Anaerobic Digestion Applications for Municipal Solid Waste: Digester Performance, Biogas Applications, Sustainability and Economics

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Outline of Presentation

1. Review of types of AD technologies and digester performance
2. Biogas applications including:
   a) Electricity production and combined heat and power
   b) Purification and injection into natural gas pipelines
   c) Use as a transportation fuel
3. Post-digestion composting and nutrient recovery
4. Sustainability and AD
5. Economics of AD for MSW

Review of AD Systems Used for Treatment of MSW

Low-solids, single-stage

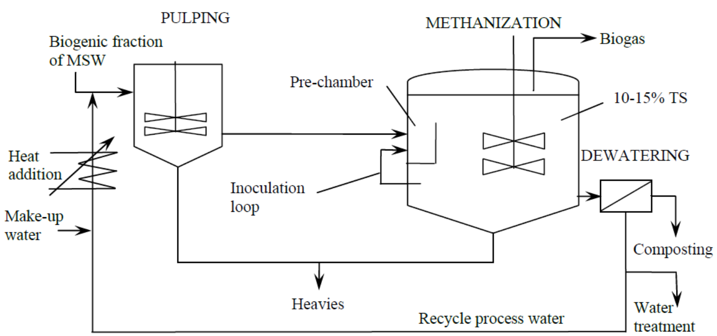
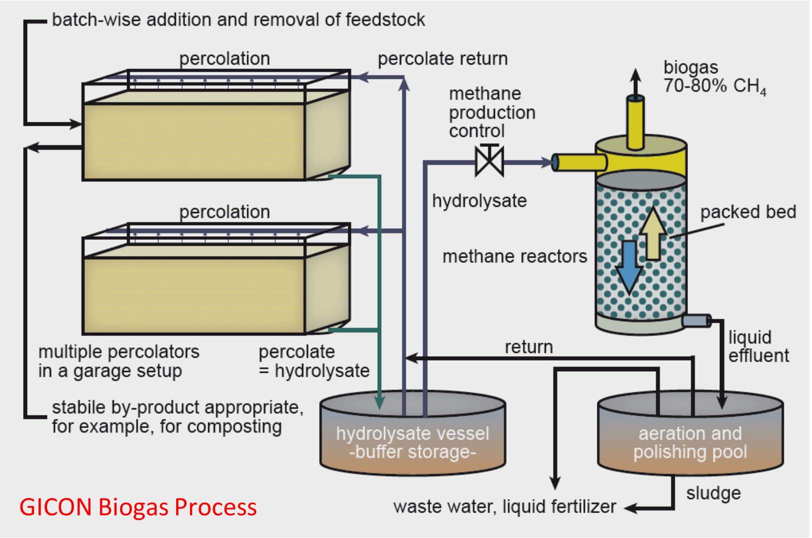


Figure 10. Schematics of the Waasa one-stage digestion process [45].

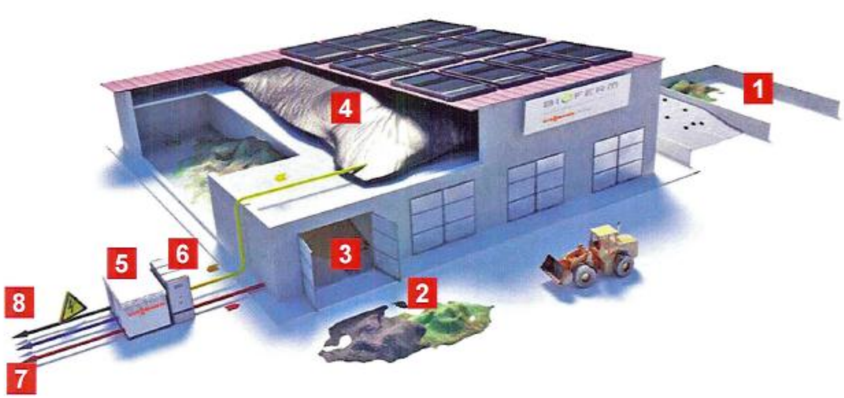
BIMA From Rapport et al., 2008

High-solids, multi-stage



High-solids, single-stage

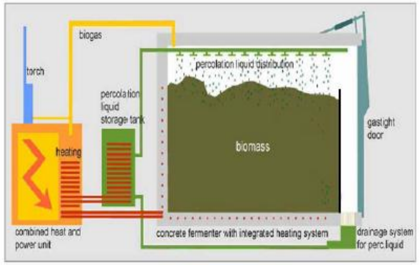
The BIOFerm™ System:



