The Bioenergy and Bioprocessing Technology Laboratory: Intersection of Renewable Energy, Waste Treatment, and Human Health

Photo: Wastewater digesters in Haiti, funded by USAID and NSF grants

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DEPARTMENT OF ENVIRONMENTAL SCIENCE & TECHNOLOGY

Bioenergy and Bioprocessing Technology Lab Overview

1. Innovations in the Food-Ag Circular Economy
   - Food waste, MSW, and algae digestion with nutrient recovery post-digestion, and Life Cycle Assessments (LCA) of the overall processes

2. Innovations in Digestion and Fermentation
   - Nanotechnology, electrochemistry, biochar, and bioplastic production from fermentation products.

3. Reducing Antimicrobial Resistance through Integration of Engineering, Public Health, and Social Science
   - Manure and biosolids treatment, social science, communication, and teaching

What is the Circular Economy in the Food System?

Regenerative Food Production

- A food system that builds natural capital and generate positive outcomes for nature, such as healthy and stable soils, improved local biodiversity, improved air and water quality.
  - Local practices could include diverse crop varieties and cover crops, rotational grazing, organic-based fertilizers, and agroforestry to build agricultural systems in a way that more mimic natural systems and bring nutrients into circular system.

Eliminating Food Waste

- Prevents food waste, redistribute edible food to people who need it, and recycle inedible food by-products into inputs for new products through composting, anaerobic digestion, or other value-added products.
- Food waste added to landfills emit CH_4, 25x more powerful than CO_2.

MORE THAN JUST FOOD

THE U.S. WASTES TONS OF RESOURCES WHEN WE WASTE FOOD

30-40% of All Food Produced in the US is Wasted

NRDC, 2016, Wasted 2.0

1,250 CALORIES PER PERSON PER DAY

THAT IS HALF OF THE RECOMMENDED DAILY INTAKE FOR ADULTS

19% OF ALL U.S. CROPLANDS

THAT IS MORE LAND THAN ALL OF NEW MEXICO

21% OF U.S. LANDFILL CONTENT

THE NO. 1 CONTRIBUTOR BY WEIGHT

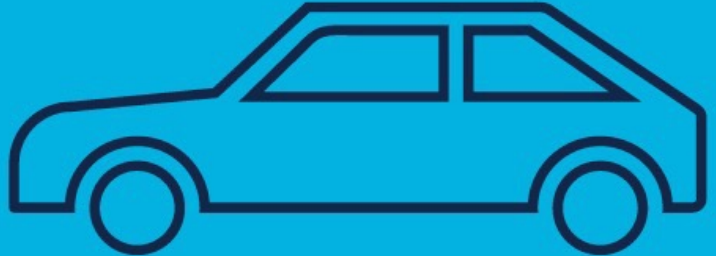
18% OF ALL FARMING FERTILIZER

WHICH CONTAINS 3.9 BILLION POUNDS OF NUTRIENTS

$218,000,000,000

WHICH IS EQUAL TO 1.3% OF THE U.S. GROSS DOMESTIC PRODUCT (GDP)

2.6% OF ALL U.S. GREENHOUSE GAS EMISSIONS ANUALLY



37 MILLION PASSENGER VEHICLES' WORTH

21% OF THE U.S. AGRICULTURAL WATER USAGE

MORE THAN: TEXAS + CALIFORNIA + OHIO

Anaerobic digestion could be used as pillar in a circular food economy by creating renewable energy (electricity, heat, or renewable natural gas) from carbon in food waste, manures, while preserving the nutrients for further crop growth in order to reduce GHG emissions from fossil fuel use from energy use and fertilizer production.

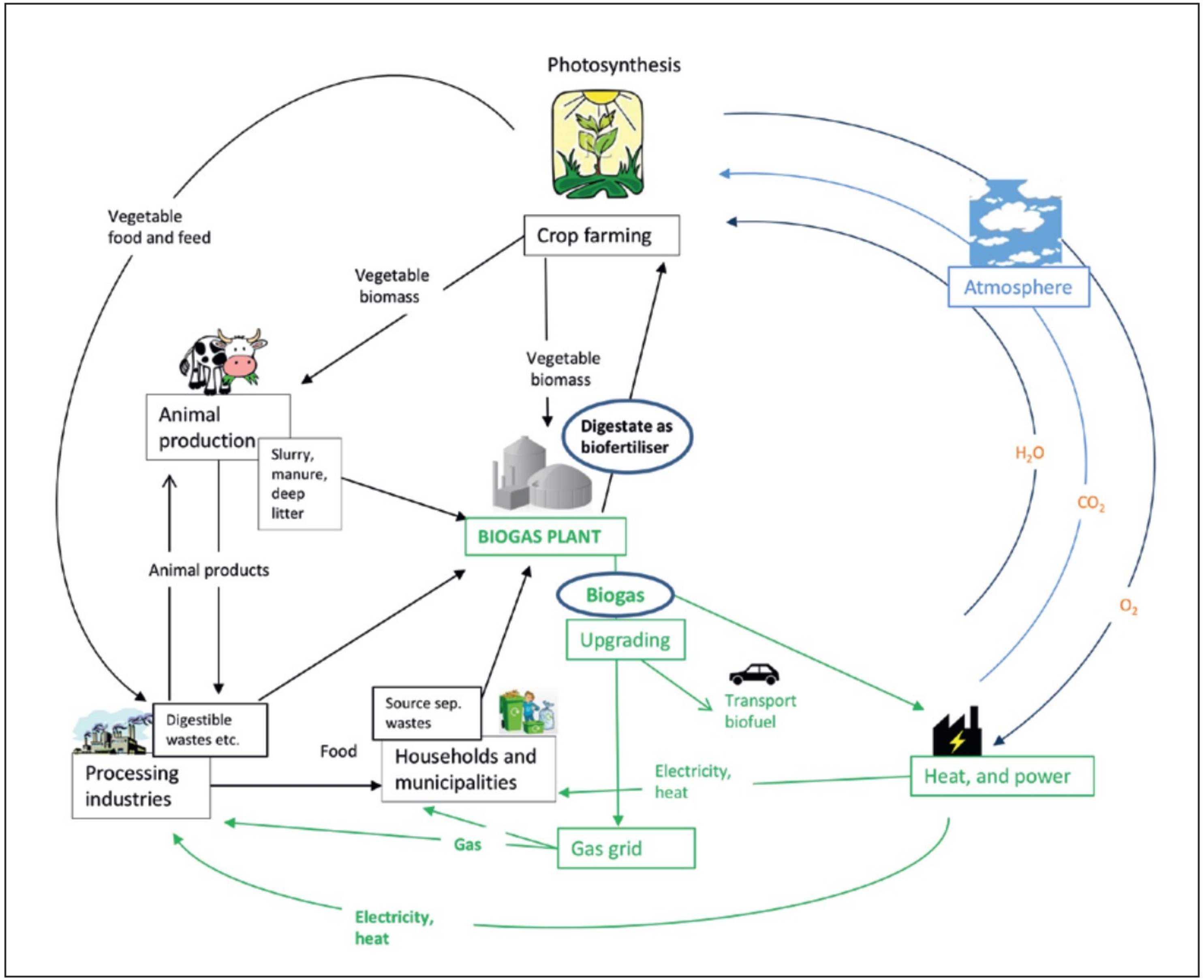
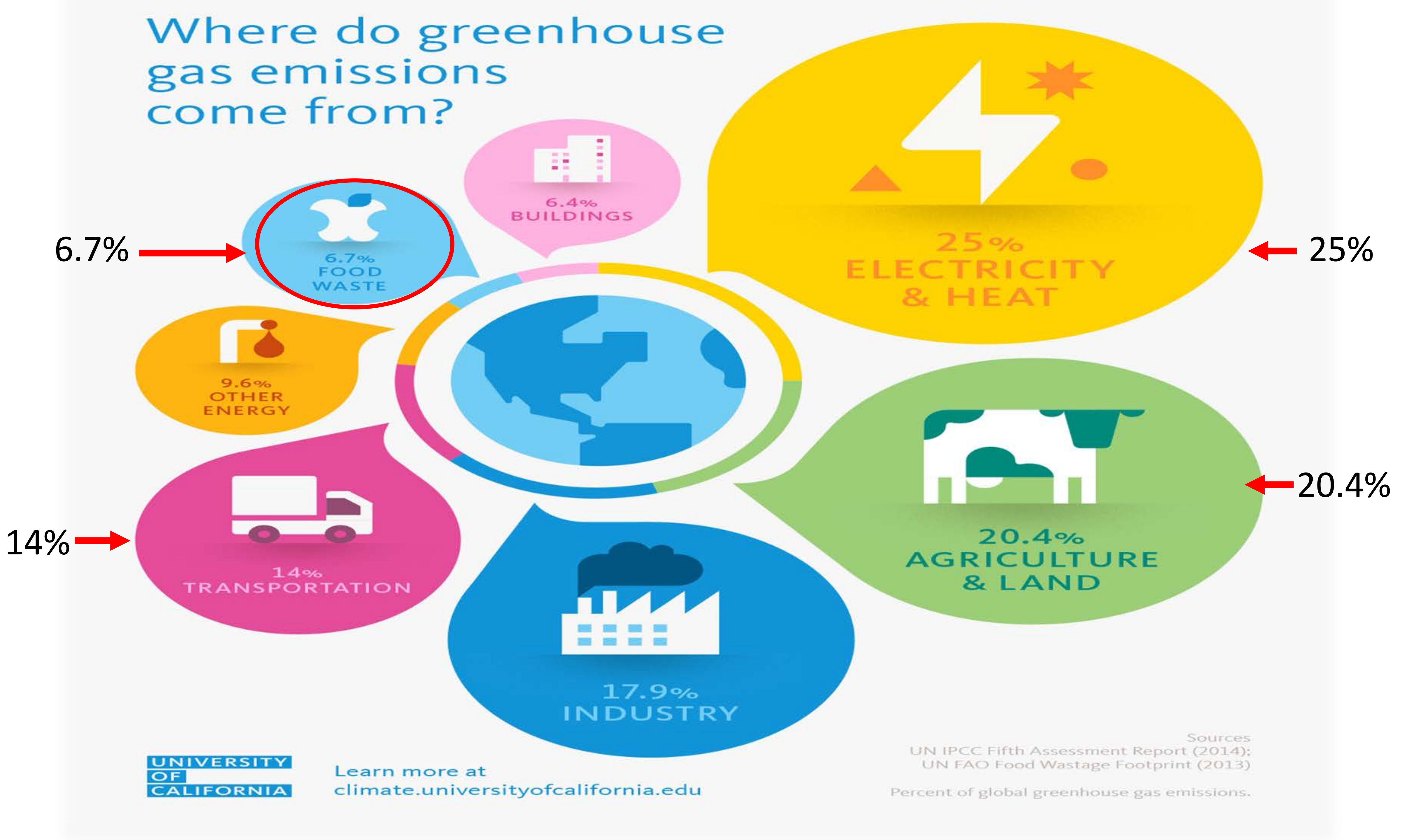
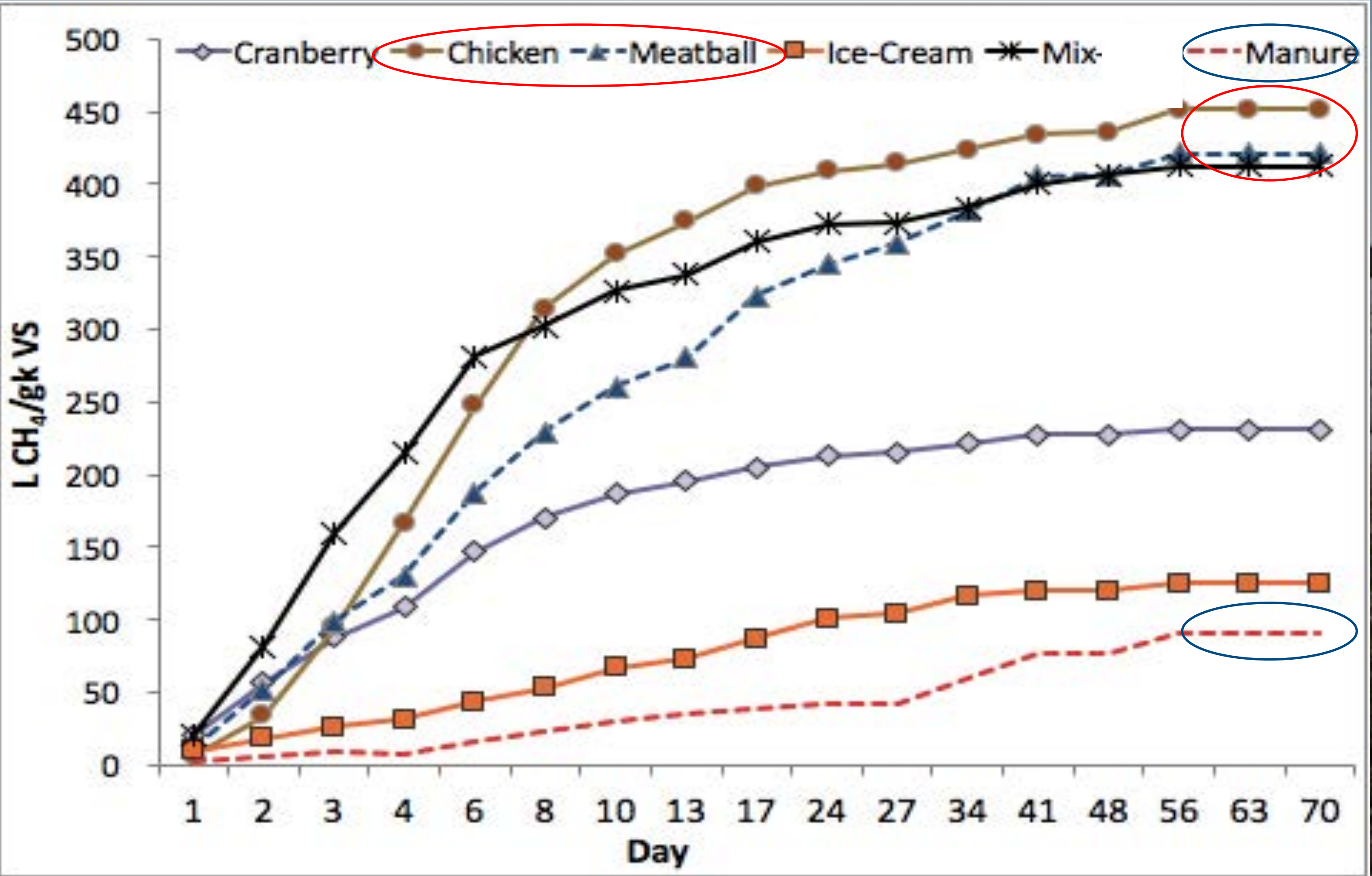


