Frequently asked questions about MFCs and our replies (Logan lab, Penn State)

1. In the paper by Liu, H., Cheng, S. and Logan, B.E. (2005b) Env. Sci. Tech., Vol. 39(14), pp. 5488-5493, you say that you produced your own carbon paper cathode by applying a mix of 5 % Nafion solution and 20 % Pt (E-TEK). From the suppliers I managed to find on the internet (Sigma, http://www.cleanfuelcellenergy.com; http://www.fuelcell.sg/store/index.php?cPath=23_35) there are a range of 5 % Nafion solutions available (e.g. water content is variable, purity). Which 5 % Nafion solution did you exactly use, or does it not matter much?

We used part#274704-100ml Nafion perfluorinated ion-exchange resin, 5% solution in low aliphatic alcohols/H_2Omix, contains 15-20% water.

2. How were the carbon electrodes were connected to the platinum wire. And where did you buy the platinum wires from?

You can use Pt for the wire as we did in early studies, but you can also use titanium as that is much less expensive. We purchased the titanium wire from VWR. The wire we used is: part # AA00362-G5, 0.5 mm diameter, 5 meters length, $264.60 USD, Manufacturer - Alfa Aesar

3. What is the difference between Toray carbon paper, carbon cloth and the carbon paper coated with carbon and PTFE (http://www.fuelcell.sg/store/product_info.php?cPath=23_32&products_id=43)?

Paper is rigid, cloth is flexible. We are not familiar with the paper coated with PTFE.

4. Where did you purchase Vulcan XC-72 from?

We obtained it from Cabot Corporation. A contact is Jesse Kleczka, Technical Service, Cabot Corporation, 157 Concord Road, Billerica, MA 01821, Tel: 978-670-6144, Fax: 978-670-7035, Additional Services Available at CABOTech, , the e-newsletter of fine particle technology.

5. Can you tell us costs and where to get anion exchange membranes (AEM) and cation exchange membranes (CEM) membranes?

The standard size sheet for AEM (AMI is the product) and CEM (CMI is the product) (48" x 120") is $300.00 plus shipping, and a 40" x 40" sheet for $125.00. Contact Dwight at: http://www.membranesinternational.com/

6. Where is the conductive coating that you used in your tubular cathode paper purchased from?

We purchased the conductive coating from Superior Graphite Co of Bedford Park, IL, ~~60638~~. Order ELC E34 Semi-Colloidal $1.455/lb, but you have to buy large quantities (45 lb pails).

7. How do you know you have a good electrical connection between the wire and electrode?

Check the resistance of the electrodes (between the wire with carbon paper, graphite plate or cathode). The connection resistance can be important. Before you setup them into the MFC, you should have resistances with Ti wire and materials on the order of:

Carbon paper with Ti wire: 0.8-1.8 ohm
Graphite plate with Ti wire: 1-2 ohm
Air cathode with Ti strap: about 5 ohm

If you find the resistance is over these values, you probably need to check what's wrong. The followings are some tips for making a good connection:

- Remove the oxide layer on the surface of the Ti where is connected with the electrode using sandpaper
- Before and after gluing the connection point, measure the resistance to see if the resistance is still around the above values

8. How are the carbon paper electrodes connected to the platinum wire in the cubic air-cathode MFCs? Are they glued to the carbon electrodes? Does the wire run all the way down to the bottom of the carbon cloth?

There are two holes drilled to be 1 mm in diameter on both side of the MFC (see the CAD drawing of the cube MFC). The holes are located so that half of a platinum or titanium wire (about 2.5 cm in total length) sticks out through the top, with another part that extends inside the chamber against the wall. The carbon electrode is pressed against the Pt wire, and a rubber O-ring is used to seal the ends. These are not glued. The electrode only touches the wire in one spot and does not run all the way down to the bottom of the carbon cloth.

9. Apparently BASF (which bought out E-Tek) isn't making the carbon cloth air electrodes any longer. Can you suggest other vendors?

We are still identifying alternate vendors. We currently order our carbon paper from Clean Fuel Energy, http://www.cleanfuelcellenergy.com. Our contact is Colleen Spiegel
Another vendor is the Fuel Cell Store. Here are some part numbers and a URL.

