Energy Recovery from Domestic Wastewater Using Anaerobic Membrane Bioreactor Treatment

Thursday, June 7, 2018

1:00-2:00 pm ET

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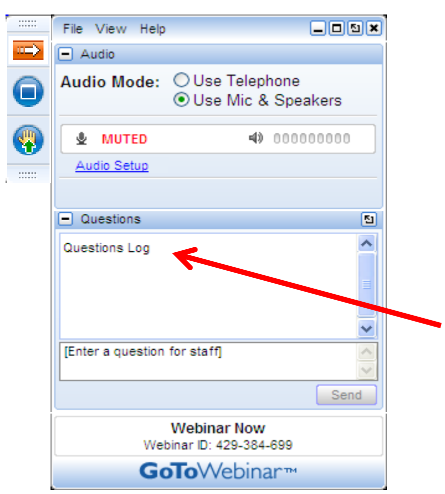
How to Participate Today



- **Audio Modes**
  - Listen using Mic & Speakers
  - Or, select "Use Telephone" and dial the conference (please remember long distance phone charges apply).
- **Submit your questions using the Questions pane.**
- **A recording will be available for replay shortly after this web seminar.**

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Today's Moderator

Christine Radke
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Agenda

1:00 Welcome and Introductions
1:05 Overview of Anaerobic Membrane Bioreactors, *Steven Skerlos and Lutgarde Raskin*
1:15 Pilot Study Goals and Results, *Tim Fairley*
1:30 Biofilm-Enhanced MBRs, *Caroline VanSteendam*
1:45 Questions and Answers
2:00 Adjourn

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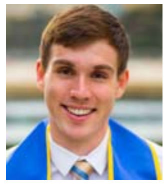
Energy Recovery from Domestic Wastewater Using Anaerobic Membrane Bioreactor Treatment

Lut Raskin
Professor

Steve Skerlos
Professor



Tim Fairley
Environmental Eng.
Graduate Student

Nishant Jalgaonkar
Mechanical Eng.
Graduate Student

Caroline Van Steendam
Environmental Eng.
Graduate Student

Adam Smith
Professor
USC
(Ph.D. UM)

Grants:

WRF – **U2R15** – Next Generation Anaerobic Membrane Bioreactor Development Utilizing 3D-Printing
NSF – **CBET 1604069** – WRF: Biofilm-Enhanced Anaerobic Membrane Bioreactor for Low Temperature Domestic Wastewater Treatment
WRF – **TIRR5C15** – Life Cycle Assessment and Analysis of Biofilm Enhanced Anaerobic Membrane Bioreactor
WRF – **ENER4R12** – Low Energy Alternatives for Activated Sludge – Advancing Anaerobic Membrane Bioreactor Research
WRRF – **10-06D** – Anaerobic Membrane Bioreactors as the Core Technology for a Low Energy Treatment Scheme for Water Reuse
NSF – **CBET 1133793** – Low-temperature Anaerobic Membrane Bioreactors for Sustainable Domestic Wastewater Treatment

MICHIGAN

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Wastewater is a resource of energy, water, nutrients, and other useful product

~~Wastewater treatment plant~~

Water resource recovery facility

Energy recovery
Conversion of carbon to biogas

Water reuse

Nutrient recovery
Struvite ($MgNH_4PO_4$) precipitation

Production of other useful byproducts
Hydroxyalkanoates (bioplastics), alginates

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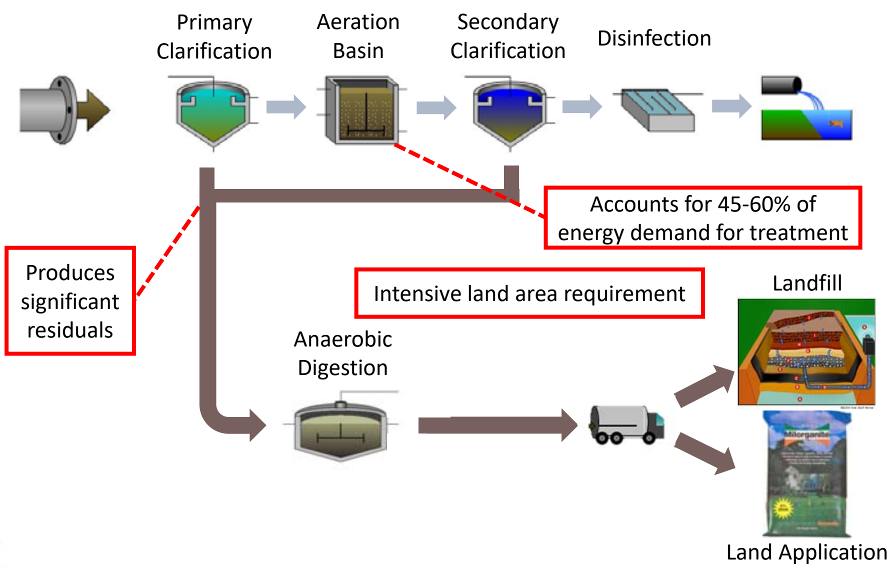
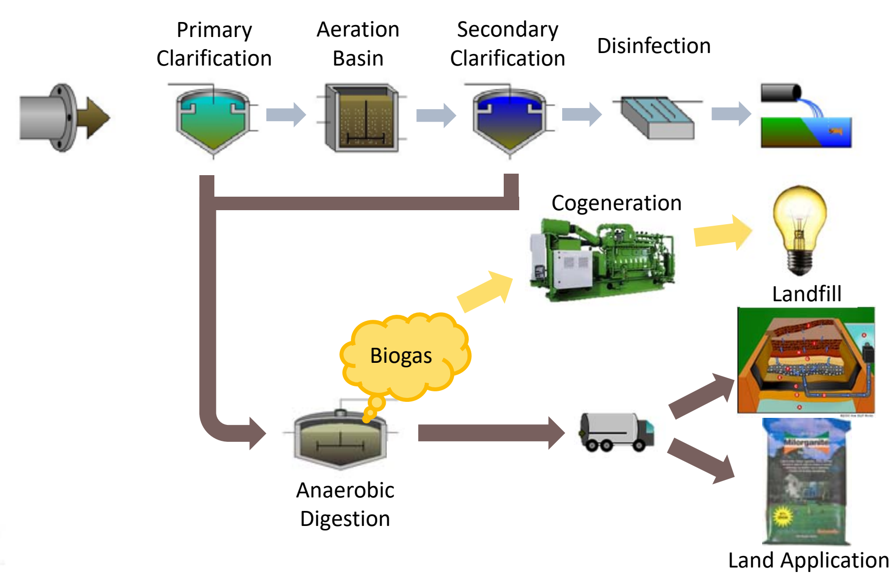
Conventional domestic wastewater treatment