Figure from: "Governance of Environmental Sustainability of manure-based centralised biogas production in Denmark" IEA Bioenergy 2018. Available at: https://www.ieabioenergy.com/blog/publications/governance-of-environmental-sustainability-of-manure-based-centralised-biogas-production-in-denmark/



Where do greenhouse gas emissions come from?
6.4% BUILDINGS
6.7% FOOD WASTE
25% ELECTRICITY & HEAT
9.6% OTHER ENERGY
20.4% AGRICULTURE & LAND
14% TRANSPORTATION
17.9% INDUSTRY
6.7%
25%
20.4%
14%
UNIVERSITY OF CALIFORNIA
Learn more at climate.universityofcalifornia.edu
Sources
UN IPCC Fifth Assessment Report (2014);
UN FAO Food Wastage Footprint (2013)
Percent of global greenhouse gas emissions.

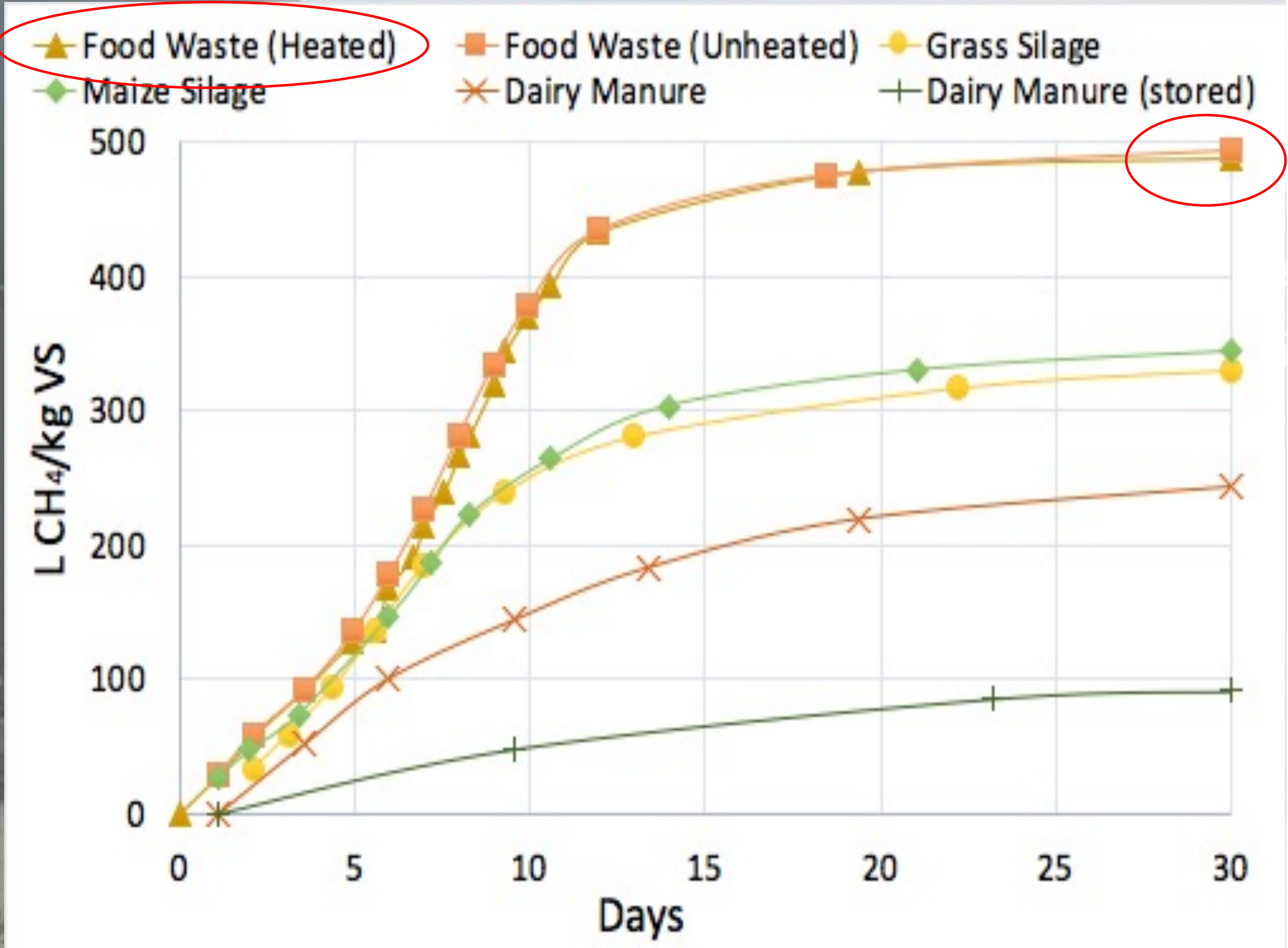
- Covered lagoon digester in Cecil County, MD
- Food processing waste (≈ 2500 gal/day) from cranberry, ice cream and chicken processing digested with flushed dairy manure from 450 cows (64,000 gal/day)



- Food waste increased biogas production from 38% (ice cream) to 398% (chicken).
- For food waste, 58 to 85% of the gas was produced in the first 12 days, while manure only had 39% of its gas total in this time.

Prior Study: Food Waste Co-digestion at a German Farm

- Food waste increased gas production by 434% and maize silage by 276% compared to only digesting manure.
- Food waste and silage had 85-89% of the cumulative CH_4 in the first 14 days compared to fresh manure with only 53% of CH_4 in this time.
- 71% of the gas was due to food waste, which was a minority of the digester volume (5.5 m^3 per day).