EC-CC1-060 - Carbon cloth, 19cm x 19cm, untreated
EC-CCC-060 - Carbon cloth, custom dimensions, maximum 3ft, untreated
EC-CC1-060T - Carbon cloth, 19cm x 19cm, Teflon™ treated
EC-TP1-030 - Toray™ carbon paper, 19cm x 19cm
EC-TP1-030T - Toray™ carbon paper, 19cm x 19cm, Teflon™ treated
EC-TP2-030 - Toray™ carbon paper, 38cm x 38cm
EC-TP2-030T - Toray™ carbon paper, 38cm x 38cm, Teflon™ treated
EC-10-PTC 5grams - Pt, 10wt.% on VULCAN XC-72 Carbon
EC-XC72R-50 - Vulcan Carbon, 50grams

A link to these products:
http://fuelcell.com/index.asp?PageAction=PRODSEARCH&txtSearch=carbon&btnSearch=Search&Page=1

Another alternative is Ballard. See: http://www.ballard.com/Material_Products/

Most recently (11-1-11) we found a relatively inexpensive vendor of toray paper:
http://blog.fuelcellnation.com/2011/10/new-toray-alternative.html

10. Can you describe how the salt bridge was constructed for the work by Min & Logan?

The salt bridge was made using 2% agar in 1M KCl. To make this solution, dissolve 3 g of agar in 150 ml of ultrapure water (Milli-Q water or distilled water), and then add 11.18g of KCl (1mole/L × 74.55g/mole × 0.15 L).

11. I inoculated Geobacter sp PCA in a U-tube MFC as same as your method in the paper (Zuo and Logan, AEM, 2008). But, their electricity generating performance was less than air-cathode reactor. I suspect that some ferricyanide from the cathode chamber was contaminating the anode

chamber, and that soluble Fe3+ reduction and/or CN- inhibition was affecting Geobacter cells. I think pretreatment of CMI membrane may have caused a problem. I conducted both 80ºC (3 hr) sterilization and EtOH sterilization procedures for the CMI membrane. But after EtOH treatment, I needed to dry up the membrane for installation to the U-tube MFC. Could you provide additional information on how to install the membrane and prevent ferricyanide contamination to anode chamber?

Here are some additional suggestions:

1. When you assemble a U-tube reactor, always add a gasket between the carbon cloth anode and the CMI membrane to help seal the chamber.
2. Look down into the tube and ensure that the gasket is continuous around the perimeter of the membrane/tube interface.
3. Pour de-ionized, distilled water into one side of the tube and let the tubes sit overnight. Inspect for leakage to the other side. There should be no water loss.
4. Don't use EtOH for sterilization.
5. Don't autoclave a completely sealed and capped system. Autoclave the system with the tubes open but covered with aluminum foil for fifteen minutes at 18-20 psi and 121ºC.
6. Visually inspect and recheck the seals after autoclaving as in steps 2. and 3.
7. Use a needle inserted into the caps when sealing to reduce the pressure inside the tubes.
8. Inject to anode first with a gentle pressure, then pour ferricyanide into the cathode and cap the cathode.
9. It may be helpful to use large rubber gaskets and membranes to be sure that you completely seal all areas.

12. Why do you add a carbon base layer between the carbon cloth and the PTFE layers? Can I coat the four PTFE layers directly?

A carbon base layer helps to reduce water loss and oxygen diffusion into the reactor, and form a better interface for oxygen reduction, resulting in increase in both CE and power. You can coat only the four- PTFE layer directly, but may not get as high a CE.

13. Why you not add a carbon based layer next to the catalyst layer? I have read many articles about the electrode assembly for the PEMFCs, and I find they all add a carbon base layer between the catalyst layer and the carbon cloth in order to improve the operating factor of the catalyst. And this layer, usually is called micro-porous layer. Would it be helpful, if we added the micro-porous too, between the catalyst layer and carbon cloth?

