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ARPA-E Energy from Wastewater

Breakout Group #1 - Clean Water from Wastewater: Science and Technology Needed, with Associated Metrics

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

Chair: Benito Mariñas, University of Illinois

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Challenges & metrics (technology)

Metrics for clean water depend upon intended use:
- Industrial Reuse
- Cooling tower/thermo-electric
- Reuse of produced water
- Potable Water
- Irrigation Water
- Non-potable water
- Considerable value exists for maintaining instream flows

- It is easier to get high quality reuse water when high nutrient removals (discharge limitations)
- **Metric should be to maximize N, P from the water and in a form that is available for use**
- Goal: Can we make an energy neutral WWTP within 4 years? Place the box just around the treatment plant. Energy neutral must include embedded energy in consumables – not just electrical/gas energy.
- Is a higher "value" placed on liquid fuels than electrical energy; produced or offset
- An important metric should be SCALABILITY. Lipid extraction from 8 MTon/year of biosolids is the upper bound – what are the bounds on a reasonable facility (upper and lower)

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- Different water streams have different requirements – quality required will depend on where water will be reused
- Impact on cost has been small for bio-energy producing processes so far
- Currently biomass is not the priority, the clean water is. Perhaps paradigm needs to be balanced so that focus can be on energy
- Losing energy in down processing steps
- In Chicago, you can make 200MW plant with the amount of energy available in the WW, but a lot more money is made off clean water produced.

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Life cycle assessment concepts

- Water is unique to a location – promote total water balance concept (LCA approach needed for metrics)
- LCA must consider “existing assets” and not only “new infrastructure”
- New systems should consider how to use existing infrastructure for new applications/conveyances
- LCA must be comprehensive: GHG emissions, gases of human health concern (respiratory inorganics & organics; carcinogens), etc and boundaries must be well developed
- LCA should consider internal recycling and off-site disposal (e.g., off-set of liquid fuels for hauling off biosolids)
- ARPA-A needs to set specific LCA targets beyond GHG (human health, natural resource, global warming)
- How do you incorporate social perceptions (odor / color of non-potable reused water)

- Life cycle assessment required - You cant just look at water – must look at all complementary cycles as well (manufacturing, toxins, etc)
- LCA must include GHG assessment, treatment necessary to remove toxic gases, must be comprehensive. Volatile organics, respiratory inorganics, radiation, ozone, exotoxicity, acidification, minerals, fossil fuels, co2, land use
- Many people have thought it a better idea to produce energy from wastewater in the form of vehicle fuel rather than electricity

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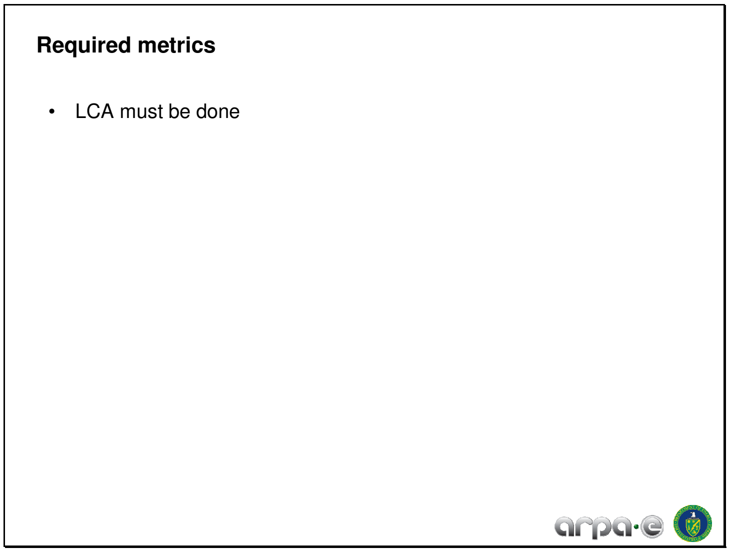

- Benchmark: Strauss Plant is able to generate 70% of its power on-site.
- A metric should be how good a system is at recovering N and P so that it doesn't need to be created to put back through the system. Algae could be part of the solution – the challenge is then it's in the form of biomass, and extraction isn't easy
- Typical biosolids production in WW treatment – 1 dryton/day/MGD

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How viable and promising are bio-energy producing processes (including hydrogen production, bio-electricity and methane gas) in a short-term and long-term perspective?