1. Biomass Storage
2. Mixing Platform
3. Fermentation Chamber
4. Flexible Gas Storage
5. Biogas Boiler
6. CHP
7. To District Heating
8. Electric Grid Connection

Landfill-based AD

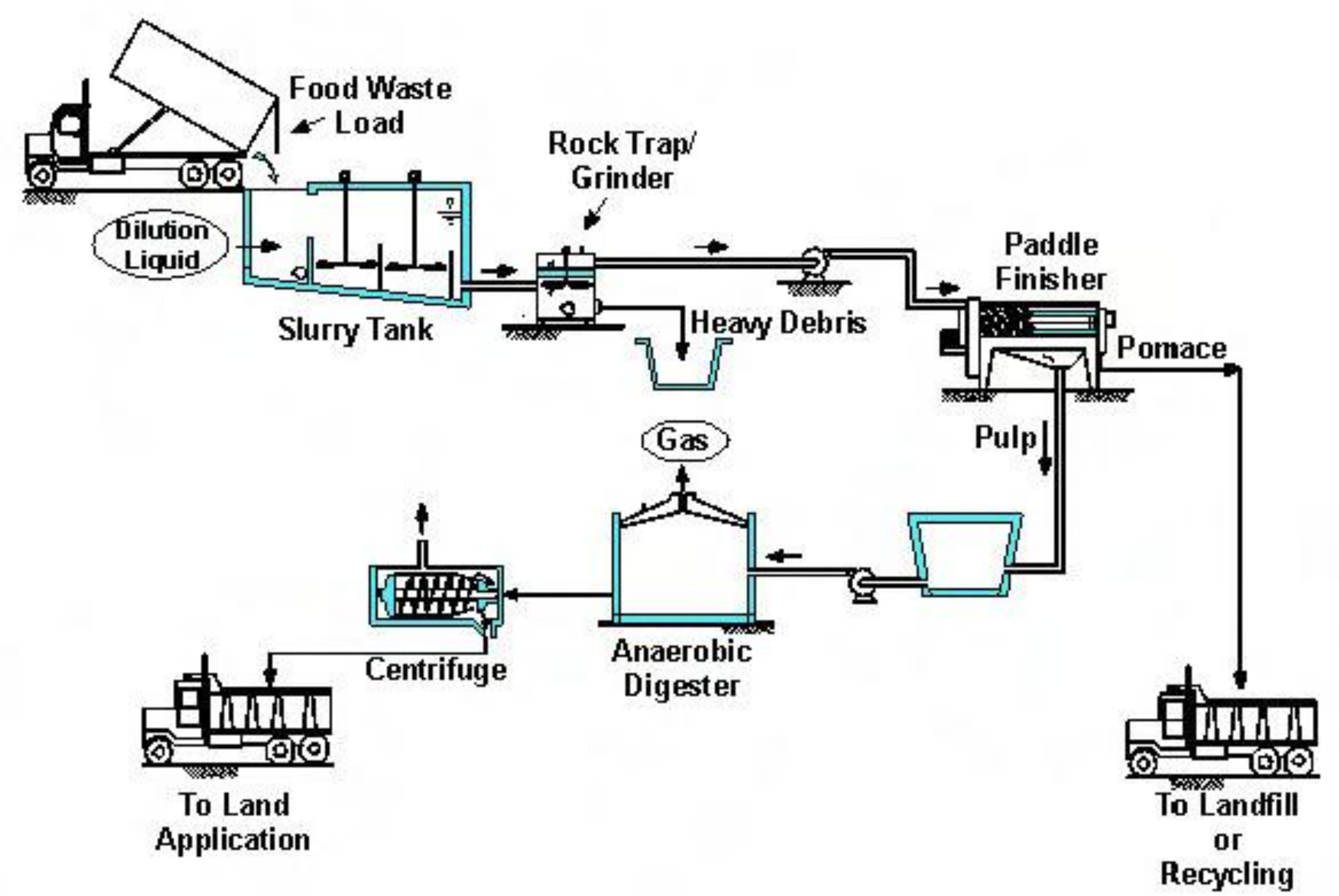
The Process



HARVEST™ Power of We™

WM WASTE MANAGEMENT Think Green.