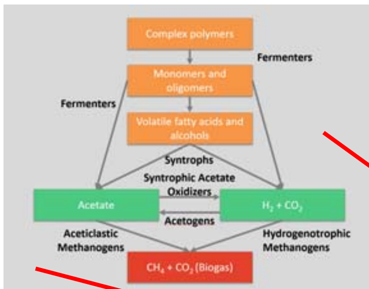


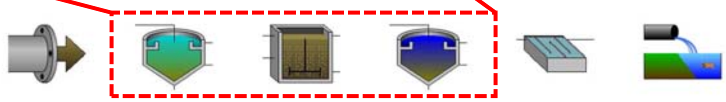
Conventional domestic wastewater treatment with energy recovery



Can anaerobic treatment be implemented in mainstream wastewater treatment?

Upflow Anaerobic Sludge Blanket (UASB)





Challenges

- Solids/liquid separation
- Heating for optimal performance
- Effluent quality

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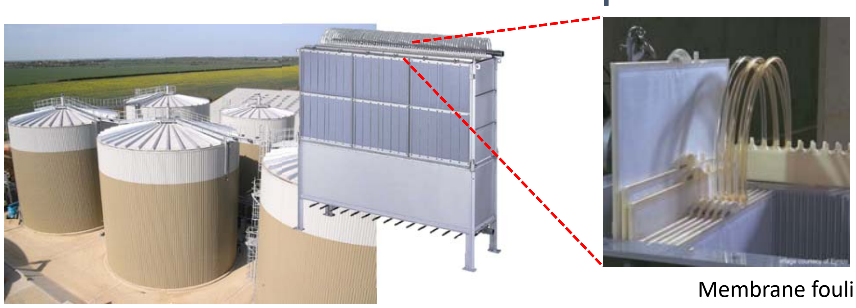
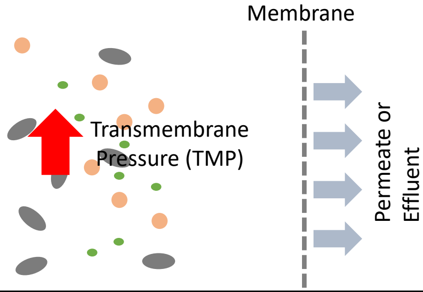
Anaerobic membrane bioreactor (AnMBR) combines anaerobic treatment with membrane separation



Membrane fouling

Biogas sparging



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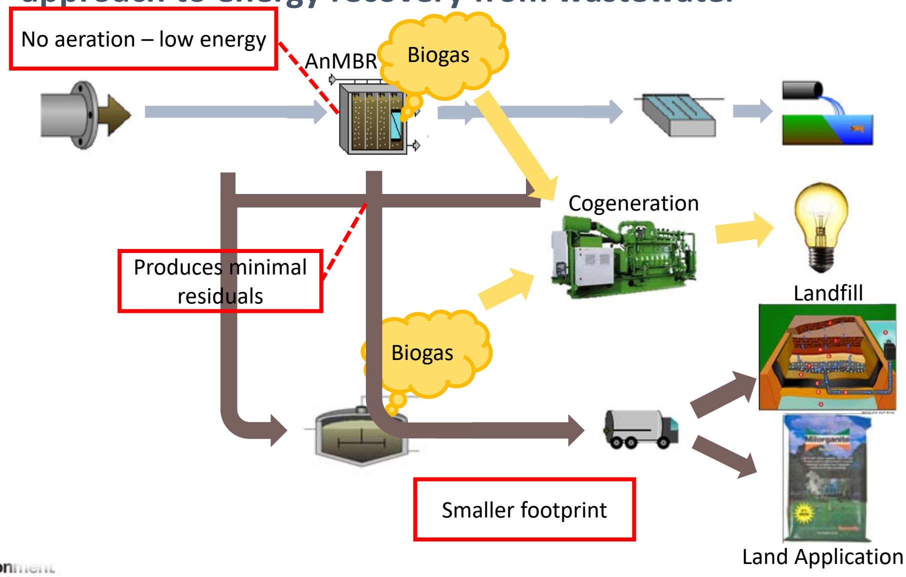
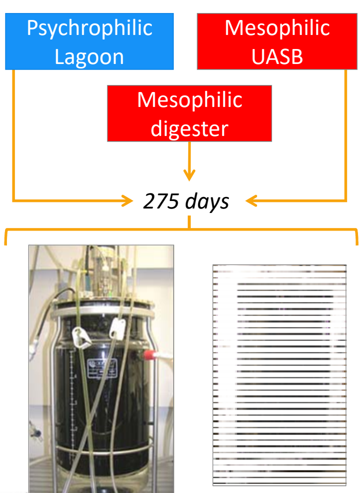
Anaerobic membrane bioreactor (AnMBR) is an emerging approach to energy recovery from wastewater



Smith, A.L., L. B. Stadler, N.G. Love, S. J. Skerlos, and L. Raskin, 2012, Perspectives on Anaerobic Membrane Bioreactor Treatment of Domestic Wastewater: A Critical Review, *Bioresource Technology*, **122**, 149-159.

Bench-scale study:
AnMBR treatment of domestic wastewater at 15°C with submerged flat-sheet microfiltration membranes



Summary of results

Wastewater	Permeate COD (mg/L)	Permeate BOD_5 (mg/L)
Synthetic	36 ± 21	18
Actual	76 ± 10	25 ± 3

- Biogas sparging was effective at controlling long-term fouling
- Approximately half of methane generated was "lost" in permeate
- Psychrotolerant, mesophilic populations dominated in AnMBR

Smith, A.L., S.J. Skerlos, and L. Raskin, 2013. Psychrophilic anaerobic membrane bioreactor treatment of domestic wastewater. *Water Research,* 47, 1655-1665.