- Metrics
  - LCA
  - Correlate cost to treat water ($/1000 gal) versus ability to produce energy (kJ/1000 gal)
- Bio-energy production of hydrogen
  - SOUR digestion
- Bio-energy production of Methane
  - This is done already as a by-product of treating water
  - Should we change paradigm – how to maximize energy with clean water as a byproduct?
  - Anaerobic is a net energy producing environment; aerobic is net energy consuming
- Produce trigylcerides from wastewater biomass – as a liquid fuel
- 8 MTon/year (this could be 10-40 million barrels/year of biofuels)

- Of the three, bio-production of methane has the most interest

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How might anaerobic biological processes provide more robust and efficient treatment than conventional aerobic biological processes (e.g., activated sludge) with positive net energy production?

- Anaerobic ties up less N & P than aerobic; Combinations of aerobic/anaerobic could achieve both
- Trace organics – biosorption depends upon biomass levels versus redox conditions that transform the organics
- Some aerobic conditions are net energy producing with liquid fuels as the product, and yet doesn't account for benefit of residual biomass after liquid fuel extraction
- Couple processes, including algae to remove soluble nutrients
- Accept other wastestreams (food, etc) – what is the impact on finished water quality?
- How low can you go in COD before it doesn't make sense because you have to "extract the energy" out of the water
- Metric should be added energy required for thermal inputs for maintaining anaerobic bacteria
- Also cooling of syngas before burning; can you take advantage of incoming WW as thermal sink/source

- Rule of thumb is that with anaerobic you can produce half of your power on-site by feeding produced biogas through a gen-set
- Aerobic systems cannot be net energy neutral is commonly thought, but some people have achieved net positive energy. Liquid fuels have been the product in this case

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Could anaerobic biological technologies and hybrid technologies, such as anaerobic membrane bioreactors (AnMBRs), be better suited than aerobic processes for treating concentrated wastewater resulting from distributed wastewater management (e.g., no dilution of black or black + grey water by storm water)?

- Producing granulars (of biomass) could reduce membrane fouling, rather than other bacterial forms
- Anaerobic systems often lead to increased membrane fouling – what can be done to manipulate the biological system, additives, change of membrane properties, etc.
- Use diffusive membranes to deliver air into air instead of traditional blowers – can we deliver appropriate membrane materials (e.g., hollow fibers similar to H2 or N2 gas addition). The benefit is reduce pressure requirements because you don't have to pump against hydraulic head in the aeration basin – take advantage of diffusive transport
- A metric should include representative pathogens to avoid unforeseen tradeoffs of switch to a new technology – for example, some filters benefit by bacterial mats to improve pathogen removal

- A lot of organics are not tractable to anaerobic reactions, you need aerobic for them. For example, industrial waste will require some sort of aerobic process.
- One deterrent against MBR is fouling in system

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What breakthroughs would be required in advanced membranes, catalysts, adsorbents and/or oxidants made with novel ceramic, polymeric and biomimetic materials for significantly more robust hybrid wastewater treatment technologies that are inert to (bio)chemical attack and irreversible fouling? Could any of these membrane, catalysis, adsorption and oxidation processes be developed such that chemical pre-/post-treatment steps could be eliminated?

- Concentrate COD from dilute WW (e.g., sorbent combined with membrane – subsequent sidestream treatment); reduces thermal and basin volume issues; what goes through and does that require further treatment
- Increasing COD from 500 mg/L to 50,000 mg/L would be great and enable new processes
- Many organics require an aerobic environment, somewhere in a process scheme, to start the degradation process
- WWTPs should embrace advanced enzyme and catalyst concepts used in other biotech industries
- Is a series of membranes, or other systems, helpful in improving net energy balances and improving water quality?
- Highly specific adsorbents for P removal / recovery, or other elements of importance
- Any approach to reduce chemical usage would reduce consumption of embedded energy in these products at the WWTP

- Add adsorbents, membranes, etc to remove COD. This means that instead of treating 100MGD which requires significant energy, you can treat 1 MGD and require a lot less heat input.
- Breakthrough can be in microbial, biology, or microchemisty. 55-60% of constituents in WW is volatiles. If you get that up to 80-85% with some enzyme or catalyst, that would be huge (50% increase)
- Granules may reduce fouling
- There is a limited supply of Phosphorous in the world (estimates say 75-100 yrs left). Try to find adsorbent that could allow you recover usable phosphorous from WW – since it will be a valuable commodity.