Food Waste Digestion – Individual Collection

Innovations in Anaerobic Digestion

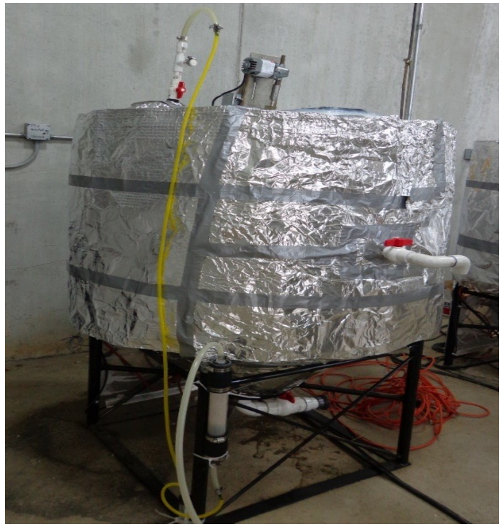
1. **Nanoparticles** (NP) to increase biogas, with NP process tracking
   - New method for nanoparticle extraction from digestate

2. **Microbial electrolysis cells** (MEC) & **Electrocoagulation**
   - MECs to increase methane content in digesters
   - Using fermentation and MECs to create bioplastics from food waste
   - Electrocoagulation to increase water quality for water reuse

3. **Biochar** to remove H_2S and increase CH_4 in biogas
   - Biochar to improve anaerobic digestion
   - Biochar to increase plant growth and pollutant absorption

4. **Small-Scale to Large-Scale Digesters**
   - Freeze-dried inoculum to start digesters in remote locations
   - > 99% reductions in pathogens using wastewater digesters in Haiti
   - Designed small-scale digester design for varying climates
   - Large-scale, food waste co-digestion systems in Germany and the US

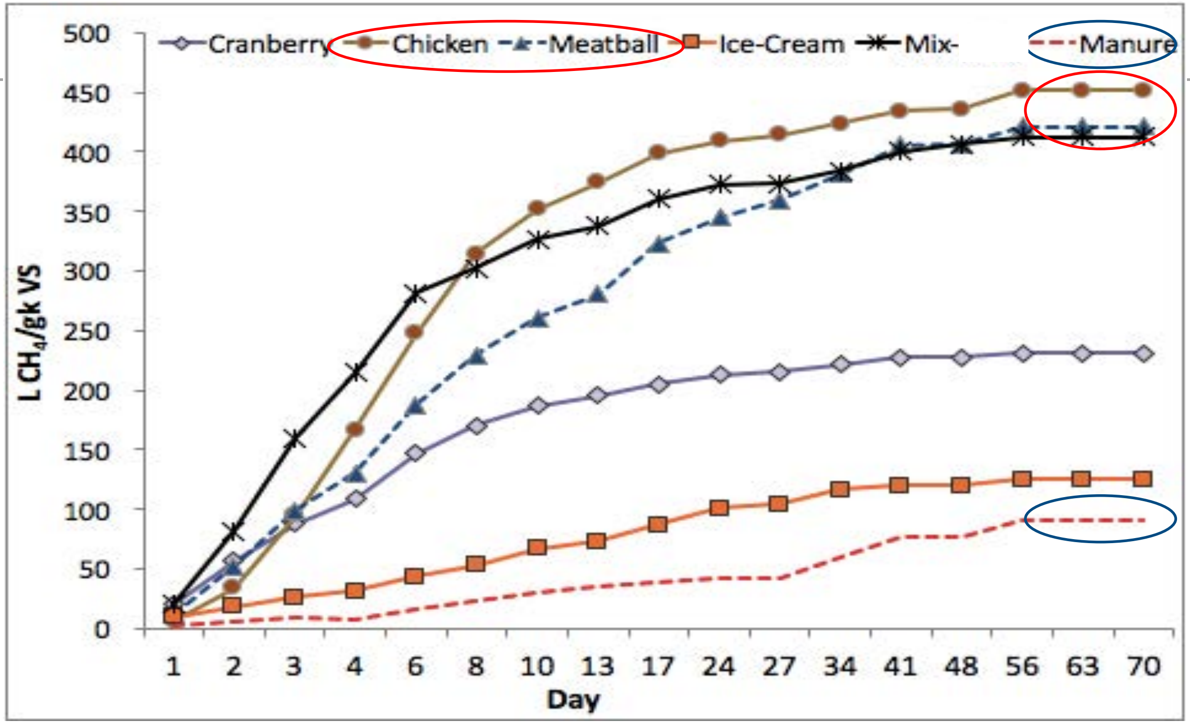
Lab-based Digesters



Digesters inside the lab range from 250 mL to 10 L digesters. Outside the lab, range from indoor 200 L digesters to 1 to 3 m^3 outside digesters.

Example Biogas Potential Testing

- Food processing waste (≈ 2500 gal/day) from cranberry, ice cream, chicken and meatball processing digested with flushed dairy manure from 450 cows (64,000 gal/day)
- Food waste increased gas production from 38% (ice cream) to 398% (chicken)
- For food waste, 58 to 85% of the gas was produced in the first 12 days, while manure only had 39% of its gas total in this time.



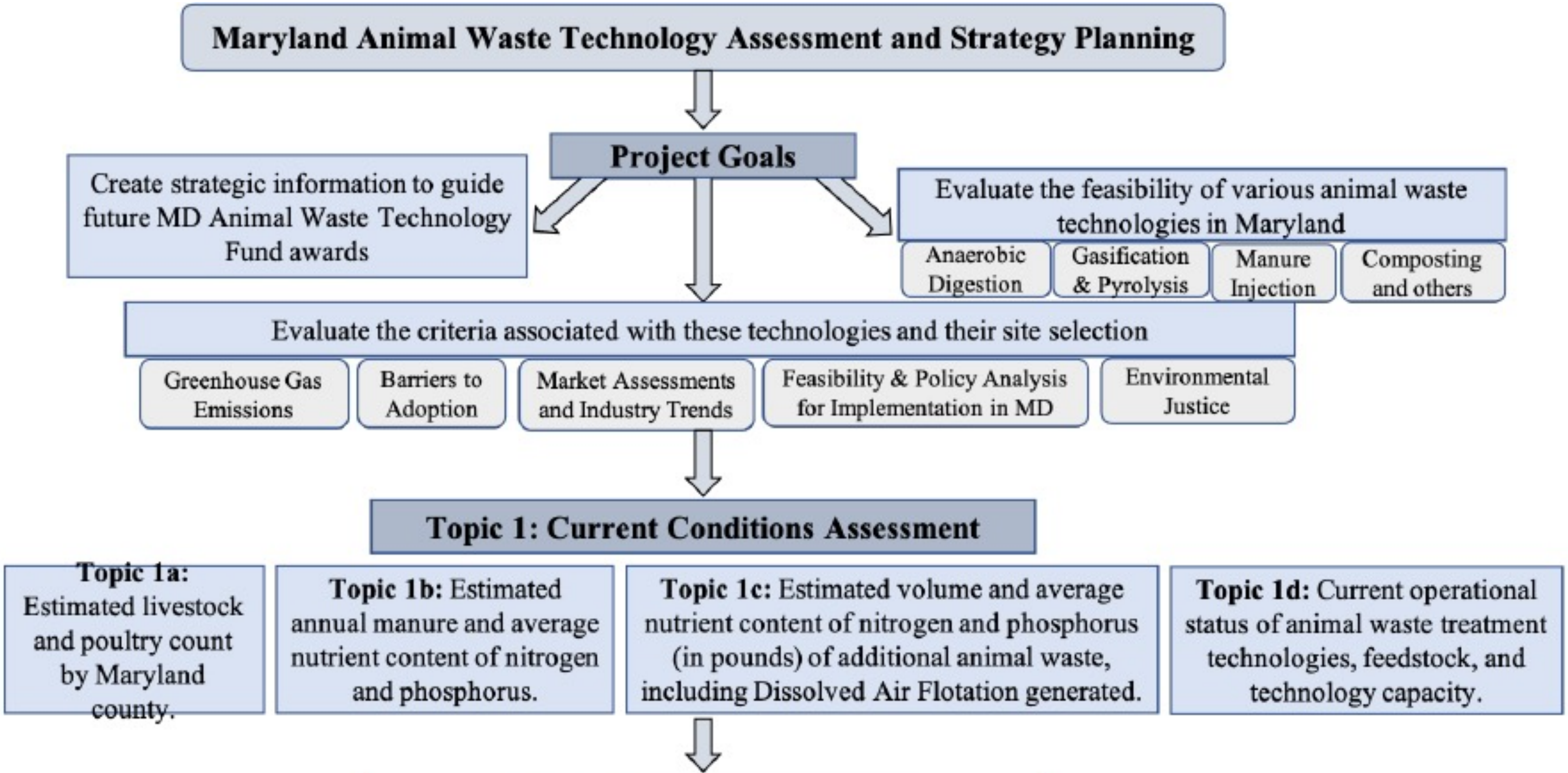
Lisboa and Lansing, 2013 in Waste Management

Maryland Animal Waste Technology Fund
Third Party Verification

Mass Balances of Energy, Nutrients and Sustainability

- Farmer Technical Support
- Comparison of biogas in the field to lab conditions
- Mass Balance of Energy (energy to run pumps and biogas production)
- Mass Balance of Nutrients and any Nutrient Reductions
- Monthly Sampling of one year period
- Life Cycle Assessment (LCA) of Sustainability of the whole process

MDA – Animal Waste Technology Fund Evaluation



Topic 2: Trends Assessment

Topic 2a: Current industry (agriculture and agri-business) trends that may affect animal waste characteristics and growth trends in animal waste volume within Maryland.

Topic 2b: Identification of other major drivers (e.g. State or national policy) that may affect growth trends in animal waste within Maryland.

Topic 2b: An evaluation of State and national climate change goals and consideration for animal waste technologies to mitigate greenhouse gas emissions.

Topic 2d: Strengths and weaknesses of animal waste technologies to address climate change goals.

Topic 2e: Impediments to adoption of animal waste treatment technologies.

Topic 2f: Summarize national efforts to incorporate environmental justice factors in the selection and siting of animal waste facilities and/or animal waste treatment technologies.

Topic 3: Emerging Markets Assessment

Topic 3a: Research and evaluate both traditional and new/emerging technologies market sectors for by-products of animal waste treatment technologies including biogas and soil amendments.

Evaluate current adoption of technologies from public sources, including EPA and USDA.

Assess existing literature on factors affecting technology adoption and use to evaluate likely adoption in the next five years.

Survey existing reports from consulting and financial firms on prospects for investment in new technologies.

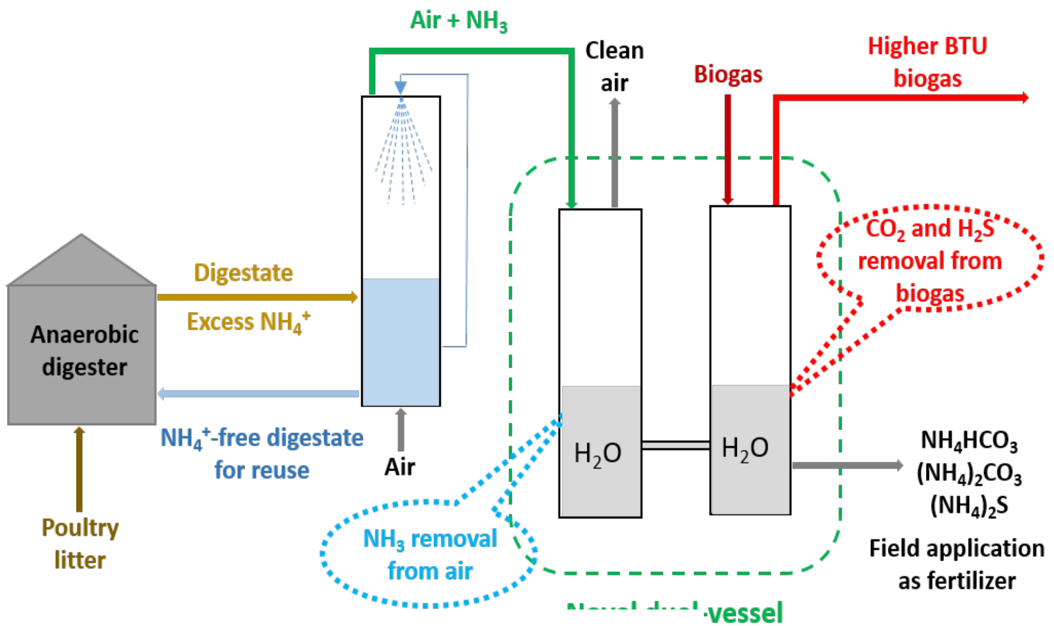
Topic 4: Recommendations

Topic 4a: Detailed recommendations on future uses of the Animal Waste Technology Fund to improve public health and the environment resulting in the reduction of nitrogen and phosphorus transport to the waters of the State while also addressing climate change goals.