Additional questions need to be answered before AnMBR treatment of domestic wastewater will be implemented

1. Can treatment performance be improved?
2. Can operating temperature be lowered?
3. How does AnMBR compare to conventional treatment technologies based on cost, energy, and environmental impacts?

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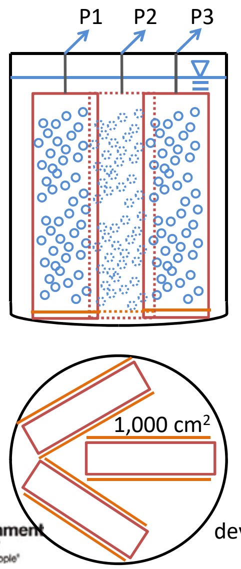
New bench-scale AnMBR study to evaluate questions generated in initial study



- Three submerged flat-sheet membranes
- Biogas sparging for fouling control, independently controlled for each membrane
- Operated initially at high sparging rate for fouling control
- Psychrophilic temperature (15°C)
- **Inoculated with mesophilic sludge only**

Smith, A.L., S.J. Skerlos, and L. Raskin, 2015. Membrane biofilm development improves COD removal in anaerobic membrane bioreactor wastewater treatment. *Microbial Biotechnology*, **8**, 883-894.

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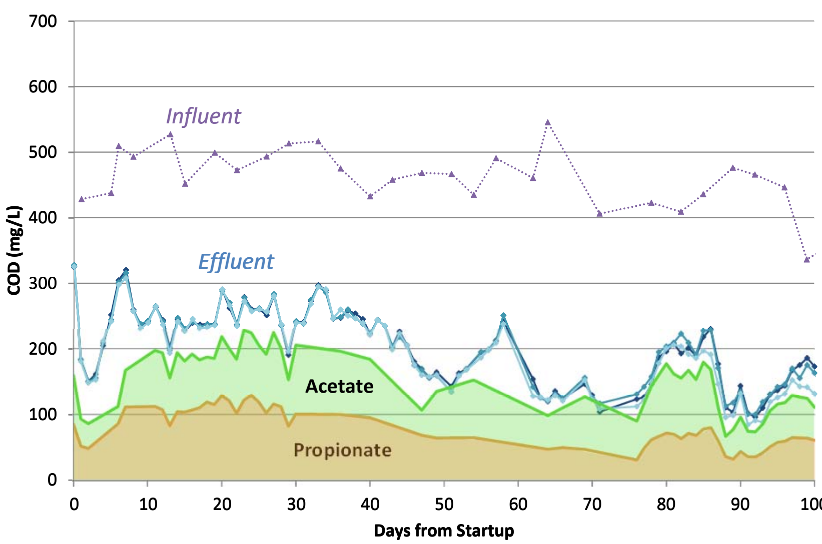
Poor permeate quality during first 100 days of operation

Was limited fouling due to high biogas sparging related to poor performance?



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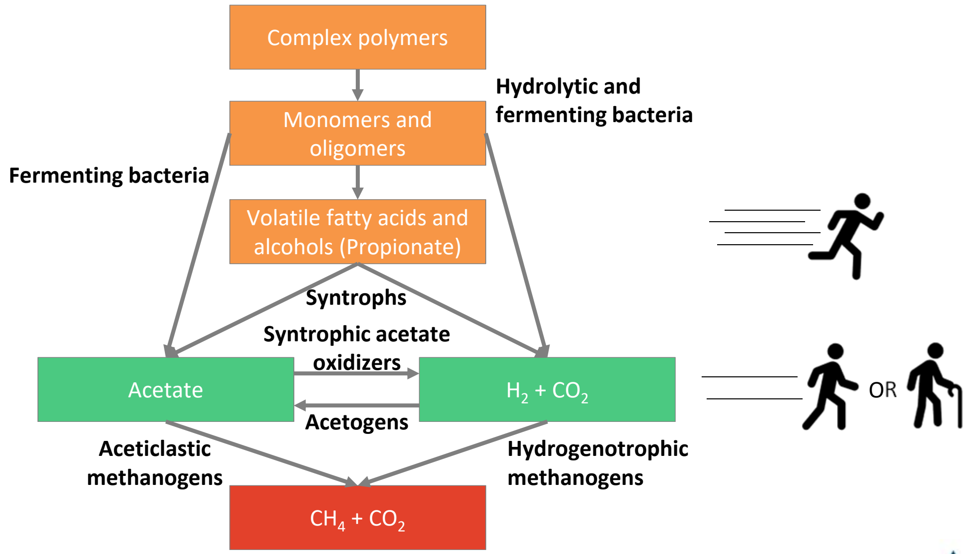
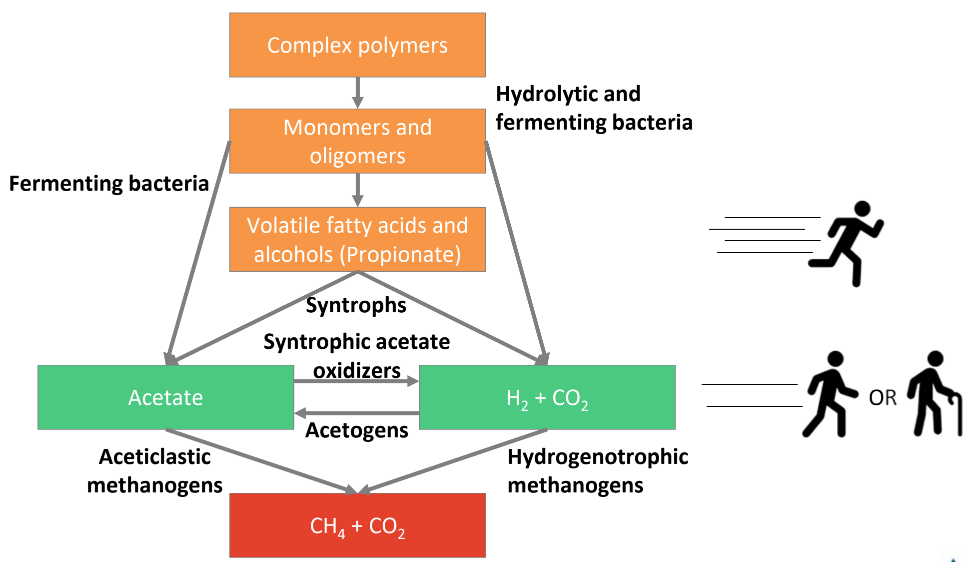
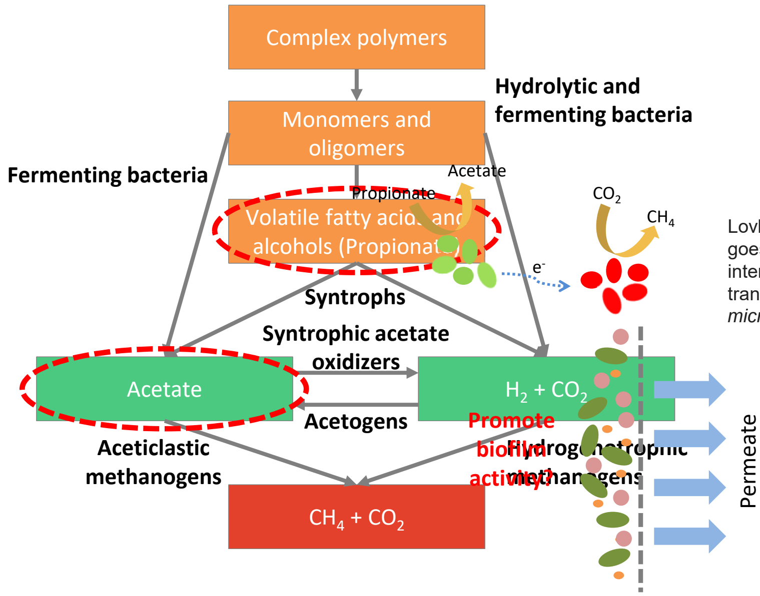
Poor membrane quality due to imbalance between reaction rates



