Kelly Shuman

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The Role of Microbial Fuel Cells in Wastewater Treatment

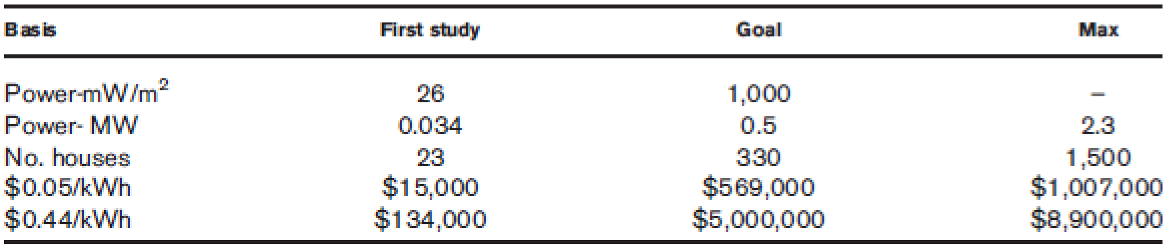
Microbial fuel cells (MFC) are a relatively new method of treating wastewater. There has been no industrial scale projects, yet laboratory and intermediate cases have realized effective wastewater treatment and feasible energy generation. The notion of waste water treatment plants (WWTP) capable of producing their total energy has become appealing as populations grow, electricity costs increase, and blackouts occur. Many anaerobic digestion (AD) units have been constructed at WWTP to reach towards these potential gains, as the technology is mature to predictably implement their use for electricity and heat production. The intent of this paper is to predict if MFCs can be utilized, as WWTP infrastructure is updated or created new, based on economic principles.

Wastewater treatment represents the largest energy user of municipal services, accounting for 35% of energy used by local services. Nationally, this equates to 50,000 GWh of electricity, or 1.4% of the nations total electricity consumption costing $4 billion annually [ACEEE]. In addition, the infrastructure is in need up repair, upgrades and additions. The American Society of Civil Engineers gave the wastewater infrastructure a D- in their 2009 report card. The budget required to repair this is estimated to be $390 billion dollars over the next 20 years according to the EPA. This sets the backdrop for why it is important to design the infrastructure in an energy efficient manner with consideration to the operational and maintenance cost.

Microbial fuel cells can replace the traditional aeration process. Aeration involves aerobic microorganisms that break down the biological oxygen demand (BOD), measured as milligrams per liter or kilograms per cubic meter. BOD is a fraction of the chemical oxygen demand (COD), typically 0.7. The terminology is often interchanged because of practical uses of the term. BOD is only determined after a 5 day incubation period, whereas COD can be measured several times a day to adjust a WWTP operation. It is important to be familiar with the terminology, as electricity is generated from BOD in a MFC. The mechanism for this involves wastewater entering an anaerobic chamber. A carbon cloth anode is covered in biofilm containing microorganisms which metabolize the BOD. A membrane must allow a proton to transport to the cathode for every electron sent, while preventing oxygen from crossing. Proton and oxygen meet on a cathode, treated with a catalyst to combine oxygen from the air thus completing an electric circuit. The amount of power generated is proportional to BOD, area of anode and cathode, membrane resistance, exclusion of oxygen, and detention time [Logan]. This set up constitutes four primary investments: an anaerobic chamber, anode, cathode and membrane. Currently, the cathode catalyst is platinum and the membrane is Nafion^{TM}, both of which incur a significant cost. A more practical MFC might utilize a ceramic membrane and cheap catalyst. An economic competitive technology will not be realized until these materials, or similar can be used.

It has been demonstrated in the literature that the amount of energy required to treat wastewater is equal to the amount that can be harvested [Logan 2008]. Not all waste streams would be suitable for MFC implementation, and so site selection is critical to success. The value MFC's have is where an AD are not economically feasible, or low COD concentration and low temperatures exist. AD units make sense when there is one to several grams of COD per liter [Clark]. As technology progresses, microbial fuel cells may make more economic sense than anaerobic digestion in more situations. This is because from 1 kg COD, approximately 1 kWh of energy can be harvested from AD, whereas MFC have the ability to harvest 4 kWh of energy [Pham]. Because the technology is so recent in development, only 0.06 kWh have been proven. A good benchmark would be 0.9 – 1 kWh in the near future for MFCs. Additional gains come from the fact that the energy derived is in a primary form for MFC, while digestion gas is mixed with carbon dioxide, hydrogen sulfides, and water, which must be removed before efficient combustion.

A preliminary examination analyzing the market value of energy produced by an MFC was conducted by Dr. Bruce Logan of Penn State. His examination considered a city with a population of 100,000 producing 16.4 Liters of wastewater annually. This approximately comes out to 120 gallons a day, which is close to 100 gallons a day specified as the average according to the EPA. Then using the standard of 300 mg/L COD, he calculates there is the potential to generate 2.3 MW, equivalent to 4 $kWh/1kg_{COD}$. This currently not possible, and instead it is better to consider an electrode that produces 1 Watt per square meter. His results show that 0.5 MW could be generated this way, corresponding to energy production of 0.9 kWh/kg_{COD}. Table 1 from Dr. Logan's study describes this information graphically, along with the market value at assuming typical American and European electrical rates.