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Can treatment efficiency and bio-energy production be maximized through optimizing microbial populations that are responsible for those energy producing steps?

- Covered previously
- Need improved on-line/real-time instrumentation tools/sensors at the molecular level – and what advantages does this have over gross measurements (F/M ratios). Tools for monitoring microbes, enzymes, food, etc
- Digestors are not "nature" and instead "anthroprogenic". Natural selection has not had time to work – tremendous opportunities may exist by studying and better engineering the system. Apply stresses to enhance the natural selectivity of communities. Many organisms have not evolved under "high energy/organics" environment in digestors.
- Stressors could also include micro-trace metals that limit specific enzyme production.
- Going "SOUR" – what is its current use in WWTPs; by products are good for other fuels.
- Systems that produce organic acids are good "pretreatment" for MFCs that require such acids
- Set metrics around "by-products" of certain biological processes which may be useful for high-value products (e.g., specific organic acids)
- Can microbial communities be managed to produce chemicals which are now purchased (e.g., acids or alkalinity consumption)
- Engineered bacteria were not highly considered favorable for WW treatment

- Better instrumentation and controls are needed if microbial communities are to be considered in anaerobic or aerobic digesters
- Microbial communities have NOT been optimized for anaerobic digestion. A lot of room for improvement in activity there. The key is to create an environment that will challenge community. The challenging environment makes them perform better. Adaptive evolution – put the stress on it, and community will improve. Can select for more robust community and optimize for anaerobic digester
- Genetic engineering of microbes will never be acceptable.
- Microbial fuel cells will likely never scale to electricity generation in plants, but smaller cells could help understanding in several different important areas.

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What types of integrated or hybrid systems can be used to maximize treatment efficiency and energy production as well as resource (i.e. nutrient) recovery?

- Highly specific adsorbents for P removal / recovery, or other elements of importance
- Combinations of anaerobic digestion – with algae to take up soluble nutrients
- Trap NO gases – they are GHG
- How do you recover P from phospho-lipids
- **Metric should be to maximize N, P from the water and in a form that is available for use. For any wastewater system**

- If Nitrogen and Phosphorous are the focus, anaerobic is better
- Anaerobic and aerobic do not need to be exclusive. Aerobic handles n2 and phosphorous
- In gasification the syngas must be cooled completely which means significant waste heat
- Take advantage of temperature of wastewater for heat recovery
- Activated sludge back into the sewer results in enhanced primary sediment (San Diego looked at that)
- Reducing chemical usage would reduce consumption of embedded energy

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Could the production of toxic by-products/residues be avoided with novel membrane, catalysis, adsorption and oxidation processes?

- Systems thinking is needed – both to “treat all the water” versus using specific systems to control/limit upsets (MFCs to control organic acids)

- Shortcoming of aerobic systems is the passing through of pathogens and other constituents that microbes don’t react with

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Could new membrane materials with order of magnitude higher water permeability and tunable water/contaminant selectivity be developed for optimal treatment of wastewater-specific complex mixtures of microbial and chemical contaminants? Could any of these membranes, catalysis, adsorption and/or oxidation processes be developed such that chemical pre/post treatment steps could be eliminated?

- Increase use of gas (air) permeable membranes - Use diffusive membranes to deliver air into air instead of traditional blowers – can we deliver appropriate membrane materials (e.g., hollow fibers similar to H2 or N2 gas addition). The benefit is reduce pressure requirements because you don't have to pump against hydraulic head in the aeration basin – take advantage of diffusive transport