Can we use biofilm treatment to improve permeate quality?

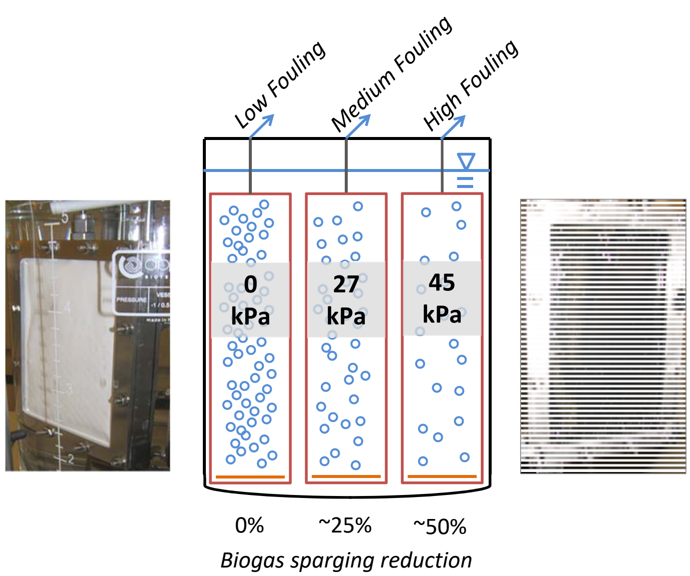


Can we use biofilm treatment to improve permeate quality?

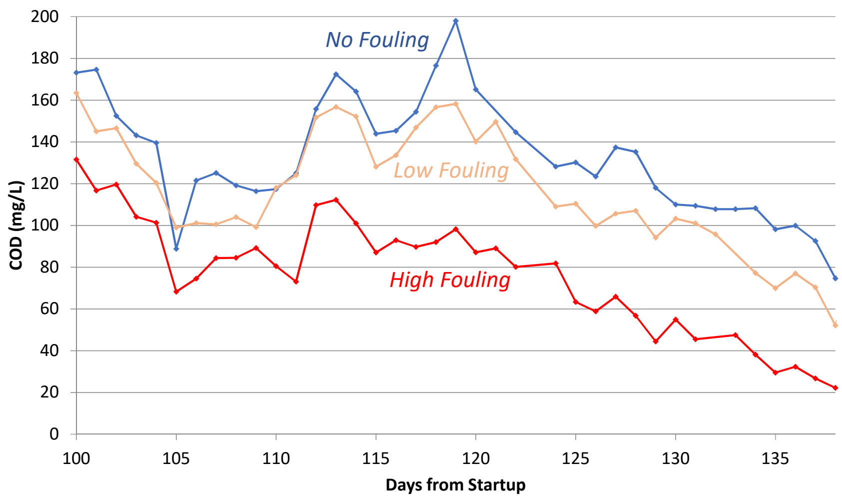


Lovley, D. R., 2017, Syntrophy goes electric: direct interspecies electron transfer. *Annual review of microbiology*, **71**, 643-664.