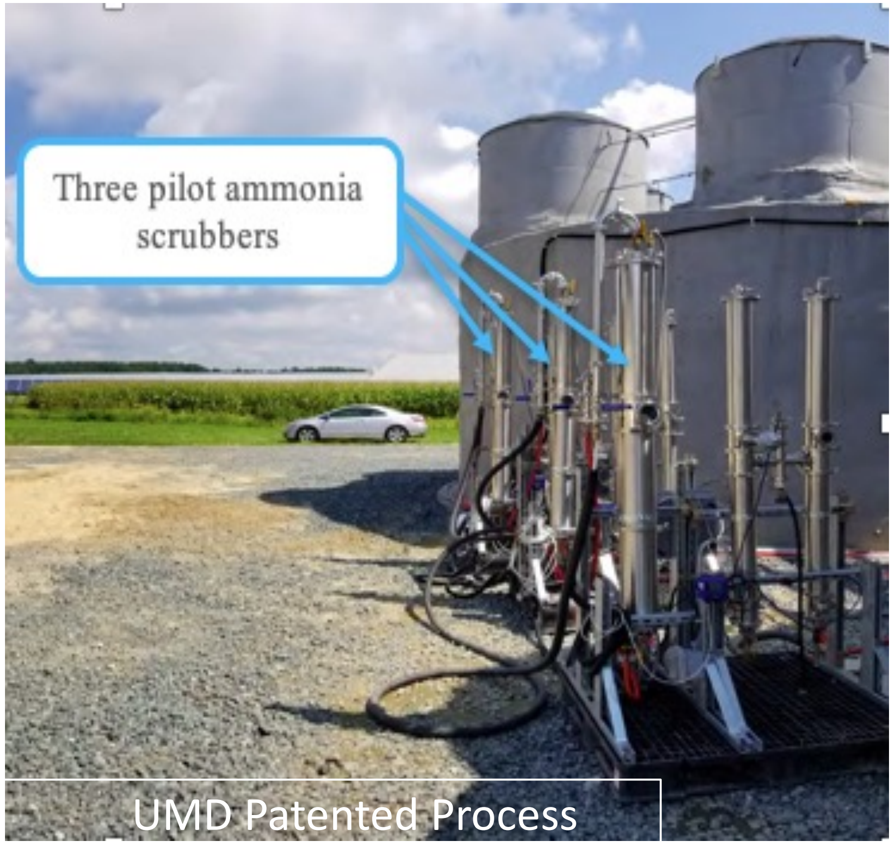
Topic 4b: Detailed recommendations on future uses of the Animal Waste Technology Fund to preserve the viability of the agricultural industry by improving animal waste management strategies.

Topic 4c: Detailed recommendations on future uses of the Animal Waste Technology Fund to incorporate environmental justice into the selection and siting of future Animal Waste Technology projects.

Post-Digestion Nutrient Extraction

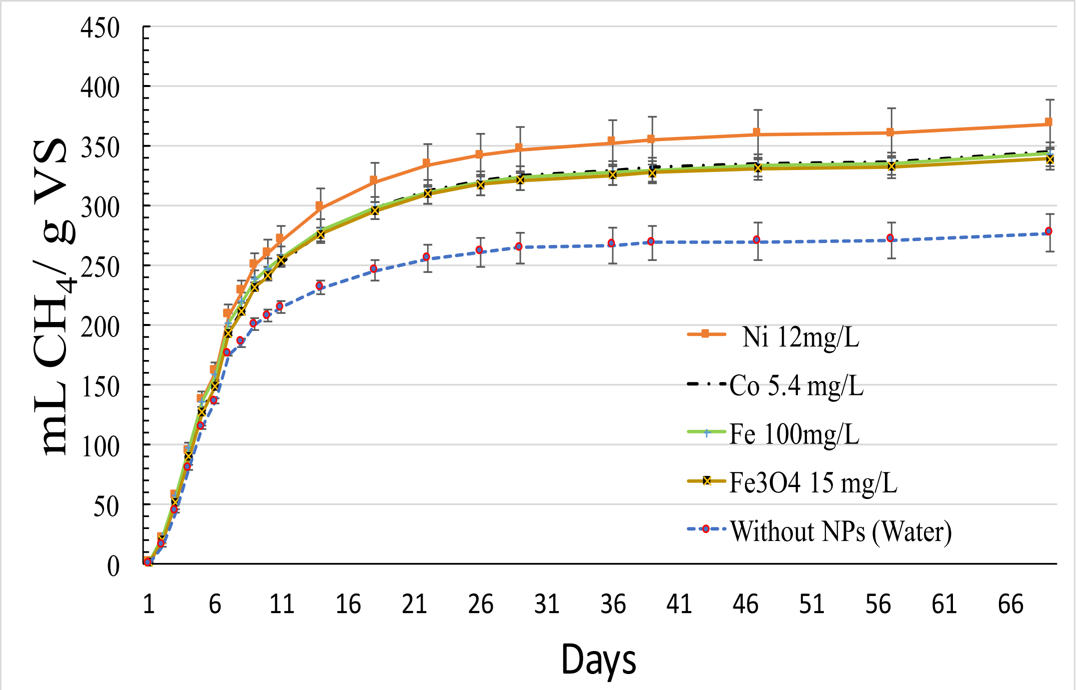


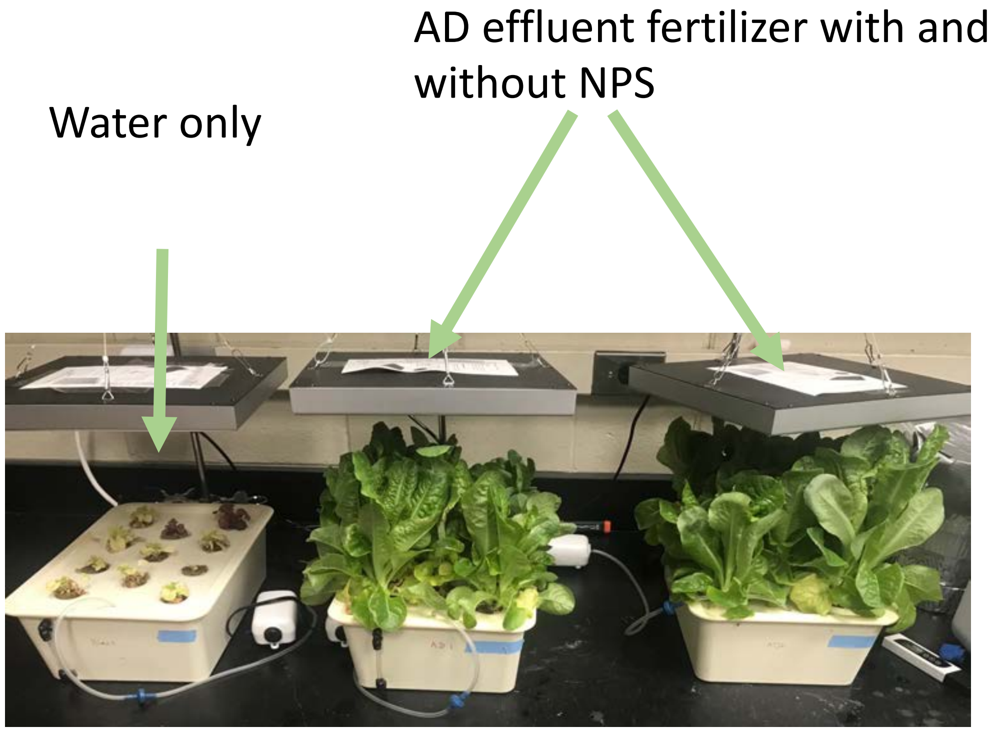
UMD patented Ammonia Scrubbers with PFED, Inc.



- Ammonium scrubber using counter-current airflow.
- Drives H_2S, CO_2 and NH_3 from the air into liquid solution.
- N-fertilizer is removed and available as a transportable fertilizer.
- Reusable water is produced.
- Biogas is upgraded through partial H_2S and CO_2 removal.