East Bay Municipal Utility District (EBMUD) Food Waste Co-Digestion with Municipal Wastewater



Source: Gray (2008)

Digester Performance

- Biogas yields
  - Methane biogas (50- 70% methane)
  - Commonly reported range: ~0.10-0.15 m^3/ wet kg (3.2 to 4.8 scf/ wet lb).
    - Not a good basis of comparison because waste composition (VS content and digestability) varies. Be careful!
  - Reported ranges ~0.20-0.6 m^3/ kg dry VS
    - Note that some VS (lignocellulosic materials) is less biodegradable.
  - 0.35 L of CH_4 per gram of BOD_L
- Reactor efficiency
  - Yield X OLR
  - More useful for determining financial viability.
  - Gas production rates range from ~1.5-3.5 m^3/ m^3/ d (0.20 -0.47 scf/gal/d)
- Leachate chemistry
  - Depends on process used

Data from Hartmann and Ahring, 2006 and Rapport et al., 2008

Biogas Yield Depends on Organic Loading Rate

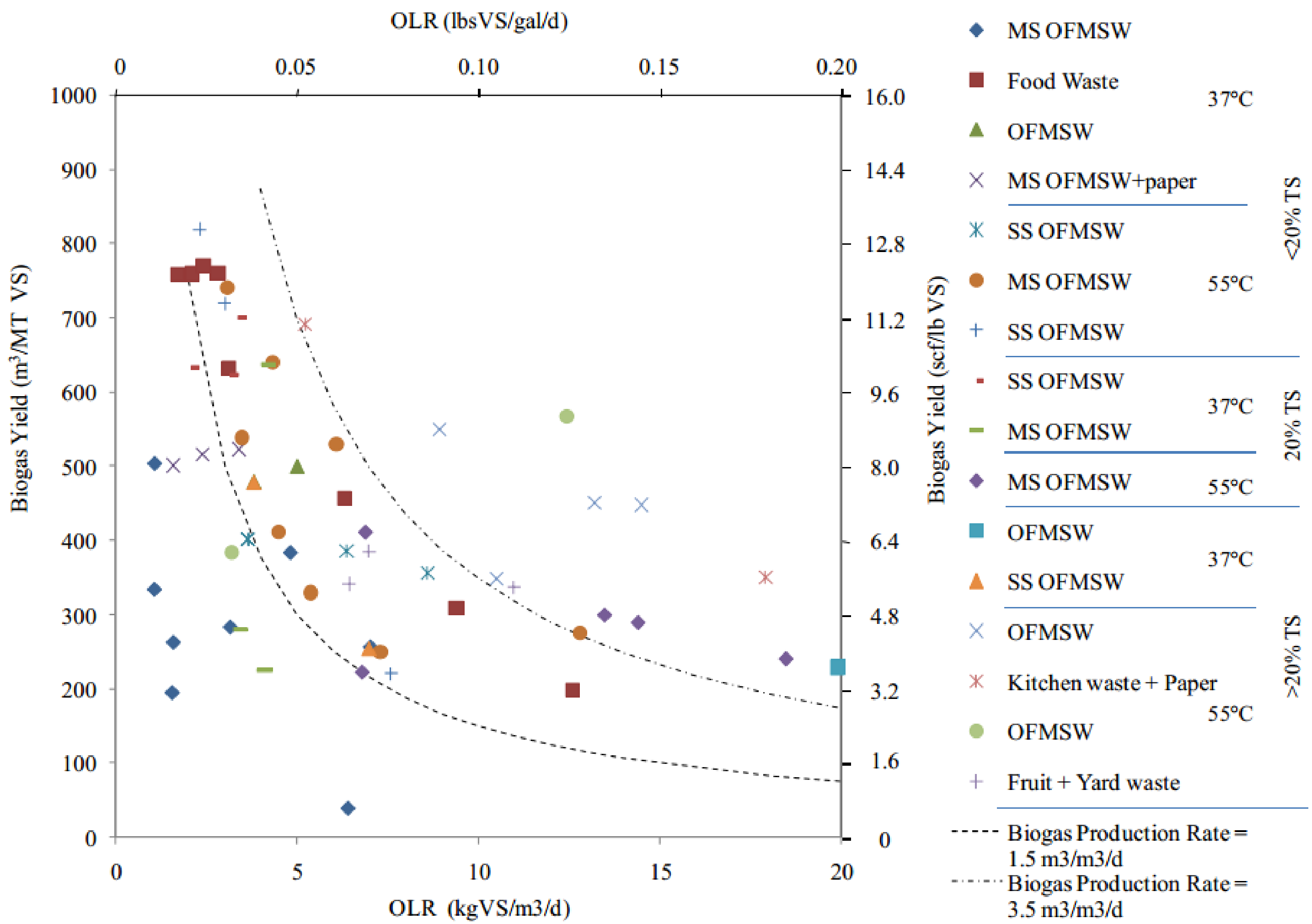
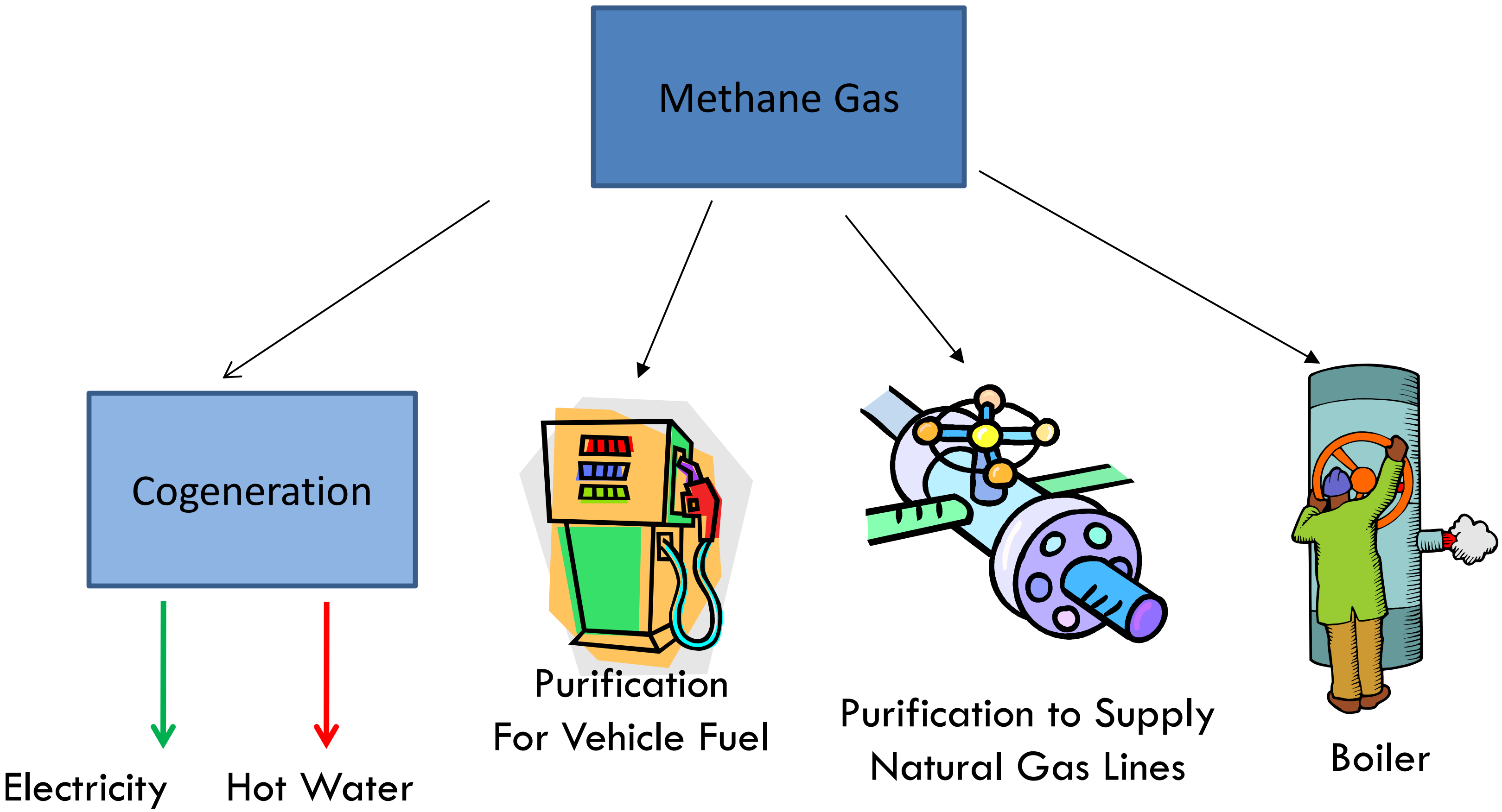