Different levels of biofilm development (fouling) on each membrane by varying biogas sparging



Biofilm promotion greatly improved permeate quality



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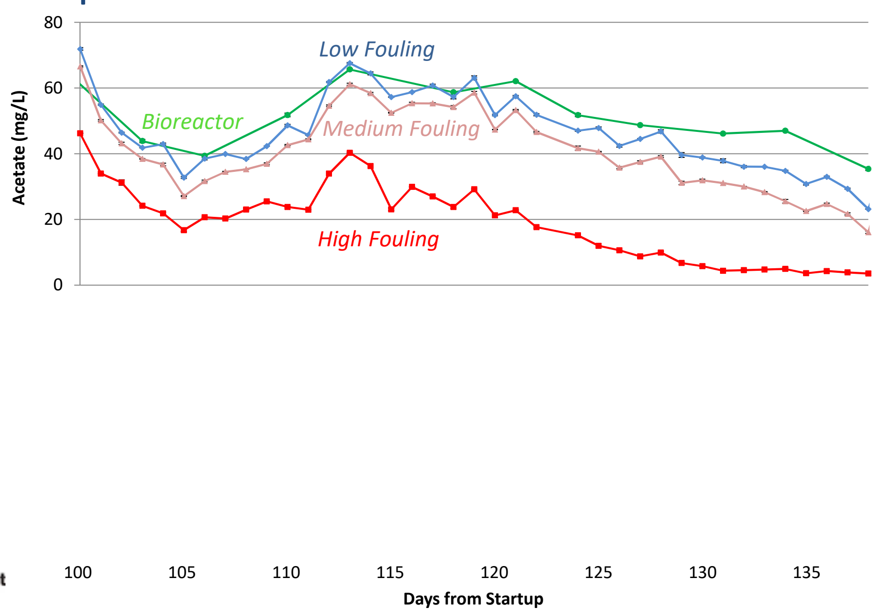
Aceticlastic methanogens and propionate oxidizing bacteria developed over time in biofilm



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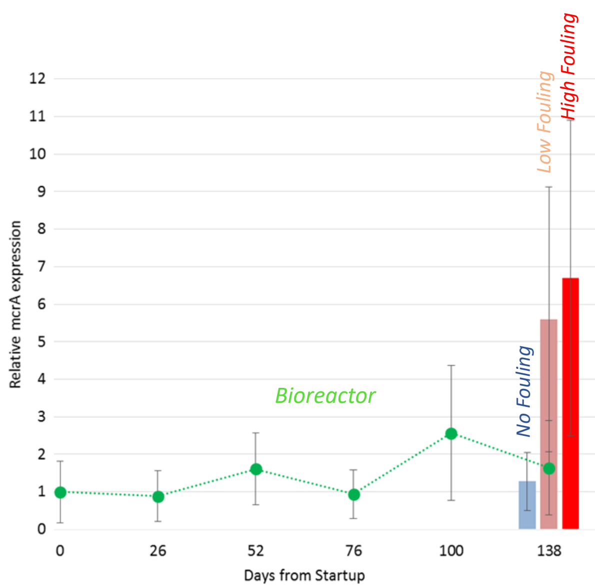
Methanogenesis in the biofilm impacted the fate of methane

Methane oversaturation =
Dissolved methane measured in permeate / calculated equilibrium concentration

Greater methyl coenzyme M reductase (*mcrA*) gene expression in biofilm than in suspended biomass



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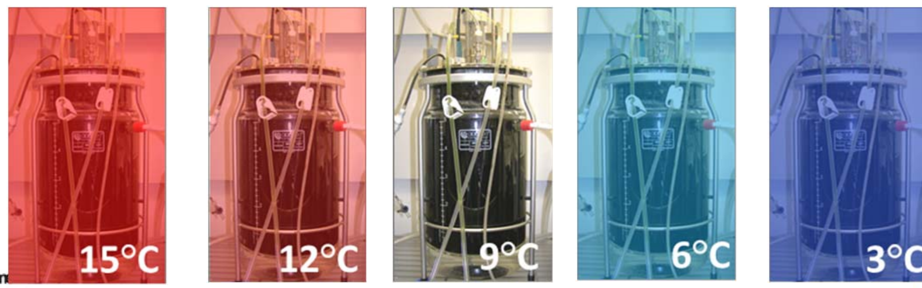
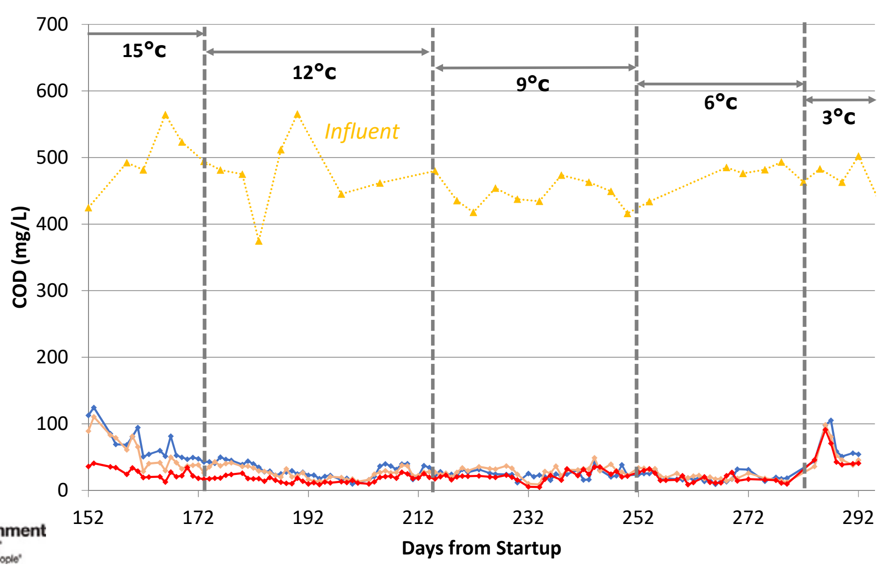
3. How does AnMBR compare to conventional treatment technologies based on cost, energy, and environmental impacts?