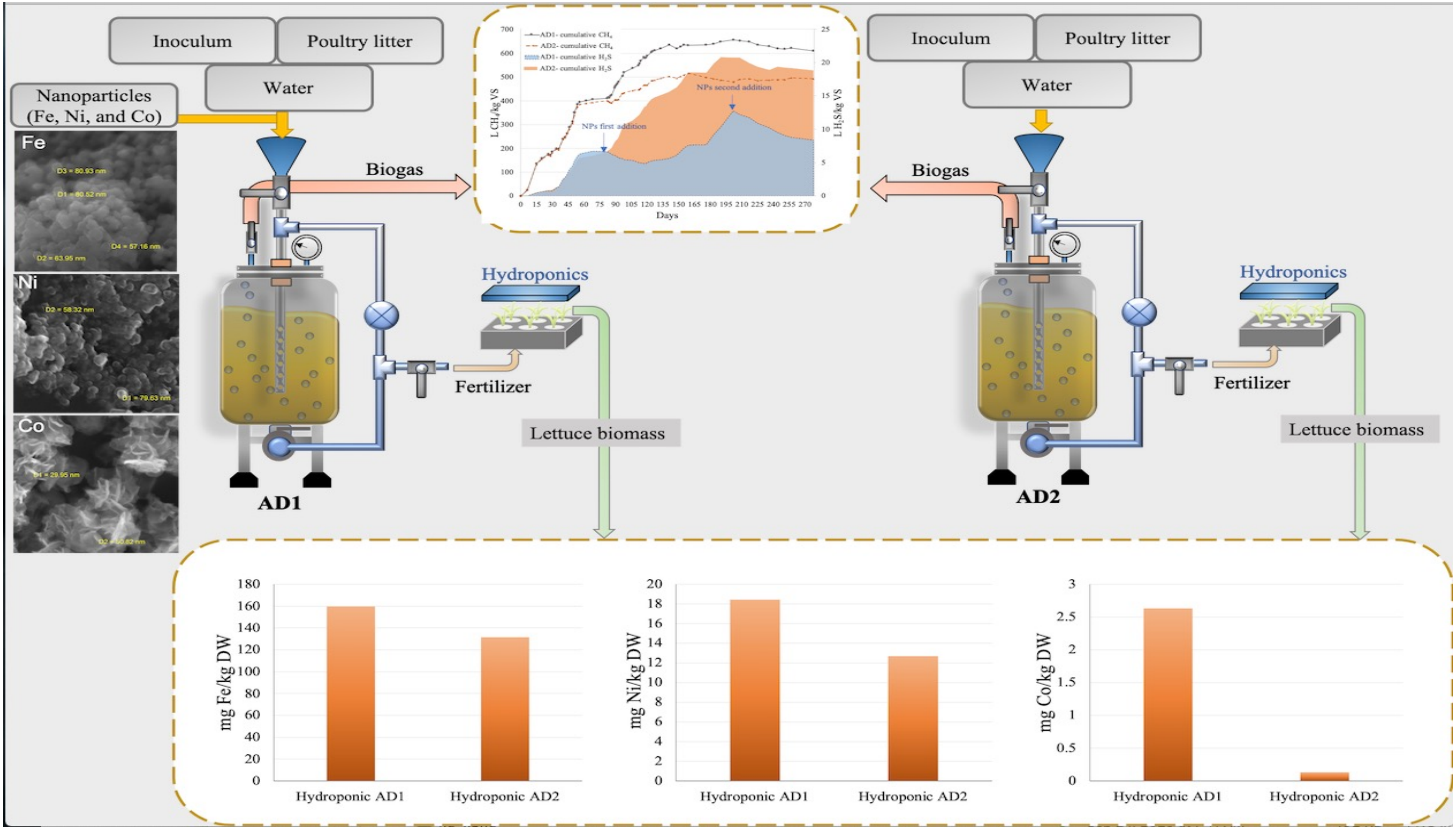
High Tech: Nanoparticles (NP) in Digestion





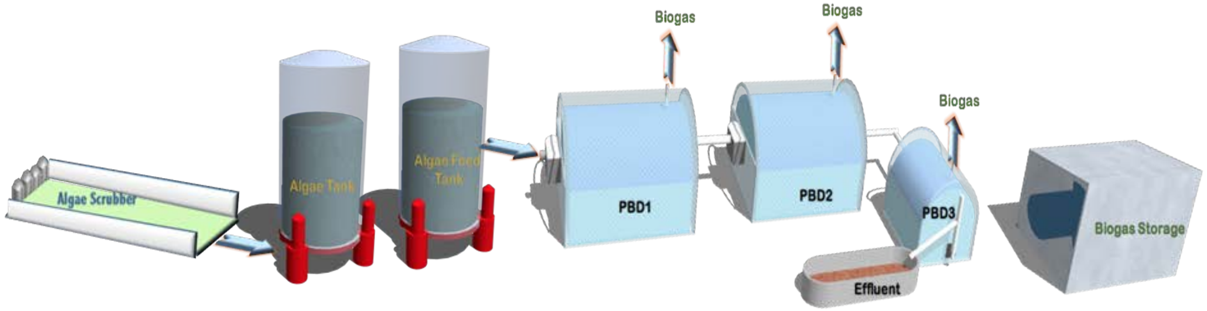
- Nickle (Ni), Cobalt (Co), Iron (Fe), and Iron Oxide (Fe_3O_4) added at the nano-scale in batch testing.
- Nanoparticle addition increased CH_4 production by 23.7% and temporarily ceased H_2S production, with an average H_2S reduction of 55%.
- Harvested lettuce had 21 to 1,900% more NP uptake, yet these values were well below toxic thresholds.

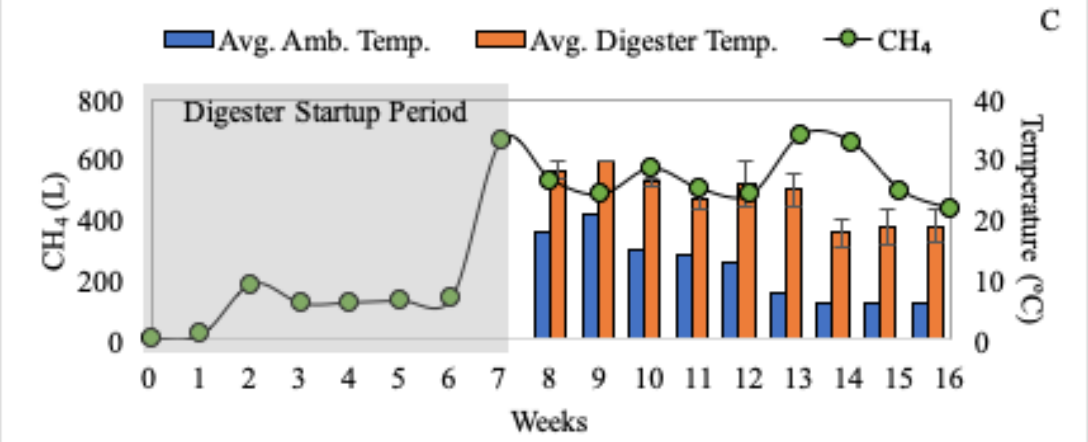
Hassanein et al., 2019, 2020



Hassanein et al., 2020

Algal Turf Scrubber with Anaerobic Digestion and Fuel Cell

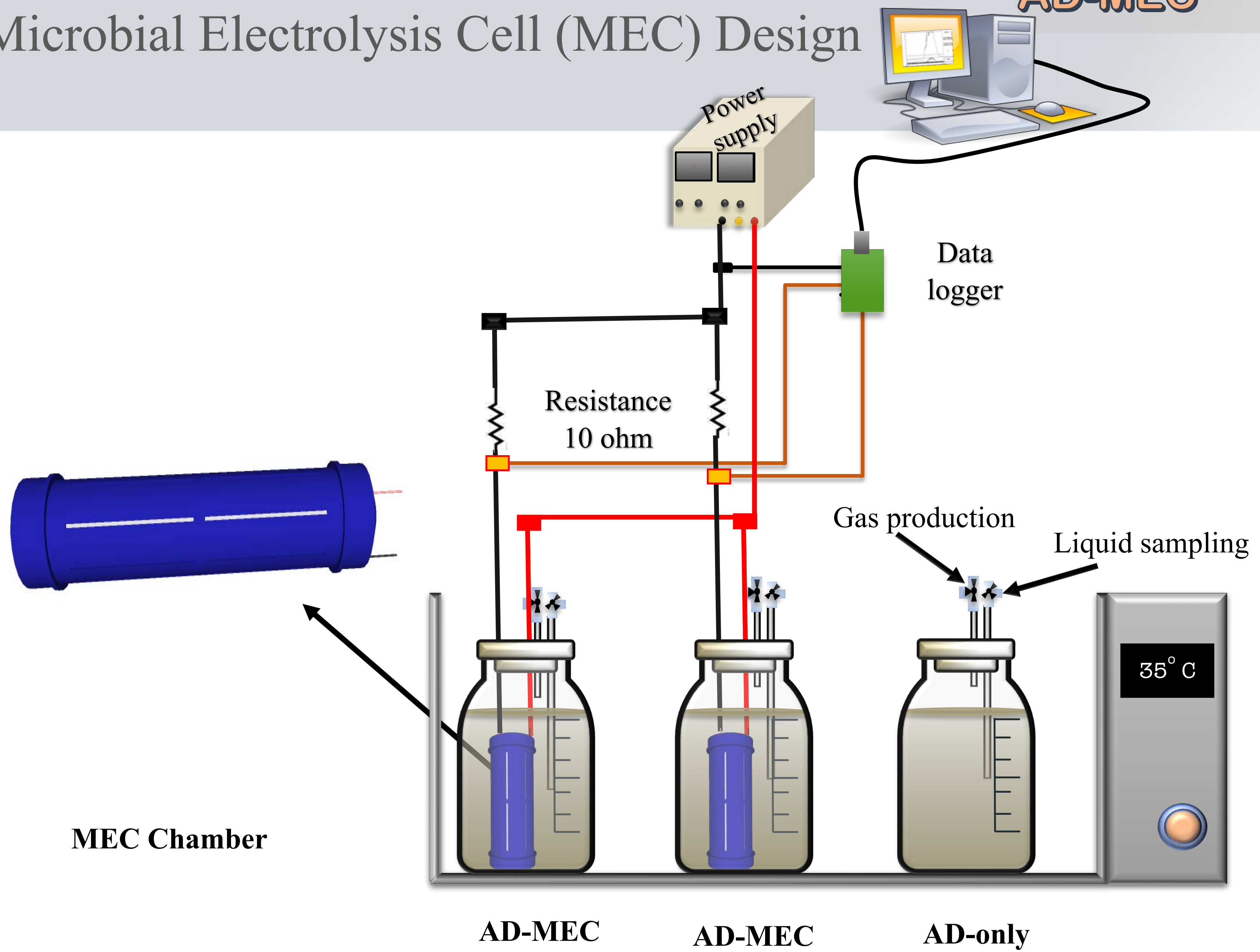




[Big Ten Network Video on Algae Digestion]()

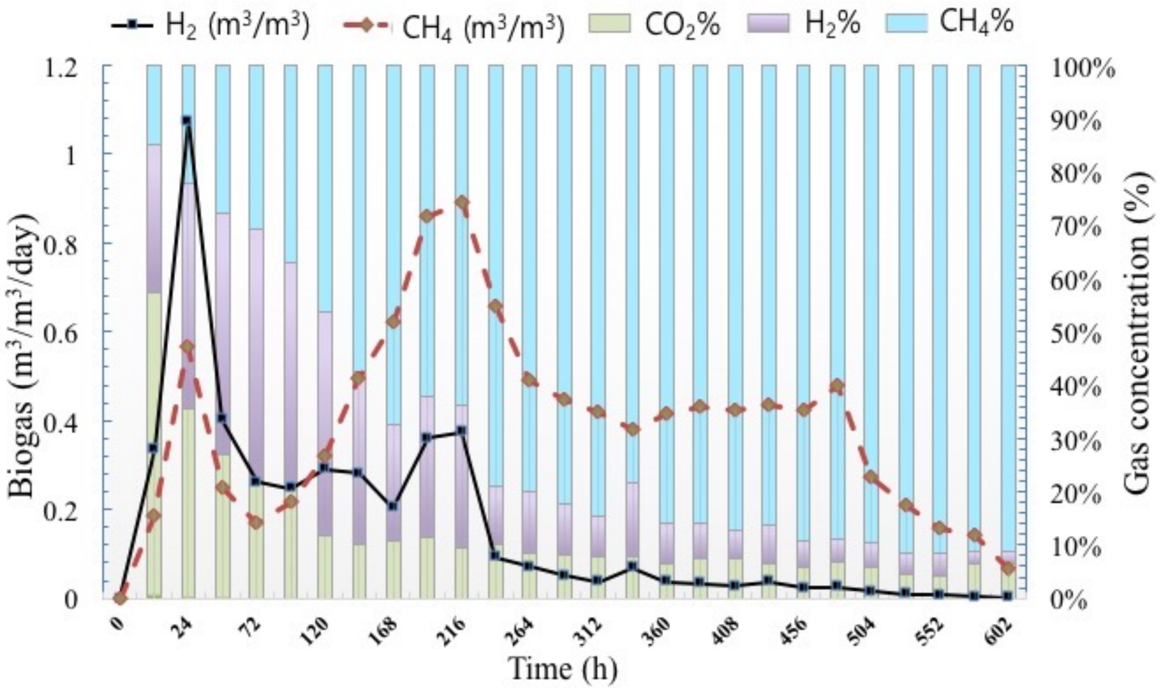
Microbial Electrolysis Cell (MEC) Design