What we add is a mixture of carbon powder, binder (usually Nafion), and catalyst (usually Pt) right on top of the carbon cloth. In a PEM fuel cell, there are many approaches but most of them apply the carbon/binder/catalyst layer to the membrane or the cloth and then hot press a membrane to the cathode. The environment of the MFC is much different with that of PEMFC because of the liquid electrolyte (i.e. the anode solution) in the MFC versus just a solid electrolyte (Nafion) in a PEM FC. The air cathode in the MFC needs a thicker catalyst layer and a hydrophobic diffusion layer on the air side of the cathode to prevent water loss through the cathode. Commercial air cathodes have poorer performance when use in our MFCs than the ones we make. But we haven't tried all variations on PEMFCs in our MFCs, so anything new is worth trying!

14. Who is your source for bottle brushes?

[Revised 7-1-10]
We currently purchase brushes from Mill-Rose that we use in our cube reactors, as they are less expensive than brushes we have purchased from others. Contact information is: Mill-Rose Company, **Nate Zappola,** Production Supervisor, 7995 Tyler Blvd, Mentor, Ohio 44060, (800) 321-3533, http://www.millrose.com/. The carbon fiber used to make these is Zoltek, Panex 35, which is .000283" (7.2 microns) in strand diameter. We usually order quantities of (50) to get the pricing below.

- 14-mm (brush diameter) x 25-mm (brush length) x 50-mm (overall length); part #310840; $3.59 each
- 25-mm (brush diameter) x 25-mm (brush length) x 50-mm (overall length); part # 311629; $4.00 each
- 60-mm (brush diameter) x 70-mm (brush length) x 150-mm (overall length); part # 313830; $4.20 each

In the past we have used Gordon Brushes, part number 499278, for bottle brushes. Sonia Rojas is the contact there, (800) 950-7950 extension 100, sonia@gordonbrush.com.

15. *Carbon cloth is expensive. Is there an alternative material that I can use?*
Yes, you can use carbon mesh for the anode. Carbon mesh is very inexpensive and costs only ~ $10-50/m^2 depending on the vendor. See the paper by Wang et al., 2009, *Environ. Sci. Technology* (it is on the website). We obtained our mesh from Gaojieshi Graphite Products Company, Ltd in Fujian, China. Note that this material needs to be heated in an oven to produce good results. We use 450oC for 30 minutes. Other times may work as well. You can get these temperatures in an ordinary oven on the self cleaning cycle. Alternatively, just heat as high as it goes (about 450°F) and use a longer period of time.

A US vender that might produce the same results (we are not sure) is Jamestown distributors. See their link below.
http://www.jamestowndistributors.com/userportal/search_subCategory.do?categoryName=Carbon%20Fiber&categoryId=522&refine=1&page=GRID

Another person has suggested PANEX® 35 Tow Weave Carbon Fabrics:
Zoltek Corporation, 3101 McKelvey Rd., St. Louis, MO 63044, www.zoltek.com
Tel 314-291-5110 Fax 314-291-8536. Inquires for product and pricing: sales@zoltek.com

For the cathode, you can make cathodes from stainless steel mesh, carbon black and a binder. See the paper by Zhang, F. T. Saito, S. Cheng, M.A. Hickner, and B.E. Logan. 2010. Microbial fuel cells cathodes constructed from stainless steel mesh that use poly(dimethylsiloxane) diffusion layers. *Environ. Sci. Technol.* 44(4):1490-1495.

16. *Can you recommend a supplier for Pt and for Pt on carbon?*
Last time we checked, it is still possible to order Pt on carbon, or C1-10 10% Pt on Vulcan XC-72, from BASF, which is what we are using in the lab.

For Pt prices, you need to email claudia.m.ortiz@basf.com. The price varies according to the current price of Pt. If they have it in stock there is a 50 gram minimum, if they don't have it

in stock, it will be a 100 gram minimum. Contact information for BASF Fuel Cell, Inc, 39 Veronica Avenue, Somerset, NJ 08873; phone: 732-545-5100

17. *I want to make a really cheap MFC. Can you recommend how to do this?*
See the website on different approaches taken by students. Recently a very inexpensive MFC was built using earthen pots and stainless steel mesh. These materials are probably available at your corner hardware store. See Behera et al., 2009, "Performance evaluation of low cost microbial fuel cell fabricated using earthen pot with biotic and abiotic cathode. *Bioresource Technology*, doi: 10.1016/j.biortech.2009.07.089. Also, see comment #20 below.