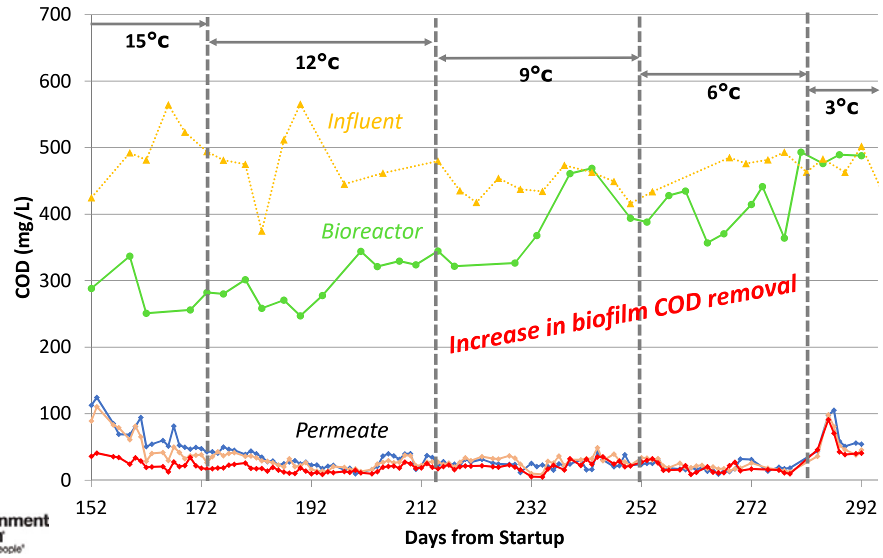


Smith, A.L., S.J. Skerlos, and L. Raskin, 2015, Anaerobic membrane bioreactor treatment of domestic wastewater at psychrophilic temperatures ranging from 15°C to 3°C, *Environmental Science: Water Research &Technology,* **1**, 56-64.

Excellent AnMBR performance maintained down to 6°C



Biofilm's role in treatment becomes more critical as temperature decreases



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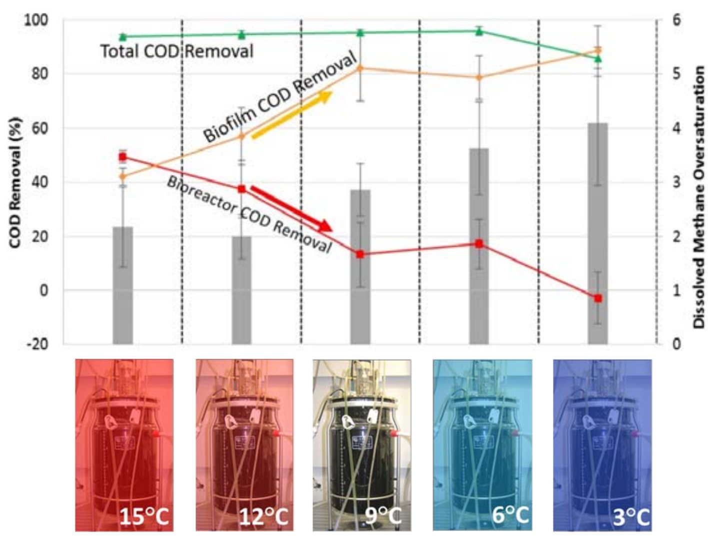
Reliance on biofilm for treatment increased dissolved methane oversaturation



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3. **How does AnMBR compare to conventional treatment technologies based on cost, energy, and environmental impacts?**

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Under what conditions could we call a design "sustainable"?

- does the design make significant progress toward an unmet and important environmental or social challenge?
- is there potential for the design to lead to undesirable consequences in its lifecycle that overshadow the environmental/social benefits?
- is the design likely to be adopted and self-sustaining in the market?
- is the design so likely to succeed economically that, due to rebound effects, planetary or social systems will be worse off because of the design?

THE ANSWERS TO ALL THESE QUESTIONS MUST BE **FAVORABLE**!

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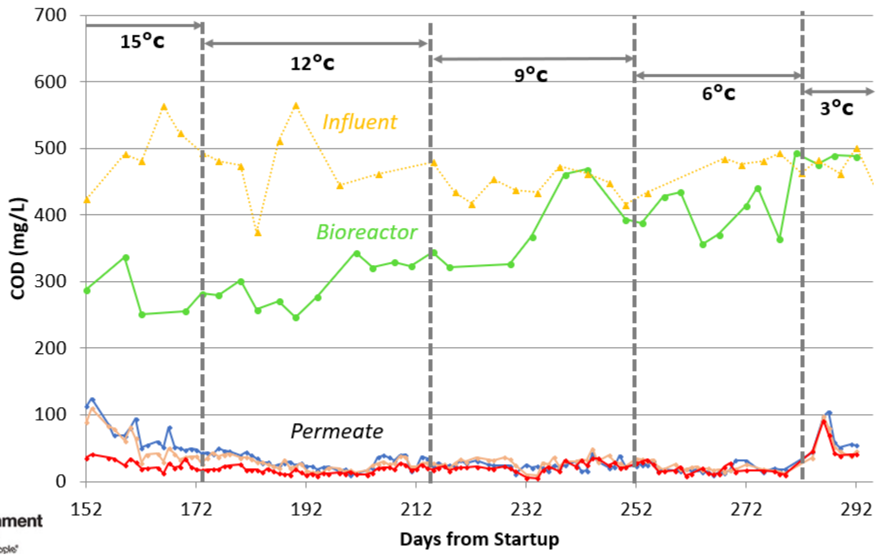
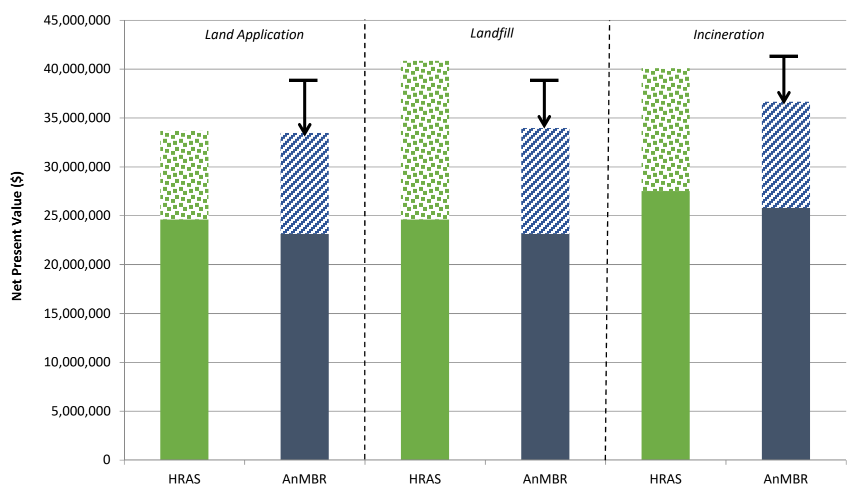
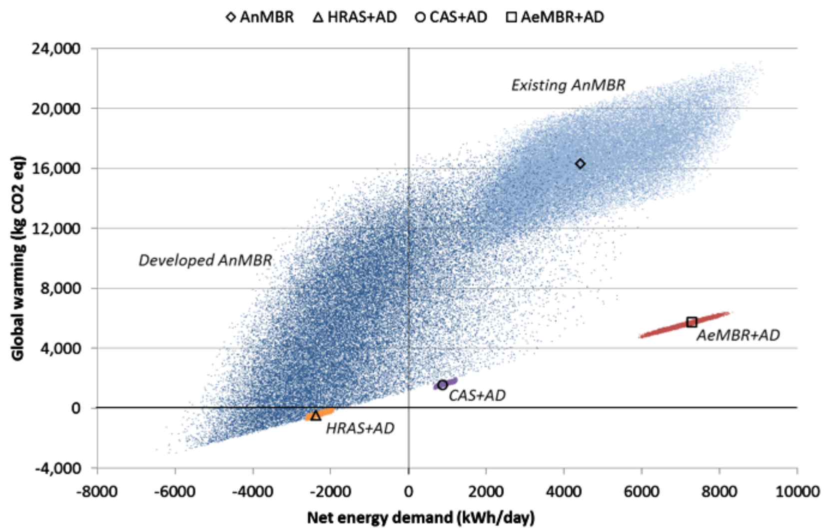
Excellent AnMBR performance maintained as low as 6°C
Looking good!!



