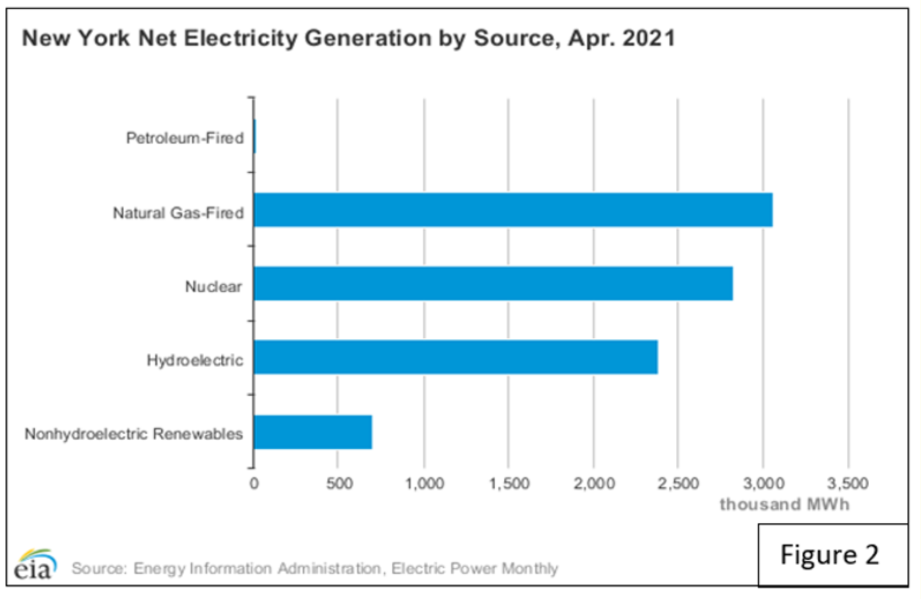

Figure 2

For better comparison, charts were created by converting the data provided by the EIA to percentages to help visualize the consumption and source breakdown. While the majority of energy consumption comes from fossil fuels such as coal, natural gas, gasoline, etc. analyzing the pie charts indicates that electricity only accounts for less than 25% of the total energy consumed annually in New York (Figure 3). MFCs have potential increase this value and offset society's need for fossil fuels by acting as a fuel backup source or supplementation. Upon further evaluation, it appears that no energy in New York was generated using MFCs (Figure 4). This is likely because MFCs are not currently efficient or robust enough to be plausible as a significant source of energy [2].

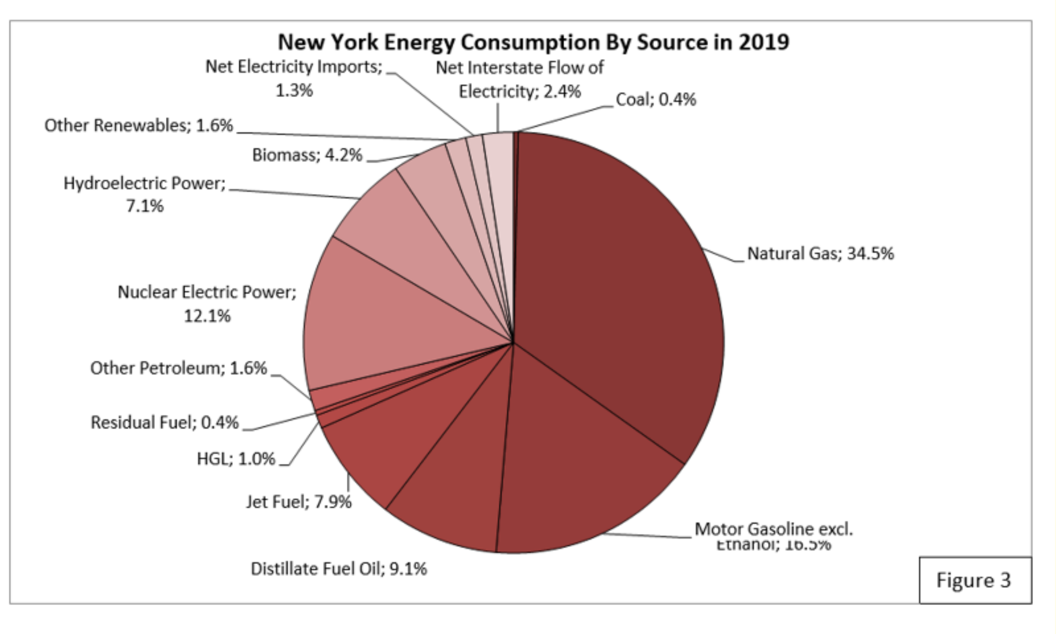

Figure 3

One MFC that seems particularly beneficial is the hydrogen producing microbial fuel cell.