18. *I'd like to get some glass bottles made with side ports and I'm not at a university. How can I do that?*
We recently have worked with a vendor that does custom glass work at very reasonable prices. Our contact information is as follows: Sherry Schwenger, Mgr, Sales Administration, Tech Glass Company Inc, 592 NW Blvd, Vineland, NJ 08360, 1-877-691-7846 toll-free, http://www.techglassinc.com/tech.htm

19. *I would like to set an electrode potential, but I can't afford an expensive potentiostat. Is there an inexpensive alternative?*
Option 1: We've never tried this, but Prof. Daniel Bond (University of Minnesota) recommended in a paper that experiments can be "conducted without a potentiostat by using a precise power supply, a relatively small working electrode, and a reference electrode that acts as the electron sink (or source). In this case, a working electrode can be suspended in a small anaerobic chamber and connected to the negative pole of the power supply. The positive pole is connected directly to the reference electrode (such as a calomel electrode), which can be linked to the growth medium via a saturated KCI-filled capillary capped by a porous frit. For instance, based on the potential of the saturated calomel electrode at 30°C, if the power supply is set at 0 V, the natural potential of the reference electrode will poise the working electrode at + 240 mV versus the SHE. Changing the power supply to plus or minus 100 mV will alter the potential vs. this reference. Many power supplies that can inexpensively attain the resolution necessary for this application are available, allowing posing of multiple electrodes for a fraction of the cost of using potentiostats. To monitor current, a sensitive ammeter will still be required."
Bond, D. R. in *Manual of environmental microbiology* (eds C. J. Hurst *et al.*) 1137-1146 (ASM Press, Washington DC, 2007).

Additional information from Daniel on this: "The pros are; hook a small (depending on what culture you have, this can be relative, but usually a cm^2 or so) working electrode up to a good sized calomel reference, and even in the absence of a power supply, the working electrode will be held at +0.24 V, period. Check the current with a sensitive ammeter, and you can have batches of these in the same reactor, or separate channels, with very little electronics. It works great so long as you are using small working electrodes/anodes, since you don't want to overwhelm the reference electrode which is acting as your sink. Plus, we always check our reference electrodes against a lab master reference to make sure they hadn't been used up (the voltage difference between two reference electrodes should be less than 5 mV). Cons: You do use up the reference electrode, and either have to regenerate electrochemically it or toss it

(in the long run, can get $$). If you want to poise the potential higher or lower than the reference, you wire in-line a power supply to boost or push back a few 100 mV, but off the shelf power supplies are usually not as accurate as a good potentiostat (more like +/-10 mV)-- this makes the amperage measurement noisy, so when you want clean data, you end up using expensive electronics again. And, if you get a good culture that is roaring along making a lot of current, the resistance of the frit in the end of the reference can be the bottleneck. It's pretty much a get-what-you-pay for setup, using something in a way it is not really designed for.

… I still use the reference trick for demos at schools or science fairs, or when I want to set up a set of independent electrodes for screening when we have a crazy idea. I think people always want to use larger electrodes, which can overwhelm this kind of system, and that is the main cautionary point."

Option 2: There is now a way to build an inexpensive potentiostat. You can find information on this on the webpage of Dr. Largus Angenet, of Cornell University. See the website: http://angenent.bee.cornell.edu/potentiostat.html
This potentiostat has only one channel, but it can be used to set potentials. The paper describing this is Freidman et al. (2012), "A cost-effective and field-ready potentiostat that poises subsurface electrodes to monitor bacterial respiration". *Biosens. Bioelectron.* **32**, 309-313.

20. *Where can I buy an MFC?*
We know of several places now where you can buy MFCs that can be used without additional purchases, or you can get the materials yourself.