Figure 29. Biogas yield as a function of organic loading rate
Amounts are for lab, pilot, and full scale OFMSW digesters in metric and standard units [115].

Figure from Hartmann and Ahring, 2006 and Rapport et al., 2008

Biogas Applications



Generate Electricity

Source: SEECO

- Reduce Hydrogen Sulfide
  - Passage through Iron packing – oxidized
  - Absorption

Purification for Natural Gas Pipeline

Source: SEECO

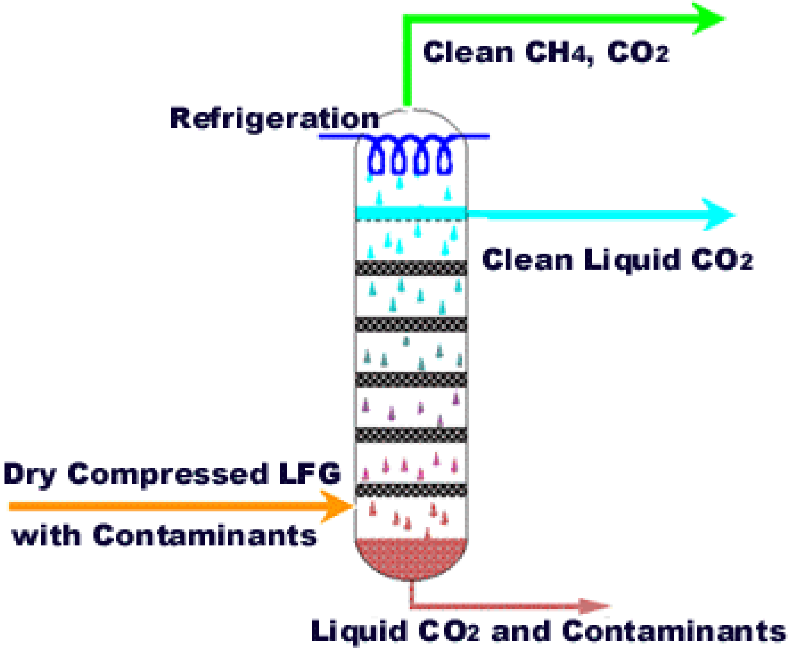
- Organics (siloxane), water removed
- H_2S reduced to 5ppm
- CO_2 Removal

Biogas Purification

- CO_2 removal
  - Membrane separation
    - CO_2 is more permeable than CH_4
  - Pressure Swing Adsorption
    - CO_2 is adsorbed more easily than CH_4 under high pressure
  - Liquid Absorption
    - Alkanolamines or pure water
  - Cryogenic separation