We compared AnMBR with the most comparable and viable alternative approach:
High Rate Activated Sludge (HRAS)
Still looking good!



AnMBRs had much higher global warming impact per energy demand



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Smith, A. L., Stadler, L. B., Cao, L., Love, N. G., Raskin, L., & Skerlos, S. J., 2014, Navigating wastewater energy recovery strategies: a life cycle comparison of anaerobic membrane bioreactor and conventional treatment systems with anaerobic digestion. Environmental science & technology, **48**, 5972-5981.

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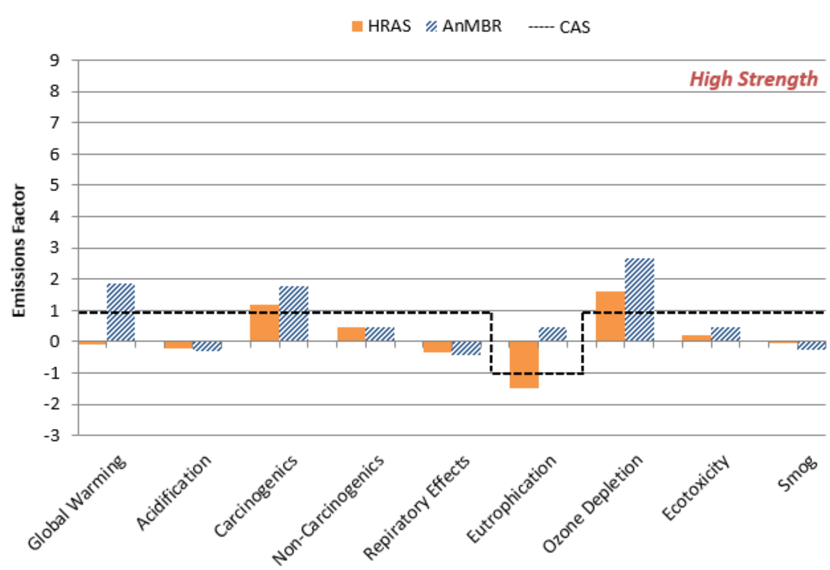
Environmental impacts were still not great for higher strength wastewater



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Are anaerobic membrane bioreactors for recovery of energy from wastewater a sustainable technology?

- Does the design make significant progress toward an unmet and important environmental or social challenge?
  - **No: the world has plenty of energy and global warming potential not addressed. More work to do.**
- Is there potential for the design to lead to undesirable consequences in its lifecycle that overshadow the environmental/social benefits?
  - **Yes: Excess greenhouse gas (GHG) emissions**
- Is the design likely to be adopted and self-sustaining in the market?
  - **The value proposition right now is mainly smaller size. Net zero energy is possible after more research. The GHG issue is of industry concern and will be a show-stopper for now.**
- Is the design so likely to succeed economically that, due to rebound effects, planetary or social systems will be worse off because of the design?
  - **No.**

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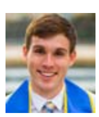
Current research focuses on *redesigning* AnMBRs to address sustainability challenges associated with low temperature treatment

Eliminate dissolved methane from permeate

Address increased fouling intensity or reduce energy consumption for fouling mitigation

while achieving excellent performance at high organic loading rates



WRF U2R15

Next Generation Anaerobic Membrane Bioreactor Development Utilizing 3D-Printing

NSF – CBET 1604069

WRF: Biofilm-Enhanced Anaerobic Membrane Bioreactor for Low Temperature Domestic Wastewater Treatment

WRF – TIRR5C15

Life Cycle Assessment and Analysis of Biofilm Enhanced Anaerobic Membrane Bioreactor

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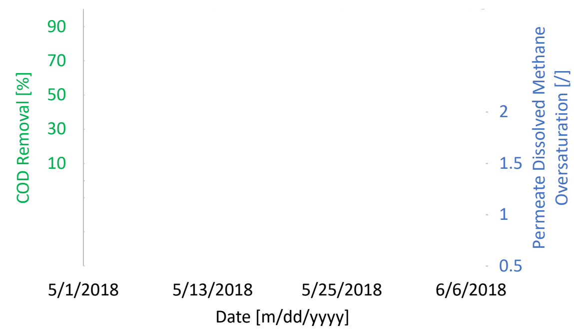
Start-up performance for project NSF - CBET 1604069

Reactor temperature: from 25 → 15°C
Hydraulic retention time: ~13.5 h
=> organic loading rate: ~0.8 g COD/L/day

COD removal: from 16 → 88%
Dissolved methane oversaturation
=> Permeate methane close to saturation: between 0.7-2