Places to buy them:

- **PhyChemi** sells single chamber MFCs of the same design that we make our single chamber systems. A link to their site is http://www.phychemi.com/en/cp/class/?76.html These are the only place I know of to buy our cube type MFCs. They also sell a very nice two-chamber system as well. Full contact information is: Phychemi Company Limited, 23/F, Seaview Commercial Building, 21-24 Connaught Road West, Sheung Wan, Hong Kong, Tel: (852) 2816 7037 ext. 625 (Hong Kong), (86 10) 6040 4693(Beijing); Contact Andy Yan, Cell: (86)189 1057 1718, email: andy.yan@phychemi.com; website: www.phychemi.com; phychemi.instrument.com.cn
*Update: It is difficult for people outside of China to buy these. My colleague in China wrote that you can buy them from Taobao: "*Taobao is the webstore, and I also have purchased reactors from the Phychemi webstore in Taobao. It seems that they can only accept Alipay as the payment method." Thus the challenge is to figure out how to pay for this as we do not have Alipay in the US.
- **KeegoTech** sells a sediment type of MFC (the price was $45 last time we checked). They have a website at http://www.keegotech.com/. This is the only company that we are aware of that sells a pre-made MFC.
- **Cambrian Innovations** sells a kit for a two-chamber MFC. They sell them direct or through Amazon.com
http://www.amazon.com/BES-Research-Kit/dp/B004XVZVDS/ref=sr_1_3?ie=UTF8&qid=1306866512&sr=8-3

http://www.cambrianinnovation.com/products-services/bes-kits/

- **MicroOrganic Technologies** sells systems for ~$100. See their website at: http://microrganictech.com/products/list/microbial-fuel-cell-kits/
- **Carolina.com** sells a fuel cell that works with yeast and a mediator (methylene blue), and ferricyanide cathode, and sells for about $260. http://www.carolina.com/product/life+science/biotechnology+kits+&+materials/transformation+and+advanced+techniques/microbial+fuel+cell+kit.do

Places to get parts to make your own:

- Bottle reactors can be made in custom formats by Adam & Schittenden Scientific Glass,
- http://adamschittenden.com/Microbial%20Fuel%20Cells.html. When we asked about price, we were told "The prices vary with size and number of ports. The glass bottles run from around $170 to $250 for a set of two; the clamp and seal set from $65 to $91. The GL14 caps and port connections are a few dollars. If you need the crimp seal fittings, the price for the glass would go up a bit."
- You can also make very inexpensive MECs, which require a power source, but are better sealed than other reactors (to avoid contact with solution outside of a controlled hood environment). Information on these is currently being published, but contact the logan lab if you need more information. Reference: "Call, D.F., and B.E. Logan. 2011. A method for high throughput bioelectrochemical research based on small scale microbial electrolysis cells. Biosen. Bioelectron. 26 (2011) 4526– 4531"
- **Penn State's Machine Shop**. As a not-for-profit, Penn State does not prefer to manufacture items for sale. In some cases, however, when items are special made and not available elsewhere, they will custom manufacture items. We have our cube-type reactors made at the Earth and Mineral Sciences (EMS) machine shop on campus. The price they would charge (estimated only) for our cube reactors: $205 per complete unit for quantities below 10, for customers that do not charge to a Penn State budget / fund. This includes the 40-mm blocks (central cubes), covers (we call them end plates: one solid and one open for air cathode), o-rings, gaskets, threaded rods and wing nuts. It does not include anodes, cathodes and other materials such as current collectors, wires, etc. This is only an estimate, the EMS shop always charges actual labor and materials for each job. (undated 3-20-17)

21. *Where can I get a fan that can run from the current produced by the MFC?*
You need a few milliwatts to make the fan run. We purchased one from Home Science Tools, 1-800-860-6272, cat#EL-Motor and EL-Propell, which is a 0.5 to 6 V motor (and blade) for $19.25. See https://www.hometrainingtools.com/motor-electric-dc-0-5-6-volt/p/EL-MOTOR/

22. *We are planning to build a single chamber fuel cell, and I have found a source for some graphite felt for our electrodes. However, I am having some trouble finding insulated titanium wire. Could you possibly tell me where your lab gets this? I thought I should stay away from copper because of corrosion and toxicity issues, but perhaps this is not as big a concern if our fuel cells are only in use for a few months.*
We do not use insulated titanium wire because this is very corrosion resistant, and thus it can be in contact with solution. See above for other information about Ti wires (#2). As for copper, you can use it but only if insulated, and where it is not (where it contacts the electrodes) it must be sealed with epoxy (you can get this at any home depot type store).