Biogas Purification

- CO_2 removal
  - Cryogenic Separation
    - Cooling and condensation

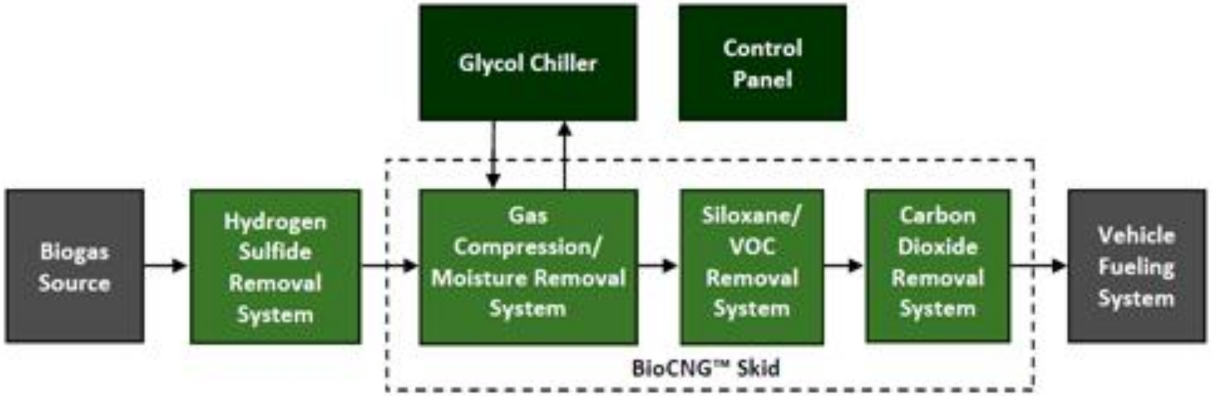


Source: Argonne, Well to Wheels Report

Injection into Natural Gas Pipes

Source: Gas Technology Institute

Use as Vehicle Fuel



Landfill Gas Collection (Riverveiw, MI)

Source: BioCNG™

Use as vehicle fuel

- Compressed natural gas and liquid natural gas often used to fuel waste management trucks

Liquified Natural Gas

Purification and Liquifaction

Altamont, CA

Conversion of Landfill Gas to Liquid Natural Gas

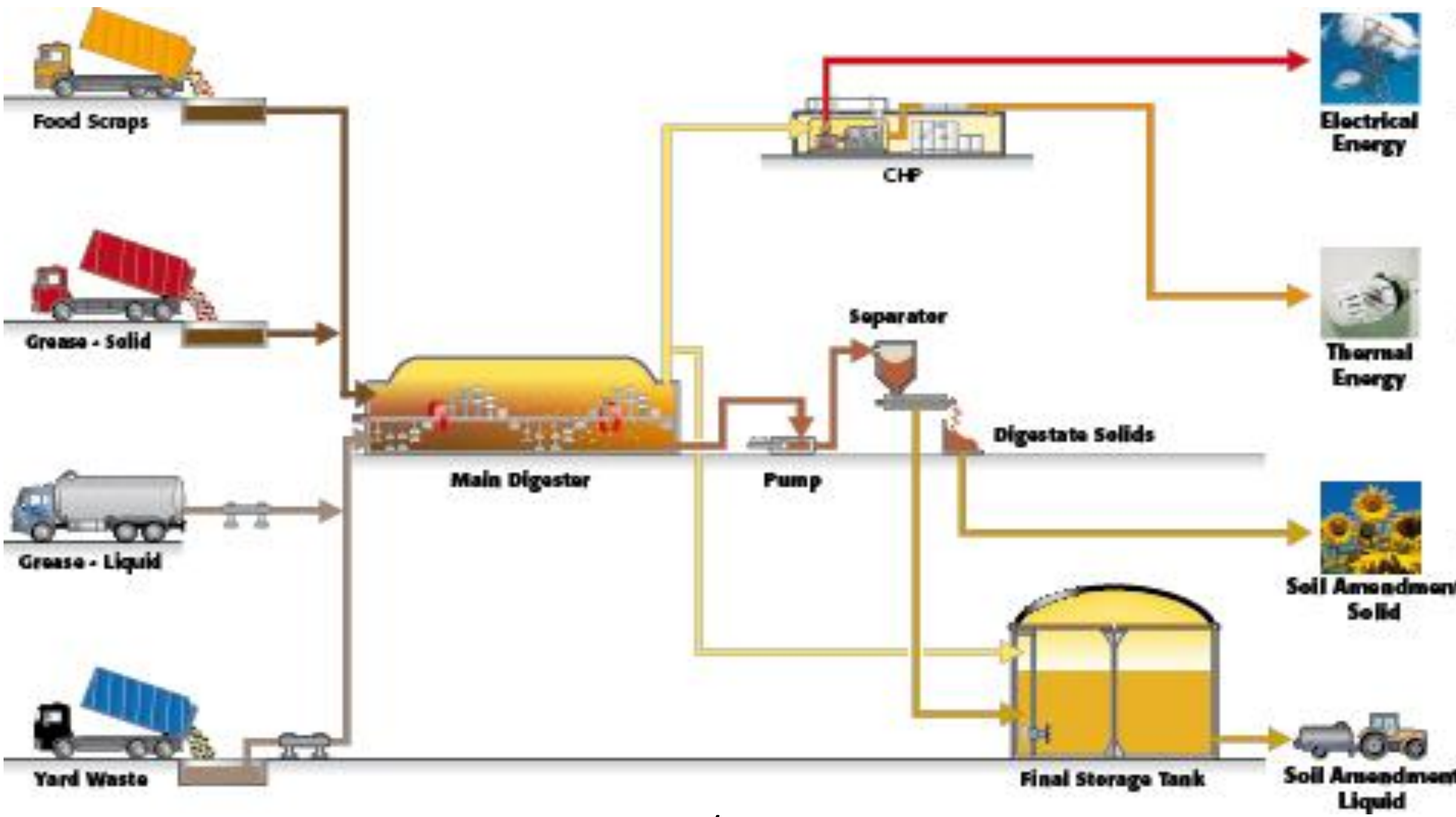
- Clean gas (methane) is cooled to –260°F
- Stored on-site as a cryogenic liquid in insulated storage vessels at 50–150 psi

