ARPA-E Energy from Wastewater

Breakout Group #3 - Net Energy from Wastewater: Science and Technology Needed, with Associated Metrics

Group 2: Emerging methods of deriving energy from wastewater with associated metrics

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Note: Additional raw reviewer notes are an attempt to capture the flow of the discussion that took place during the breakout sessions. Please pardon any errors in transcription or note-taking.

How much do the kinetics of reactions (such as in microbial fuel cells, anaerobic digestion, enzymatic hydrolysis) need to be increased for widespread deployment? What breakthroughs in the development of new microbes could satisfy this gap?

-Improving the Process—Increasing the net energy
--IT'S NOT JUST THE KINETICS
-introducing large particles
-increasing concentration
-increasing mixing rate
-System stability not just kinetics
-Economics
--Microbial ecology
--pretreatment
--Controlling growth
What breakthroughs in the development of new microbes?
--If hydrolysis is the limiting step:
--Development of strains
--Adaptive evolution in a highly artificial environment
--Augmentation
--Maximize microbial interaction
--Mixing systems

Not just a kinetics, but there are system stability issues, and of course, cost issues. The jury is still out on mixing and limits of its impact on kinetics. Agitation helps.

Solids and pre-treatment - If we can avoid growing too many cells, we can have more easily hydrolyzed and digestible solids. Perhaps you could ideally concentrate in advance.

Yields from aerobic and anaerobic processes are very different. Maybe 50% vs. 10%.

What is limiting factor for anaerobic digestion? Hydrolysis. What limits hydrolysis? Perhaps mass transfer, and surface area?

Microbial approaches face other limitations. For example it took a year to select the right microbes for a particular system. Needed the key organism. Sometimes bio-augmentation works, sometimes not. You have to wait until the organisms adapt. Sometimes bio-augmentation introduces the right organism.
Maybe not right design for 30 days. Perhaps we could develop strains with better hydrolysis capabilities. Or make sure that they cannot possibly washout. How do we measure that?
We only have some idea of what are the best hydrolyzers. Clostridia always washes out after 2-3 months. There might be some aversion to genetically

engineered organisms. But perhaps some sort of adaptive evolution approach would work.
Also, partnerships and synergies between organisms matter. We need to be able to maximize microbial interaction.

That gets at system stability. AD is not always deployed due to low strength front-end. Can we make them stable over the range of ecologies?

If you separate the digestion phases, you can sometime achieve better stability or robustness. You do the souring, then you are at a lower pH. A lot of other organisms then matter. Maybe acidification to produce fatty acids, then leachate digesters can go after solid waste. Separating the different biological activities could be big. Mixing systems that have not been mixed before would be a real breakthrough. We would need to look at the different biological components and reactors.

How could these new microbes be cost-effectively developed and scaled up for widespread deployment?

- Microbial-based technologies are in competition with other technologies
  - Gasification as a replacement for digestion
    - Gas cleanup costs
    - Control through design
    - Char and tar (sludge)
    - Need: Novel syngas cleanup technologies
- Need: Microbes that produce trigl directly from sludge
- Extraction of oils for production of trigl (conversion of lignocelluloses sugars)
- Developed a suite of microbes depending on the wastewater stream
- Capability to blend different waste streams
- Smart digesters
- Widescale deployment: Appropriately scaled for applications: both distributed and large scale systems
- Anaerobic digestion

Gasification and producing triglycerides through fermentation is another approach. Gasification could replace AD. It has lower residual solids production, has a higher CAPEX, though. But syngas cleanup needs to take place. Sulfur, siloxane, ammonia , chlorine will all kill engines. Gasifier design allows some independence of feedstock. They just burn the syngas, usually. To use it in an engine for electricity production would require some cleanup.

For triglycerides, we want as many cells as we can get, since they have the enzymes that we need. Nutrients there are used to grow up the catalyst. To expand this, you need to have enhance extraction techniques.

Aren't there bugs that just eat sludge? Sludge has 4-7 percent lipid content, typically. That can be raised to 10-15%. What about yeast?

Could we develop microbes that produce triglycerides directly from sludge (and can overcome the nitrogen ratio limitation)?

Do we need a matrix of approaches? Do you need a suite of these to happen? Why choose municipal wastewater? Compartmentalization could perhaps be overcome to get the right wastewater treatment streams. Consider the recipes for composters is an analogy. Let's look at innovative ways of using cheap byproducts from other places to combine into the streams to get what we need as a combination.

Mix different reactors, mix different feedstocks – either could be viable pathways. Perhaps you could site a new wastewater treatment plant next to an agricultural or other process with a complementary waste/byproduct stream. How do we condition and blend the waste?
SmartDigesters might be an interesting concept.

We again have the issue with unwillingness to take on any risk at the municipal level.

Maybe you want to use sludge to grow ethanol? But the appropriate approach will vary by location and respective resources and regulatory regimes. AD is proven in Europe. In Hawaii, you want triglycerides. For access to grid, you want to produce electricity. This is hard to answer.

Consider that 80% of farms are less than 100 animals. People have been bringing up the need for small scale systems, not just the need to scale pilot systems up to large scale. Can you, for example, scale AD down?

Google has some sort of "Google trees" concept for visualizing forest resources. Can this help identify and select the carbon to select optimized processes? But people may not want to say what they have outside of a business relationship. How do we get to improved sale and trading of byproducts?

How could these new microbes be cost-effectively developed and scaled up for widespread deployment? What are promising strategies to increase the robustness of these microbes?