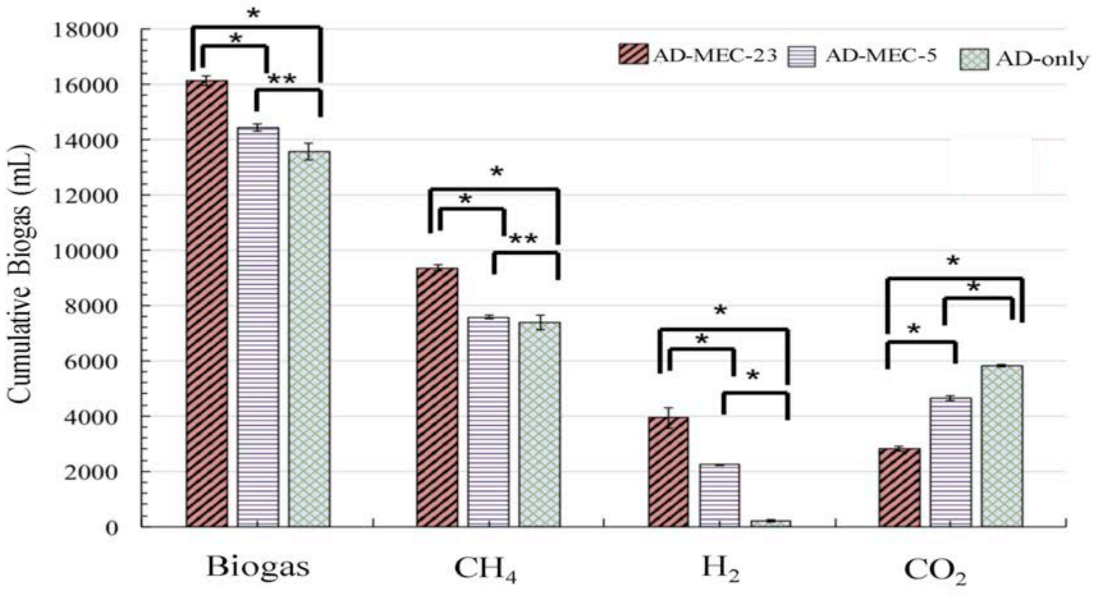
AD-MEC



MEC-AD Results

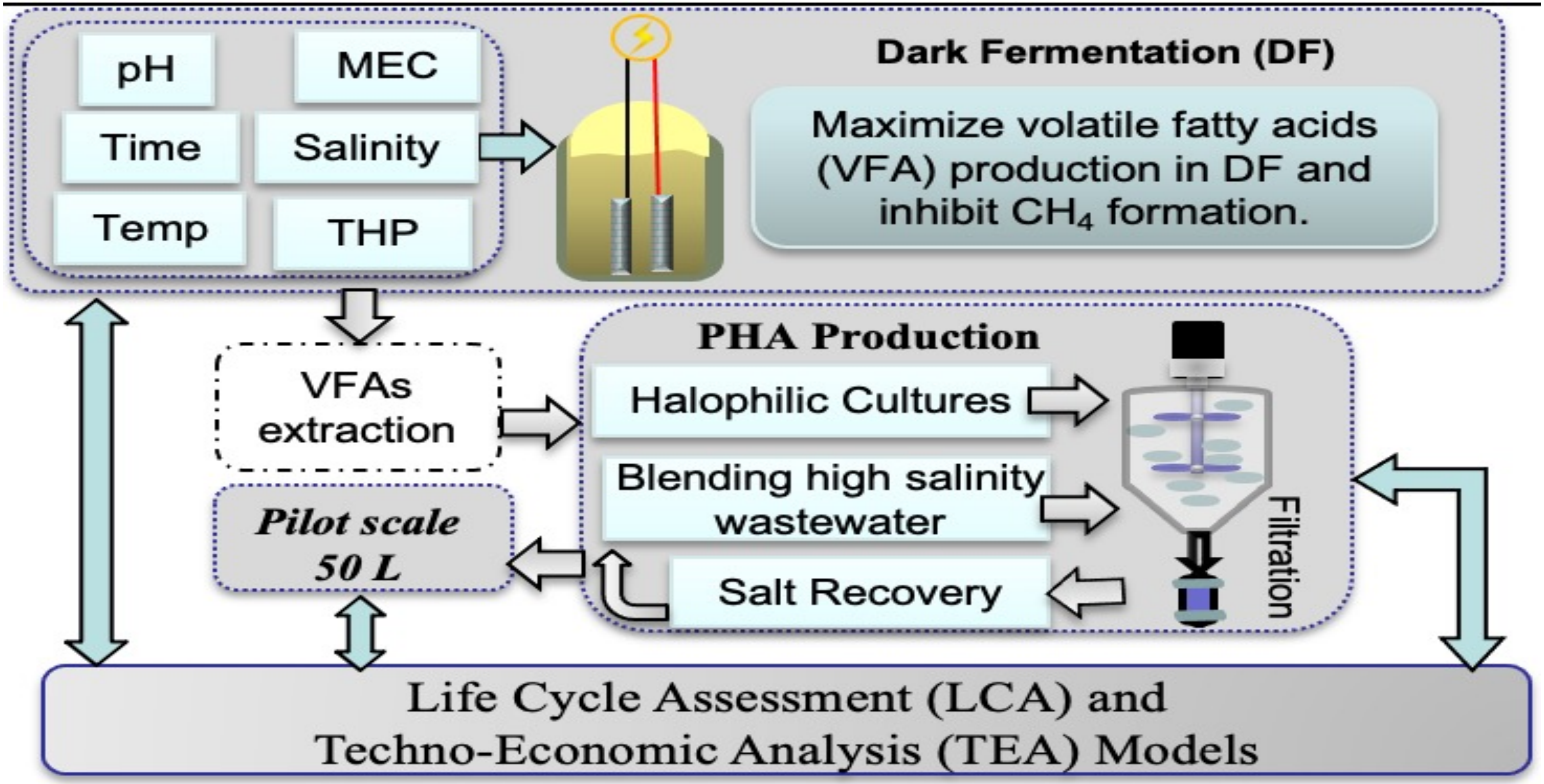
- The AD-MEC produced 27% more CH_4 and 1,680% more H_2
- The CO_2 concentration was reduced to 4% (96% CH_4), with 83% less CO_2 accumulated.
- There was 75% more daily CH_4 and H_2 production (0.59 $m^3/m^3/day$) compared to the food waste-only treatment (0.34 $m^3/m^3/day$).
- Achieved 14% more COD removal than AD-only treatment (83% reduction); at the higher end of COD reduction literature values.





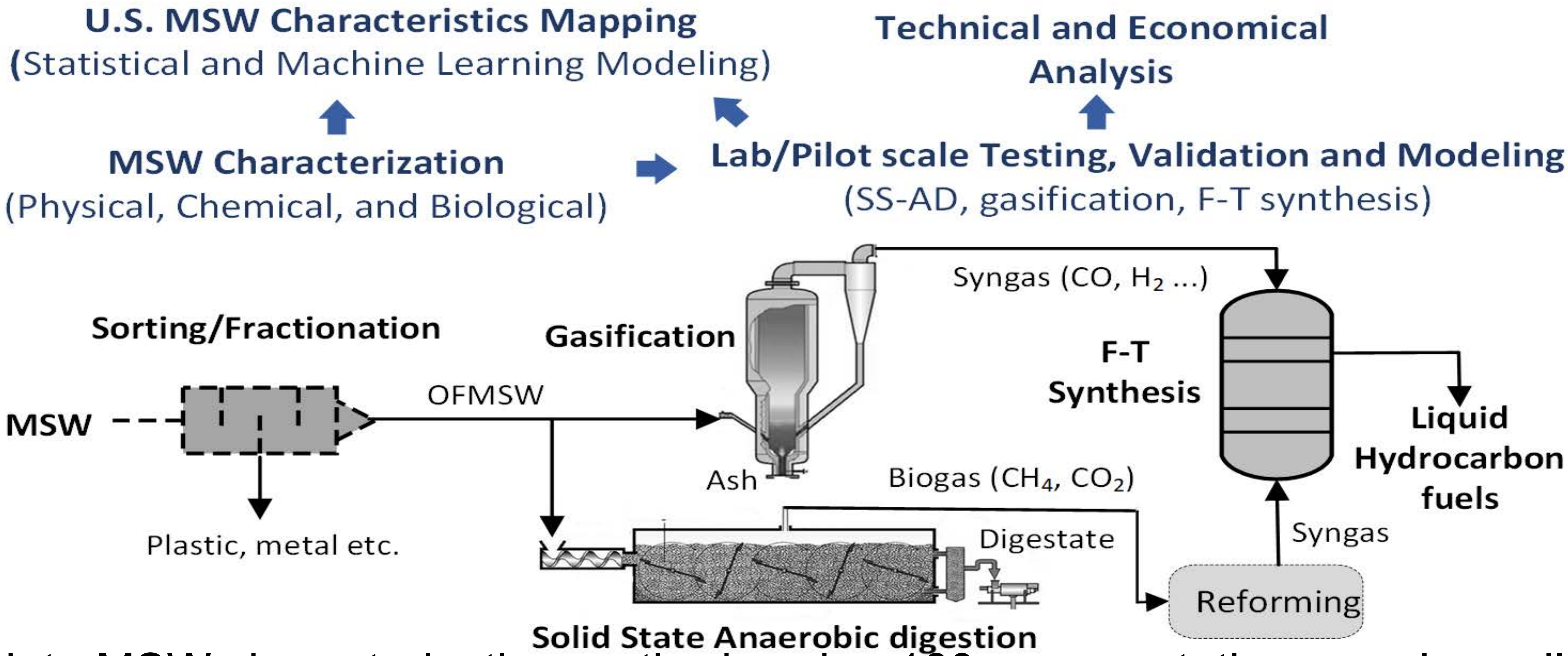
Hassanein et al., 2017; 2020

Innovative Polyhydroxyalkanoates (PHA) Production with Microbial Electrochemical Technology (MET) Incorporation for Community-Scale Waste Valorization



DOE funding ($2.5 million; 2021-2024).