Copper corrosion can result in false current (corrosion current) or if large amounts, toxicity to bacteria and reduced current.

23. *(1) Is the ammonia treatment described on your website required on the brush anodes? We all recalled you mentioning a heat treatment, but were unsure about this ammonia part.*
    We don't use the ammonia treatment anymore as it is difficult to do and so we just heat treat the brush electrodes at 450 deg C for 30 minutes. This is described in a paper by Feng et al. (Journal of Power Sources 195 (2010) 1841–1844), that I am attaching to this email.

24. *I read your procedure for making the PVA separator, but am looking into any commercially available sheets/membranes. Are you aware of any commercially available PVA sheet?*
    Separators are not necessarily ion exchange materials, and therefore they can be cloth fabrics or other materials such as glass fiber mats. We are not aware of PVA sheets you can buy, but we haven't really looked. It probably would require a commercial lab to custom make sheets.

25. *I am designing a circuit to boost a voltage from MFC. I saw your paper, "Capturing power at higher voltages from arrays of microbial fuel cells without voltage reversal". When I connected the digital output pin from Arduino Microchip to pin1 of DPDC(G5V-2), the output of Microchip is decreased to about 2V while the original is 5V. As a result, the DPDC cannot be switched under this voltage. So I want to ask if you have encountered this problem. If so, how did you solve that?*
    To solve this use multiple pins to output the same 'high' signal to drive the switches. For instance output a high signal (or low signal) to pins 1,2,3,4 simultaneously and then connect these to a column in the bread board, which you then wire directly to the DPDT switches. Depending on how many switches you use, you may have to use as many as 5-10 pins to output your signal.

26. *Has anyone ever done an art exhibit using MFCs?*
    Yes.
    1. An MFC was shown running a fan at the London Science Museum in 2012 to 2013.
    2. There was an art demonstration of MFCs by Mick Lorusso, see www.micklorusso.net, where he exhibited sediment type MFCs running lights.
    3. There is an MFC that move around on water. See http://ivanhenriques.com/2016/03/14/caravel/

27. *How do you collect gases from the MECs?*
    We connect a gas bag via a tube with a needle at the end that pierces a septum or rubber stopper inserted into a hole or access port into the cathode chamber. The gas fills up and the quantity can be analyzed by volume expelled (less accurate) or by a method developed by Jack Ambler (see Ambler and Logan, IJHE, 2011). The gas bags we use are typically 0.1 L capacity, Cali-5-Bond, Calibrated Instruments, Inc.

28. *Could you tell me where you purchase Lexan to make the MFC cube reactors so that they can withstand autoclaving?*
    Lexan is a commercial name for polycarbonate. We get it from McMaster-Carr.

29. Several questions about culturing *Geobacter sulfurreducens* for its used in METs.

a. What medium do you use?
ATCC medium 1957. You can also use freshwater medium (ATCC 2260).

b. Can resazurin be used?
Resazurin won't harm the bacteria, but since it is a redox mediator, we do not use it. You may wish to initially use resazurin to make sure your anaerobic culturing methods are working.

c. How do you maintain bacteria for a long time?
We use standard protocols to store bacteria at –80ºC). You can find more information in: ATCC Preservation Methods: Freezing and Freeze-Drying, available at: http://www.thermoscientific.com/en/about-us/general-landing-page/storing-bacterial-samples-for-optimal-viability.html
The main difference is that we store our cultures in sterile, anaerobic 5 mL serum bottles. Also, we use a final concentration of 15 to 30% glycerol.