Energy in Biomethane

Fuel	LHV (MJ/kg)	CO_2 (g/kWh)	Theoretical CO_2 Reduction (%)
Methane/Biomethane	50.0	198.0	29.2
Propane	45.6	236.8	15.3
Butane	45.3	241.2	13.7
Diesel	42.7	267.5	4.3
Gasoline	42.4	279.5	0.0

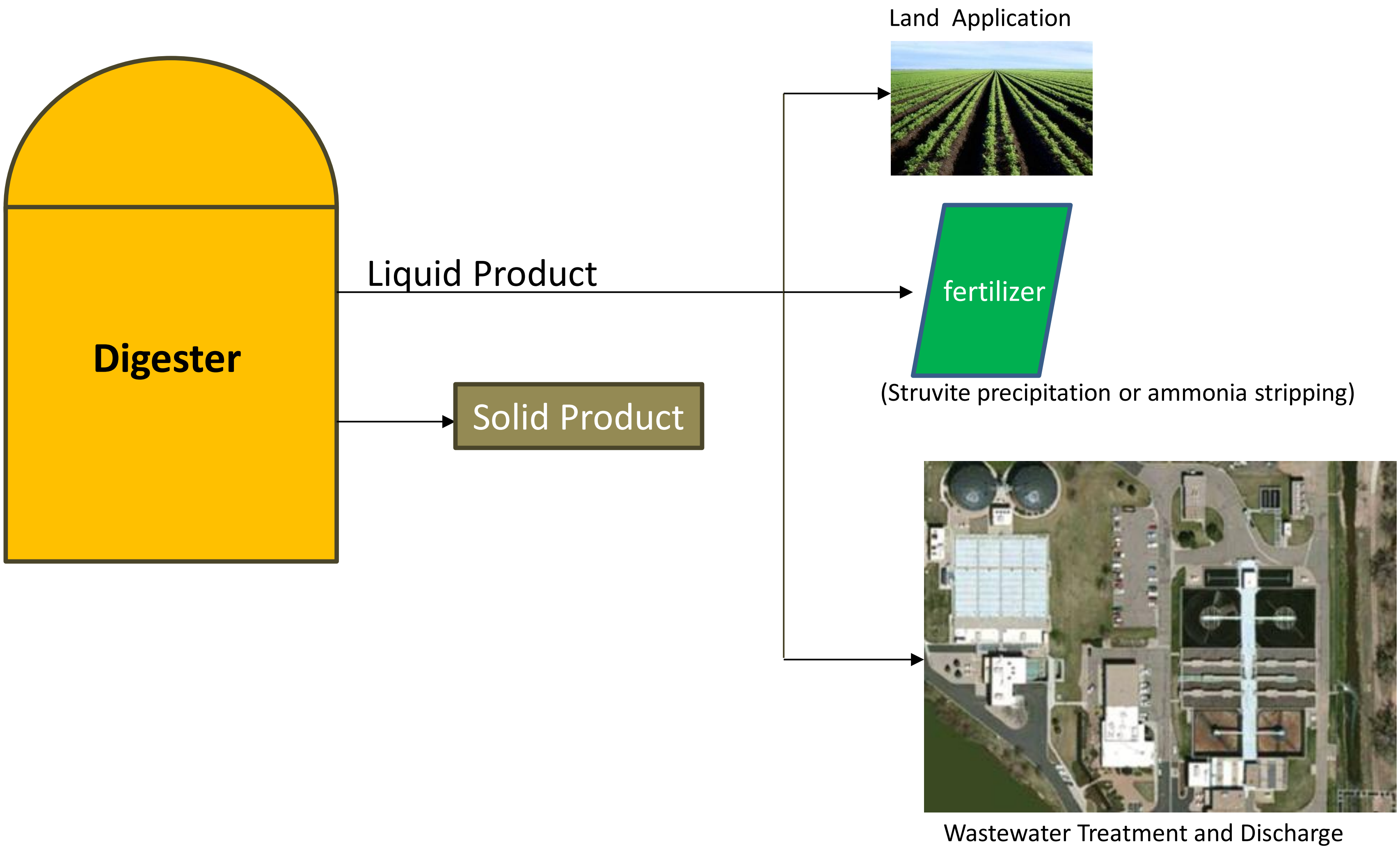
Source: NGVA, 2009

AD Reactor for Source Separated Organic Waste Material



Source: www.eisenmann.com/usa

Liquid Waste Handling



Post-Digestion Composting & Nutrient Recovery

- Composting digestate (from wet or dry systems) can generate valuable soil amendments
  - Separate facility
  - In-vessel composting as last stage of AD process