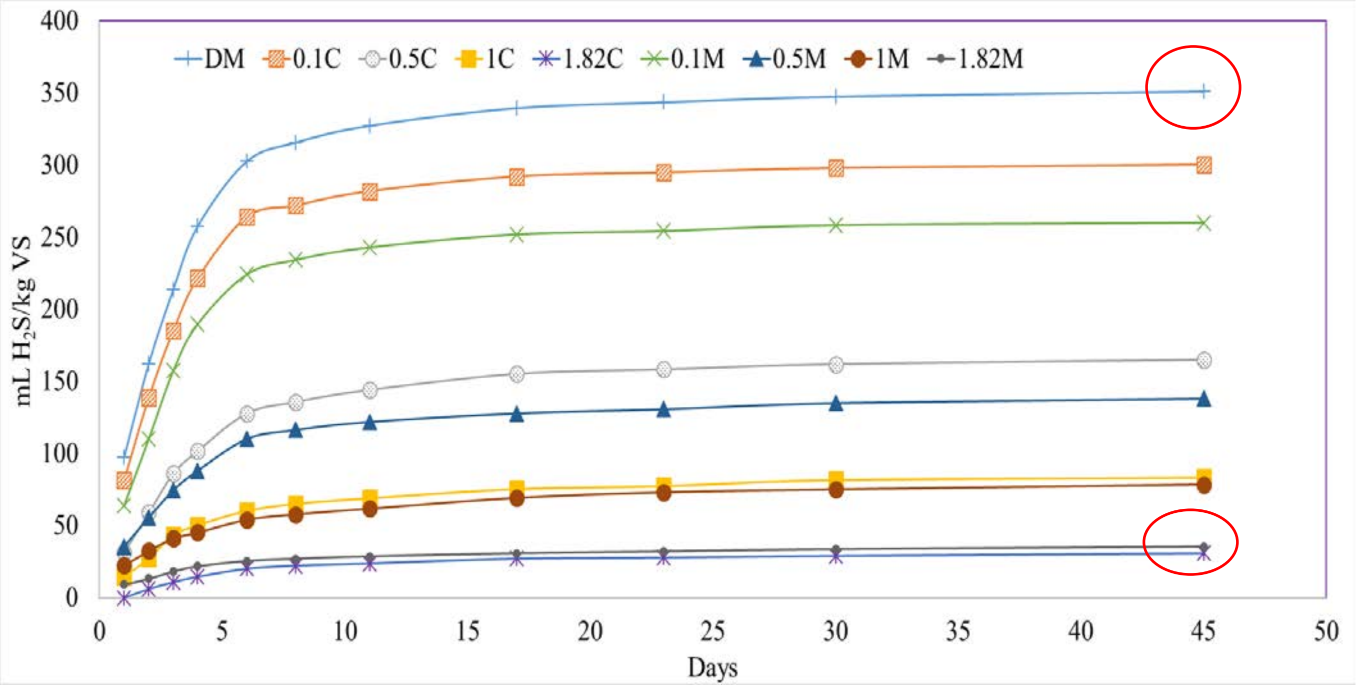
Systematic Characterization of Variability in MSW Streams to Identify Critical Material Attributes for Fuel Production

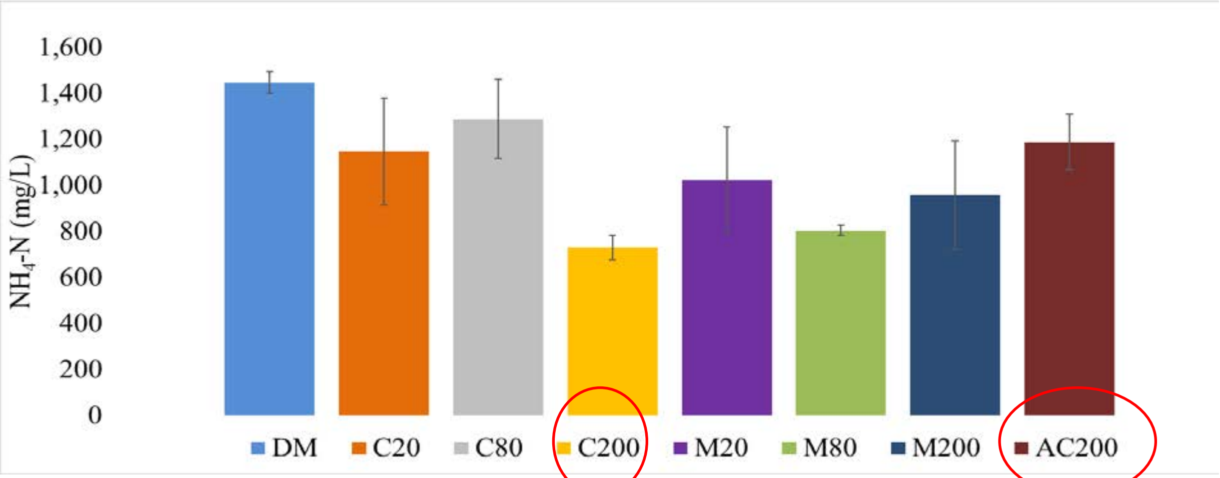


- Validate MSW characterization methods using 160 representative samples collected from 20 MSW facilities/entities for 3 years across the US.
- Develop statistical and machine learning models based on MSW characterization.
- Use LCA and TEA to determine CO_2 emissions for MSW to energy pathways.

DOE funding ($4.3 million; 2022-2025).

Biochar in Anaerobic Digestion



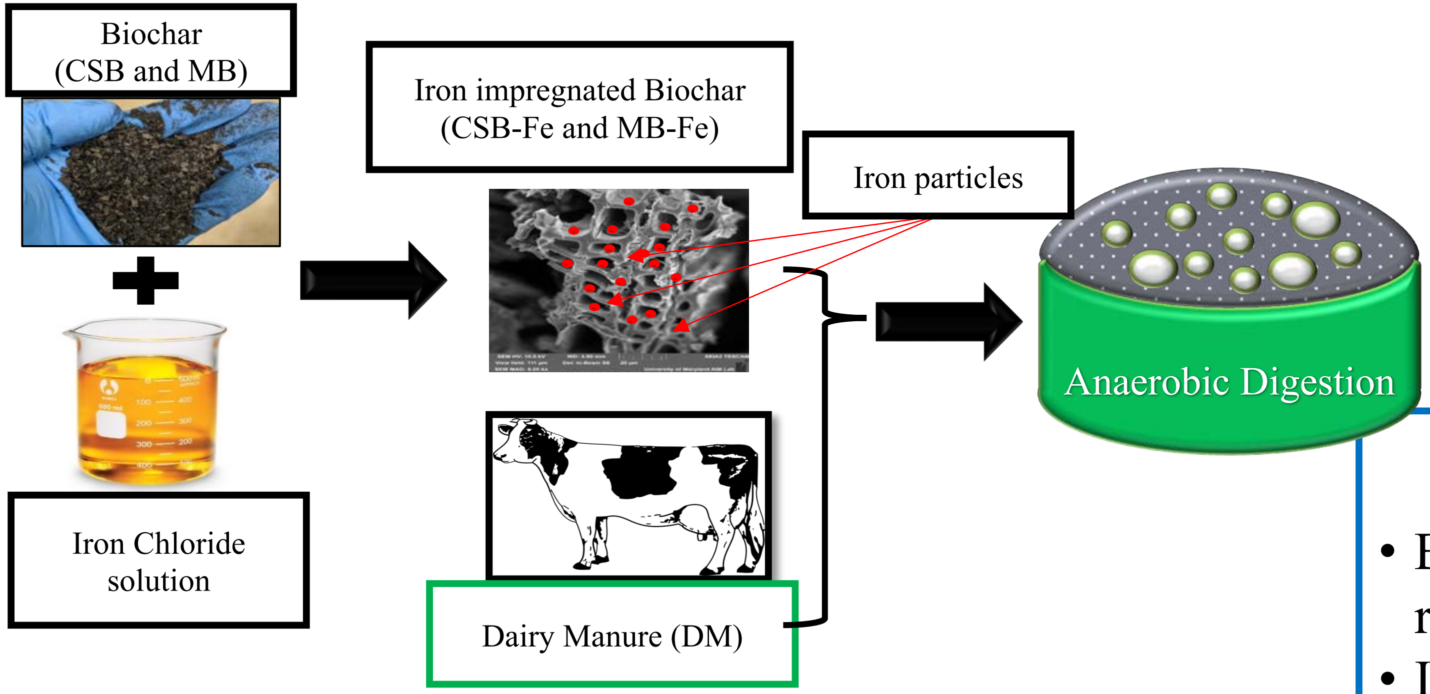


- Two types of biochar: corn stover and wood chips.
- Highest biochar additions had up to 90% reduction in H_2S.
- The biochar absorbed the NH_4-N in the effluent, with a 50% NH_4-N reduction.
- Future research to further understand nutrient removal properties.

Choudhury and Lansing, 2019; 2020a, 2020b

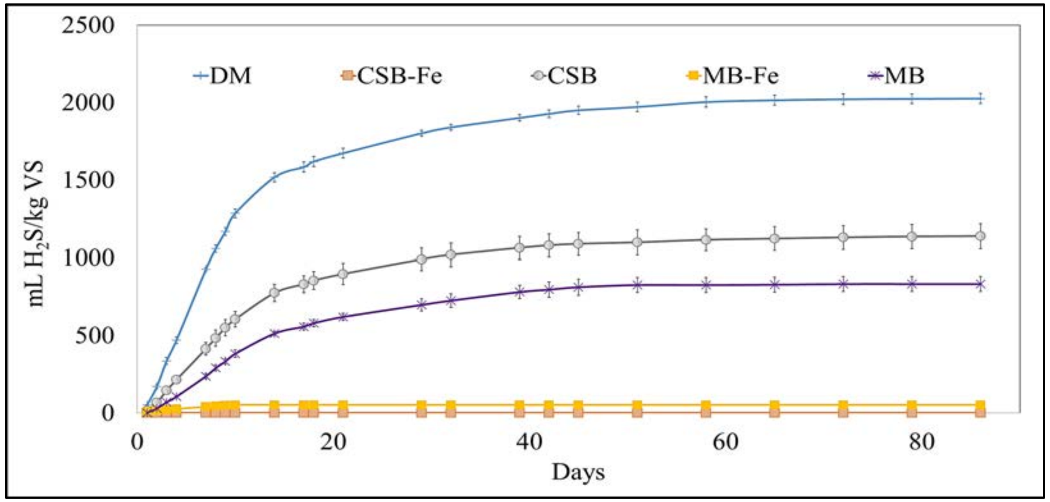
Biochar in Anaerobic Digestion

Corn stover and maple biochar (CSB and MB) with and without Fe-impregnated biochar (CSB-Fe and MB-Fe).