e. How do you revive the bacteria after freezing?
We use this method: http://www.atcc.org/How_to_Revive_Cultures.aspx#bacteria2

f. Do the bacteria grow as red aggregates and as a smooth red layer on the bottom of the bottle.
Yes, usually red aggregates are seen in cultures that are younger than those that have formed a layer. We usually grow our cultures in a shaking incubator to increase the growth rate and prevent formation of a film on the bottom of the bottle.

g. Do you use an anaerobic incubator?
We have not done that. We inoculate the bacteria into sealed bottles under an N2:CO2 80%:20% headspace. We also use sterile anaerobic medium sparged with 80/20 CO2/N2. Therefore, you don't need to work in an anaerobic chamber.

h. How often you inoculate the bacteria and in which temperature you keep it?
We usually inoculate the bacteria into growth medium and then wait ~1 week for it to grow. Then we transfer to a new culture sometime during the next couple of weeks. We make additional stocks of the first culture or store it at 4C for up to an additional 2 months. After that it is autoclaved and disposed. The incubation temperature is 30C

i. Do you use special needles or syringe for the inoculation?
We only use sterile needles and syringes for inoculating cultures and making stocks. Everything we use when dealing with pure cultures is pre sterilized. Also we work in an laminar flow biosafety hood and sterilize all surfaces and septa using 70% ethanol. Be careful if you work with ethanol in an anaerobic glove box as it can build up in the gas and could kill your cultures.

29. *Is carbon black essential or can other materials be used?*
Yes, other materials can be used. We usually use Vulcan XC-72 (Cabot Corporation, USA). See the paper by Yu et al, J Appl Electrochem (2009) 39:705–711. She used Ketjenblack EC 300, from Akzo Nobel.

30. *Can you tell us the source of the Lexan used to make the polycarbonate MFCs?*
Here is a complete list of the materials used by the Penn State mechanical shop to make the MFCs: Viton Fluoroelastomer sheet 1/16" X 12" X 24", McMaster-Carr part no. 86075K52; Polycarbonate Sheet 2" Thick, 12" X 24", McMaster-Carr part no. 8574K49; Polycarbonate Rectangular Bar .220" X 2" X 48", McMaster-Carr part no. 1749K32; Viton® Fluoroelastomer O-Ring #218, McMaster-Carr part no. 9464K39; Stainless steel threaded rod 10-24 thread 24" lg., McMaster-Carr part no. 98804A011; Stainless steel wing nuts 10-24 thread, McMaster-Carr part no. 92001A301.

31. *I want to keep the cost of an MFC $200. For the polycarbonate stock, o-rings, anode (Torary paper), tungsten contacts, and PEM, the cost is ~$150. Following your posted procedure for making the cathode, the cost of materials is fairly high (carbon cloth ~$20, Pt/C catalysis ~$55/gram, PTFE dispersion ~$80). I noticed that Fuel Cell Earth sells a 0.5 mg/cm^2 10% Pt carbon cloth electrode (model EC1019-5) for $15. The Fuel Cell Store sells something similar (Product code 1610004) for $23. Could I use one of these as a cathode without further treatment to achieve similar performance? While these electrodes seem to have a PTFE treatment, I am not sure how it compares to the 4 layers you describe.*
You describe fuel cells with and without a PEM. It seems like there are both advantages and disadvantages to including a PEM in these types of fuel cells. Do you have a recommendation for my project. Leaving out the PEM would save some money and simplify the construction. If you do recommend including a PEM (e.g., Nafion 117), does it have to be attached to the cathode, and if so, what is involved?
You don't need a PEM.
The cathode Product code 1610004 should work, but without a "diffusion layer", it will leak water. You can seal it with PDMS (silicone) or you can "hot weld" a piece of gortex fabric to the outside. These are available on my website. The PDMS can't be directly applied as it will soak too much into the cathode, so you mix it with carbon black. (Zhang, F., G. Chen, M.A. Hickner, and B.E. Logan. 2012. Novel anti-flooding cathodes constructed using poly(dimethylsiloxane) (PDMS) binder for microbial fuel cells. J. Power Sources. 218:100-105. Luo, Y., F. Zhang, B. Wei, G. Liu, R. Zhang, and B.E. Logan. 2013. The use of cloth fabric diffusion layer for scalable microbial fuel cells. Biochem. Eng. J. 73:49–52.)