Conclusions

1. **Can AnMBRs successfully treat low temperature, domestic wastewater?**
   - Yes! - Biofilm treatment effective, especially at lower temperatures
     - Must evaluate at lower HRTs/ higher OLRs
2. **How do AnMBRs compare to conventional treatment technologies?**
   - Not well - higher net energy and global warming impacts
     - Energy for fouling mitigation must be reduced
     - Methane release must be avoided to have comparable or lower global warming impacts

Next Steps

- Evaluate performance of new reactor designs to address the above concerns

Acknowledgements

Freddy Ordonez
Environmental Eng.
Graduate Student, UM

Juliana Huizenga
Environmental Eng.
Undergraduate Student, UM

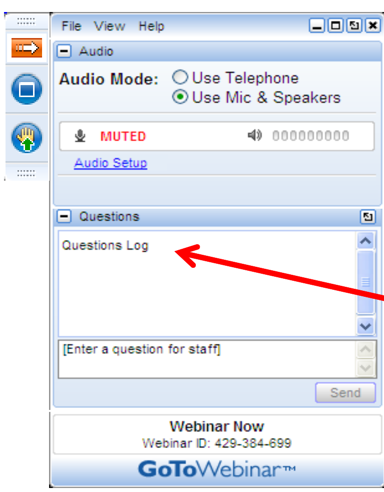
Nigel Beaton
Environmental Eng.
(Previous)
Graduate Student, UM

Ilse Smets
Professor
KU Leuven

Nancy Love
Professor
UM

Charles Bott
Director of Water
Technology and Research
HRSD

Questions for Our Speakers?



- **Submit your questions using the Questions Pane.**

Thank You

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Today's Speakers

Lutgarde Raskin, Ph.D., WEF Fellow, AAM Fellow
"Lut" Raskin is the Altarum/ERIM Russell O'Neal Professor of Engineering at the University of Michigan. She is a pioneer in molecular microbial ecology applied to water quality control and anaerobic bioprocesses. Her research focuses on developing anaerobic bioprocesses for resource recovery from wastestreams and managing the microbiome of drinking water systems. She has published about 130 peer-reviewed journal papers and 350 conference proceedings papers and abstracts.

Dr. Raskin is passionate about graduate education and has mentored approximately 15 postdocs and 90 graduate students, including 25 Ph.D. students. She received BS and MS degrees from the KU Leuven in Belgium and a Ph.D. degree from the University of Illinois at Urbana-Champaign. Prior to joining the faculty at the University of Michigan in 2005, she was a faculty member at the University of Illinois at Urbana-Champaign. She is an elected Fellow of the Water Environment Federation and the American Academy of Microbiology. Past honors include the Association of Environmental Engineering and Science Professors (AEESP) 2018-2019 Distinguished Lecturer, the University of Michigan Rackham Distinguished Graduate Mentor Award, the International Society for Microbial Ecology-IWA BioCluster Award, the AEESP Frontier Award in Research, and The Water Research Foundation Paul L. Busch Award. She is an Associate Editor for *Environmental Science & Technology*.

Steven J. Skerlos, Ph.D.
Steven Skerlos is Arthur F. Thurnau Professor at the University of Michigan. He is a tenured faculty member in Mechanical Engineering and Civil and Environmental Engineering. He also serves as a U University of Michigan Distinguished Faculty Fellow in Sustainability.

Professor Skerlos serves as Director of the Center for Socially Engaged Design and Co-Director of the Engineering Sustainable Systems Program. He is founder of Fusion Coolant Systems and was also a co-founder of Accuri Cytometers (a company acquired in 2009 for over $200M), both technology spinouts from Professor Skerlos's research at UM. He also serves as faculty advisor to BLUElab, a 250-person student organization at the University of Michigan performing sustainable design projects globally.

Professor Skerlos' Ph.D. students in the Environmental and Sustainable Technologies Laboratory have addressed sustainability challenges in the fields of technology policy, manufacturing, and water systems. Their ideas and research papers have been widely used and cited by academics and practitioners alike.

Caroline Van Steendam
Caroline Van Steendam is currently pursuing a dual Ph.D. degree in Environmental Engineering at the University of Michigan and in Chemical Engineering at the University of Leuven (Leuven, Belgium). Her dissertation research focuses on developing a novel anaerobic membrane bioreactor (AnMBR) to increase the sustainability of (domestic) wastewater treatment in temperate climates. Specifically, her work is studying low temperature effects on operational limits and treatment performance of AnMBRs to single out design characteristics that address current sustainability challenges. She has bachelor's and master's degree in Chemical Engineering from the University of Leuven. Since starting her Ph.D. in 2014, she was awarded the Civil and Environmental Engineering Ph.D. fellowship, the Integrated Training in Microbial Systems fellowship, and most recently, the Rackham Predoctoral fellowship. She was invited by the Royal Flemish Academy of Belgium for Science and Arts to support Glen Daigger and Margarat Catley-Carlson in evaluating and improving water management in Flanders. She is the co-outreach officer for the graduate chapter of Society of Women in Engineering at the University of Michigan, and organizes and participates in weekly high school tutoring events and engineering clubs.

Timothy Fairley
Tim Fairley is a graduate research assistant at the University of Michigan (UM) currently exploring novel designs for anaerobic reactors. He graduated with his Master's in Environmental Engineering Winter 2017, and during his time at UM, has worked on both pilot- and bench-scale anaerobic membrane bioreactor projects. He graduated from UCLA with a B.S. in Civil and Environmental Engineering and during his undergraduate, he worked as a student research assistant for the R&D team at L.A. County Sanitation's Joint Water Pollution Control Plant where he worked on a variety of projects including food waste co-digestion, nitrification/denitrification columns, and biosolids odor control.

Nishant Jalgaonkar
Nishant Jalgaonkar is currently pursuing a Master of Science in Engineering degree in Mechanical Engineering, specializing in Engineering Design at the University of Michigan. His focus is on using digital fabrication technologies such as additive manufacturing to inform the engineering design process. He obtained his bachelor’s degree in Mechanical Engineering from the National University of Singapore.