Basis	First study	Goal	Max
Power-mW/m^2	26	1,000	–
Power- MW	0.034	0.5	2.3
No. houses	23	330	1,500
$0.05/kWh	$15,000	$569,000	$1,007,000
$0.44/kWh	$134,000	$5,000,000	$8,900,000

Table 1: Logan et al. study of MFC

We can now try to determine the initial system cost. Dr. Logan's data was used to determine the square meters of electrodes and membrane required for this plant. A back of the envelope calculation is presented that assumes carbon cloth to be $50/m^2, an additional $50 added to the cathode cost for an unknown catalyst, $10/m^2 for a clay membrane, and an additional $100/m^3 for the anaerobic chamber. The chamber has to be sized to contain the membrane electrode assembly (MEA), and hold the quantity of wastewater for a specified detention time. Literature suggests detention times of 12 hours corresponding to 60 square of MEA per cubic meter . Realistically, only 80% of BOD can be eliminated at the present moment, requiring some aeration.

The cost avoided using MFC is significant to a WWTP. Aeration can consume 30 – 50% of a plants electricity cost, typically requiring 1.2 kW/m^3 [Clark]. Aerobic microorganisms require signicant handling, as their high energy conversion leads to large amount of bio-solids that must be dealt with. This can account for 20 – 50% of plant operating cost. This leads to a significant cost avoided over all. Assuming average energy input, and an 80% reduction in aeration requirements, an avoided cost can be calculated. Table 2 shows additional data for the theoretical WWTP.

Square meters	Cubic Meters	Cost per m^3	Total Construction	Cost Avoided/year	Electricity Value
500000	8333.333	$15,600.00	$130,000,000.00	$662,256.00	$569,000

Table 2: Material quantity and System Costs

A simple payback period (SPP) and simple return rate (SRR) can be calculated from this data as 106 years and 0.9%, respectively. By receiving federal grants and tax credits, this may be significantly improved. This is especially true as infrastructure developments are sited. There is a strong movement to move towards a decentralized wastewater infrastructure. This could lead to a more suburban or rural network. This in addition to the fact that many rural location currently lack infrastructure at all make rural development very appealing. The USDA's rural development programs provide significant incentives, in addition to the more traditional incentives. Table 3 demonstrates the possible outcome of these incentives.

Rural Energy for America	\$50,000
Rural Business Enterprise Grant	\$500,000
ARRA Payment in Lieu of Tax Credit	\$1,500,000
Additional State Programs	NA
Total	\$2,050,000
Net Construction Cost	\$127,950,000.00

Table 3: Available Federal Incentives

This leads to an updated SPP and SRR of 103 and 1%. Clearly, despite wonderful incentives, the initial plant cost must come down before the technology is viable. Assuming an payback period of 20 years is acceptable, then the construction cost would have to come down to approximately \$3000 per m^3 and \$50 per m^2. Better energy capture would significantly improve this figure, at which point a loan structure could be devised. Lowering the initial cost is far more productive now, as this plant is not economically feasible. Models based on other data lead to a much more promising outcome.

In reality MFC s do not compete with AD. Instead, they are very complementary. The lower BOD content from the output of AD is well suited to run a smaller MFC. If these systems are seen as biological lifeforms and WWTPs as eco-niches, then additional elements of biodiversity always prove beneficial to the whole. There is also room for improving the initial estimates of power output. Determining a proper geometry is currently the major drawback, and typical fuel cell limitations are not realized until 15-17 W/m^2. Also, the proper material selection is also critical. Currently, it is possible to obtain carbon brush electrodes on the order of \$0.58/m^2 [Clark]. High values were used to account for unknown costs and different material selection. Overall, the technology is still developing, and could quite quickly provide a better balance. At this point it would be necessary to develop a life cycle analysis (LCA) to compare this technology with other industry leaders.

Microbial fuel cells represent an upcoming means of treating wastewater. Determining their best implementation alone or in conjunction with anaerobic digestion is a necessary first step to determine the parameters by which a system may be economically feasible.

References

Clark Prize Lecture, 2009. Bruce E. Logan Ph.D. National Water Research Institute

Logan, Bruce et al. "Simultaneous Wastewater Treatment and Biological Electricity Generation." Water Science and Technology, 2005. Vol 52, No 1-2, 31-37.

Pham, T. H. et al. "Microbial Fuel Cells in Relation to Conventional Anaerobic Digestion Technology." Eng. Life. Sci 2006. 6, 3, 285 – 292.

ACEEE (American Council for an Energy Efficient Technology). Website, http://www.aceee.org/topics/water-and-wastewater

ASCE (American Society for Civil Engineers). Website. http://apps.asce.org/reportcard/2009/grades.cfm