32. *Where can I get graphite felt for MFC electrodes?*
We have not tried this material, but one source is the fuel cell store.
http://fuelcellstore.com/fuel-cell-components/gas-diffusion-layers/carbon-felt

33. *On your website, http://www.engr.psu.edu/ce/enve/logan/bioenergy/pdf/Cathode_093008.pdf, you have a pdf file called* How to make Cathodes with GDL. *You provide materials. Can you suggest some alternatives?*[4-11-16]
The list mentioned is:

Materials

- Carbon Cloth with 30% by Weight PTFE Wet-Proofing (E-TEK B-1/B/30WP)
- Carbon Black Powder (Cabot Vulcan XC-72)
- 40% by Weight PTFE Solution (diluted from 60% solution)
- 60% by Weight PTFE Solution (Aldrich PTFE 60 wt. % dispersion in water)
- 10% by Weight Platinum on Carbon Powder (ETEK C1-10 10% Pt on Vulcan XC-72)
- 5% by Weight Nafion® Solution (Aldrich Nafion® perfluorinated ion-exchange resin)
- Pure Iso-propanol (99%) (Alfa Aesar)
- De-ionized (DI) Water
- Solid glass beads, 3mm in diameter (Propper Manufacturing Co. Inc.)

Daniel W, sales@fuelcellstore.com, provided the following alternatives.

"Carbon Cloth with 30% by Weight PTFE Wet-Proofing (E-TEK B-1/B/30WP) --> Carbon Cloth with MPL (Fuel Cell Store PN: 1595000) We've found through experimentation that this is the closest to the original non-catalyzed ELAT LT1400W.
or: Carbon Cloth Wet Proofed - No MPL (Fuel Cell Store PN: 7302008)

Carbon Black Powder (Cabot Vulcan XC-72) --> Carbon Black Powder (Cabot Vulcan XC-72, Fuel Cell Store PN: 590106-1)

60% by Weight PTFE Solution (Aldrich PTFE 60 wt. % dispersion in water) --> 60% by Weight PTFE Solution - DISP 30 (Fuel Cell Store PN: 72500300)

5% by Weight Nafion® Solution (Aldrich Nafion® perfluorinated ion-exchange resin) --> 5% by Weight Nafion® Solution (Fuel Cell Store PN: 72500221)

10% by Weight Platinum on Carbon Powder (ETEK C1-10 10% Pt on Vulcan XC-72) --> 10% by Weight Platinum on Carbon Powder (HiSPEC 10% on Carbon; Fuel Cell Store PN: 599001)

We also have lots of catalysts that can typically be purchased in as little as 1g http://fuelcellstore.com/fuel-cell-components/catalyst

I notice you have a number of vendors listed in you "MFC Questions" document {this document}. I believe we are lower cost than most of them (e.g. Sigma sells 25mL of D521 for $143 vs our 60 mL for $120).

Note that the websites cleanfuelcellenergy.com has closed. The FuelCellStore sells all of the products previously sold by that site, including materials by Toray, AvCarb, SpectraCarb, and others."

Also, you might consider seeing our YouTube *MFCTechnologies* website, which shows how to make your own cathode with some other ingredients, which may be simpler (but it uses a press).
MFC sites: twitter.com/MFCtechnology; youtube.com/user/MFCTechnology; www.IS-MET.org

34. *Are there any courses based upon MFCs or articles on classes based around MFCs?*
Yes, but not a lot of people have shared that information. One published paper is:
Gadhamshetty, V., Shrestha, N., Kilduff, J.E. 2016. Project-based introduction to an engineering design course incorporating microbial fuel cells as a renewable energy technology. *J. Prof. Issues Eng. Educ. Pract.*, 10.1061/(ASCE)EI.1943-5541.0000272.

35. Can you list other sites where it shows people making MFCs?

Yes, there are several out there. Peter Thuvander peter.thuvander@gmail.com contacted me and provided a link to some sediment/Mud type MFCs that can be used to power an LED light. See: http://www.superaccu.com/