Hydrogen fuel can be produced as a secondary fuel from MFCs through a minor and simple modification. Dark fermentation is an indirect technology in which bacteria can use carbohydrates, proteins, and lipids as substrates to produce H_2, CO_2 and organic acids, through the acidogenic pathway [8]. Combining dark fermentation with an MFC design can results in bio-hydrogen. This is done by maintaining completely anaerobic conditions in the cathode and applying an additional voltage of 0.23 volts or more to the cathode chamber to form hydrogen [9]. These are also known as microbial electrolysis cells (MECs), and the obvious disadvantage is that this type requires an outside power source. When integrated with a proton-exchange membrane, hydrogen and electricity are produced simultaneously [10]. Hydrogen has the highest energy content per unit weight among gaseous fuels, with an energy content of 120 MJ/kg. This is significantly more than gasoline, which has an energy content of just 44 MJ/kg [11]. To take it even further, experiments could be done to genetically modify a consortium of organisms to increase stability and electricity generation. Further research to promote understanding would be worth investing in for this type of MFC, as this concept seems particularly beneficial and should be further pursued. By devoting time and money into more research, the progress of MFCs might be advanced.

England, for example, accelerated its development of MFCs by investigating the possibility of using urine as a substrate. While there were many successful field studies, the first field trial was Pee Power in Glastonbury Music Festival, known as the biggest music festival in the United Kingdom [12]. A self-sufficient lit urinal system was modified and implemented with a stack of 12 self-stratifying membrane less MFC (SSM-MFC) modules [13]. The set up resulted in an average power generation of 242 mW at 156 mA [13]. This indicated that these modules could behave as a conventional power source while handling large quantities of urine. By using urine, useful energy could be produced while simultaneously reducing the burden on wastewater treatment systems.

Despite the success of the trial, the implantation of systems similar to what was tested have several hurdles. In addition to the logistics, the main obstacles that this technology must overcome is the low energy generation [14]. Until the limitations such as power generation, microbial performance, and cost issues can be addressed, it does not make sense to fully commercialize MFCs as a primary fuel source [15]. A future challenge for England is that mass production of MFCs would require significant time, money, and labor for activities such as acquiring MFC materials or building the necessary infrastructure. That being said, the United States might benefit from adopting a similar system of producing energy from urine and microorganisms using MFC energy. Urine has unique characteristics that allow its extensive utilization in MFCs for electricity production, wastewater treatment, and nutrients recovery [16]. In domestic wastewater, approximately 10%, 75%, and 50% of the chemical oxygen demand (COD), nitrogen, and phosphorus, respectively, comes from human [17]. This is considerable despite the fact that urine only makes up 1 % of domestic wastewater [16]. According to MedlinePlus [18], a service of the National Library of Medicine (NLM), an adult produces an average of 1.5 - 2 liters of urine a day.

According to the United States Demographic Statistics [19], there are approximately 209,128,094 adults in the USA. This equates to roughly 314 million - 418 million liters of human adult urine that needs to be treated each year. Even if the energy produced by the MFC is a fraction of what the wastewater plant requires, the electricity produced could offset the overall energy consumption of the treatment plant over the course of several years, especially if the MFC design is optimized. Additionally the sheer volume of urine produced makes it cheap and readily available.

Lastly, the development of MFCs relies heavily on market forces and government involvement. Investing in companies dedicated to the research, evaluation, and implementation of MFCs is crucial for their growth. By purchasing stocks, society is providing such companies with the resources to potentially make groundbreaking discoveries that ultimately contribute to the improvement of MFC design.

However, before providing these resources and investing in these companies, it is important to ask the right questions. For a company building a microbial electrolysis company, questions should include the following: what outside energy/fuel source is being utilized? Can the use of this type of MFC be justified for its application? How will perfect conditions be controlled? How expensive is it to implement?

For a company developing algae farms using wastewater for MFC, questions may arise on the robustness of the bacteria in a changing environment. Given that the algae undergo photosynthesis, how efficient is the system in events of low sunlight? For a company investing in constructing a remote power source, one might question the availability of required materials and the convenience to maintain and oversee its implementation. Lastly, for a company that produces sludge panels like that in Toronto, one might ask what bacteria species is required for both for power generation and wastewater purification, and if the species is readily available.

In summary, MFCs are a power technology that present many advantages over conventional sources of energy. While not economically and practicably feasible at present, the success of MFCs in laboratory studies and field trials indicate that it is a technology worth pursuing.

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