- Smart digesters
- Marry the membrane bioreactors and anaerobic digestion (AnMBR)
- Widescale deployment: Appropriately scaled for applications: both distributed and large scale systems
- Anaerobic digestion as an example
  - Immobilization (robustness)
  - Faster flow through (robustness)
  - Separation of reactors (robustness)
  - Phase separation
  - System control for robustness
  - Different strategies for different scales
  - Strategies for concentration of waste streams (e.g., using different types of sludge)
- Systems Biology approach to robustness
  - Growth conditions
  - Genetic sequencing of promising organisms (e.g., methane)
  - Adapting GTL tools

Focusing in on AD, for example. How do you make these robust? Stability is something you want all the time. Otherwise it takes time to restore operations. Some ways to define performance in this area would include:

- Recover within some defined period of time after an upset.
- Immobilization would be one.
- You could specify that you can't wash them out. They are contained in something.

Separating the reactors can help make things more robust, since they can have specialized environments. How would an individual microbe be robust? Or how can the community be robust? High organic loading rate will cause things to crash. Consistency of feed, or some sort of equalization may have to be specified. Phase separation could also be good.

Specialization in system control can help neutralize pH. Digestion is done to meter things, but a farmer won't do that and find a crash.
Robustness may require different strategies at different scales.

Bioabsorption of anaerobic sludge could offer new possibilities. Colloidal and particulate COD. USB has a problem. At cold temperature and you can't run it. We can concentrate the COD. Need to start at EPS. Can you use sludge as bioabsorption to do the concentration of the COD for you? The number one challenge is concentrating. Cheapest thing is sludge itself. Why is anaerobic better than aerobic? How do we maximize the bioabsorption of the sludge.

What breakthroughs and systems would be required to enable the conversion of biomass from wastewater into CO2 + nutriments to grow algae? What species are the most promising? What are the largest costs of such systems? Can things be done to make them cost effective for widespread use?

- Picking species is the wrong way to go
- Strain selection has not been successful
- Modification of existing algal systems
  - Harvesting
  - processing
- Breakthroughs:
  - Sunlight (light driven system)—Amount of area needed
  - Downstream processing (dewatering, lipid processing, etc)
  - Photoreactors (cost reduction)
  - Flow through processes are too expensive
  - Different methods for extraction of oil (self-extraction)
  - Other utilizations for algae

Moving on to algae, since nanofabricating cathodes did not make the cut . . .

Picking species is not the right way to go. Strain selection alone doesn't get us there. Native species always take over. Whatever survives in the engineered environment is what we end up with. You can do an approach that involves slightly stressing a system with pure cultures, but how applicable could this be to the range of WTP needs we could consider?

What about de-watering the algae? Fundamentally, algal approaches are sunlight driven. And they require land. If land prices are high, that makes it difficult. There is algal production in the bay, though. Sunlight is a limit. Harvesting and processing innovations will be required to make it worthwhile. Presently, biomass is of no use. Too dilute in comparison to what comes out of an AD. Hard to concentrate the energy. It appears that harvesting is the main research need.

Photobiorectors are just too expensive for fuel.

It also needs to be considered that you have an avoided energy cost that algal systems allow (treatment that you didn't have to do). Robust native systems running on sunlight could be a global approach. But what is business model to support deployment of a cheap product/approach? Algal systems for cleanup could be given away.

Other issues and technologies

- Attached growth Digesters—
- In North America, need for low temperature systems
- High temperature systems
- Dealing with real wastewater
- Ohmic resistance in large reactors
- What product do we want to produce (electricity, liquid fuels, process heat?)
- Advanced Fuel Cells (specifically designed for biogas)
- MFC(electrode design, oxygen intrusion, packaging, ultra-low/no Pt loading), feedback from pilot plants; What about the nutrients?
- Membrane distillation combined with anaerobic treatment

Open discussion on other technology pathways

- How about an attached growth digester? Something right in the front of the receiving stream. A fixed film approach, perhaps.
- Temperature is a key factor. Why not a system able to work at low temperatures?
- A microbial fuel cell. This will have the same challenges with digestion (microbially, that is), but more challenges with materials. Dealing with ohmic resistances in large reactors. And what product do we want? Electricy, ethanol, dewatering?

What's holding up chemical fuel cells like molten carbonate? Digester gas feedstock in one case. Problems are probably contamination related, and chemical fuel cells.

- If you increase temperature, you increase production. So maybe something at the high temperature range. Can you make a consortium that does what you want. Or better system design for specific populations.
- Define the organisms, how they are regulated under what kind of growth conditions. Goes back to robustness. Has been proved out with bioremediation. More organisms need to be sequenced. Only sequenced organism is ____________ But it is really the genome scale metabolic engineering. It may be that DOE already invested in this and developed a tool for doing this in the bioremediation work. A tool for triglyceride production?

- Algae could be used as a fertilizer, and again, you have avoided energy costs that would have gone into the production of fertilizer.

What would we need to solve microbial fuel cells?
Municipal wastewater the conductivity is very low. You have to close the circuit in the solution. Electrode cathode spacing ends up being critical. Then you have issues like oxygen intrusion. What about a microbial community that doesn't mind that? Electron loss by anaerobic processes. Maximize fixed film surface areas per volume. And getting rid of platinum. A realistic biocatalyst or cheaper metal. These are the main barriers.

What about the nanocenter tools developed across the country? Could they help?

Membrane distillation combined with anaerobic treatment. Can you use the low-temperature waste heat?

Whole concept of system integration.

AD to gasification to genset being done by a group at Stanford.

END OF DISCUSSION