Additional studies with biochar in cassava waste digestion and biochar (Achi et al., 2020)

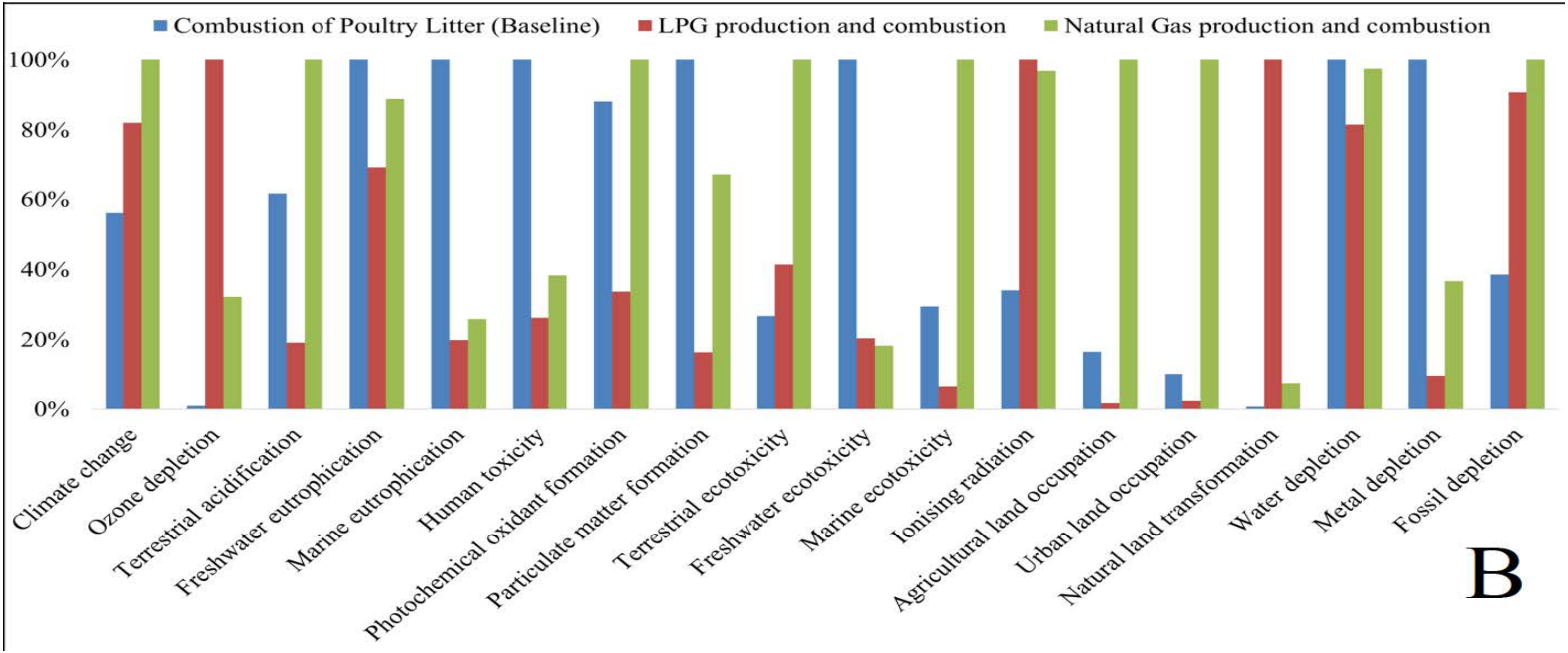
H_2S Reduction



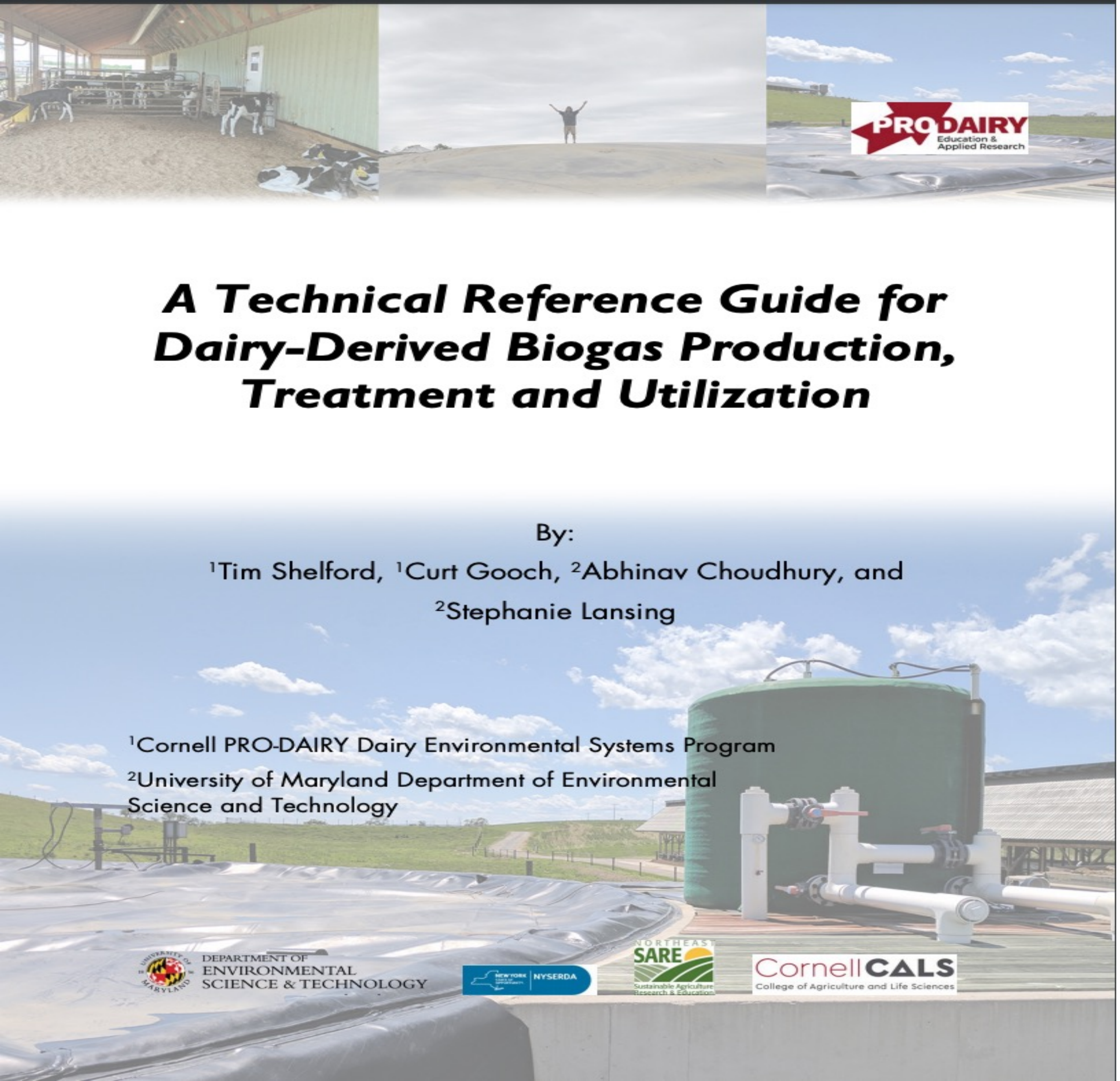
Results

- Biochar (CSB and MB) had a maximum H_2S removal efficiency of 59%.
- Iron-impregnated biochar (CSB-Fe and MB-Fe) had a maximum H_2S removal efficiency of 100%.

Life Cycle Assessments (LCA)



Environmental impacts of poultry litter combustion compared to liquified propane gas (LPG) and natural gas (NG) production and combustion.



PRO DAIRY
Education & Applied Research

A Technical Reference Guide for Dairy-Derived Biogas Production, Treatment and Utilization

By:
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Available at:

go.umd.edu/FarmerBiogasHandbook

UNIVERSITY OF MARYLAND EXTENSION

Solutions in your community

Anaerobic Digestion Series: Draft

Fact Sheet FS-xxx 2017

Draft

Microaeration for Hydrogen Sulfide Removal in Biogas

Introduction

Anaerobic digestion (AD) is the process of microbial decomposition of organic substances in the absence of oxygen. The biogas produced by AD is composed of methane (50-80%), carbon dioxide (20-50%), and trace levels of water vapor and other gases, such as hydrogen sulfide (H_2S).

H_2S is toxic to humans and corrosive to biogas plumbing and utilization equipment. A concentration of 100 ppm is considered immediately dangerous to life and health by the National Institute for Occupational Safety and Health (NIOSH)[1]. Even at low levels (100 ppm), H_2S can cause negative health effects, such as nausea, headaches, and breathing problems, while at higher levels (> 300 ppm), it can cause suffocation[1].

H_2S is toxic and reactive with metals and cement and is readily converted into SO_2 and H_2SO_4, which are also highly corrosive. In addition, combustion of H_2S in gas engine generators forms sulfur dioxide (SO_2).

results in the production of elemental sulfur as the end-product instead of H_2S in the biogas. This biological desulfurization process does not require chemicals or water inputs, which can be costly to purchase, in addition to the time and cost associated with properly managing the purchasing and disposal of any chemical additions[4].

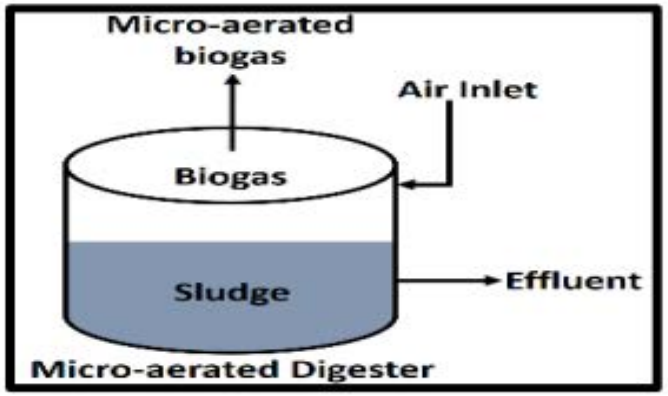

Figure 1: A basic representation of In-situ microaeration.

In-situ Microaeration

Acknowledgements

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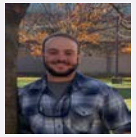

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