- Direct use of liquid waste
- Environmental benefits and potential revenue source

Picture 16: Trucking the finished excavated compost for final curing

Picture 17: Windrow of compost for further curing

Images from Yazdani, 2010

Sustainability and AD

- Produce green energy
- Reduces methane emissions from landfills
- Reduce biodegradable content of organic waste prior to composting →reduces emissions of pollutants and GHGs
- Composted digestate can replace chemical fertilizers

Most sustainable option

Life Cycle Assessment for Commercial Food Waste

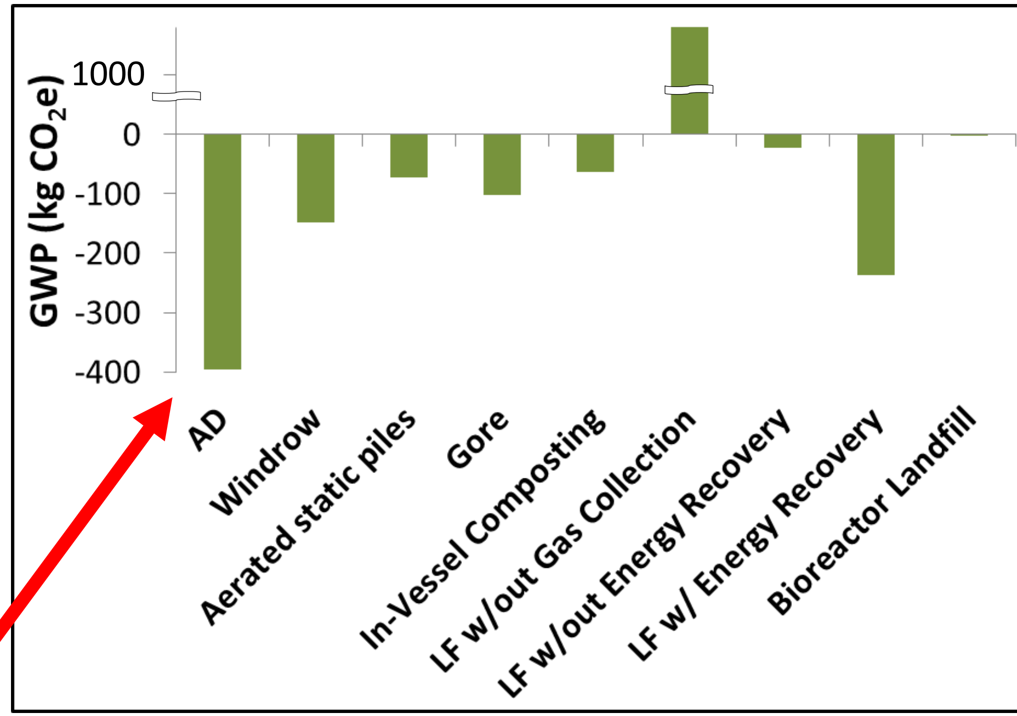
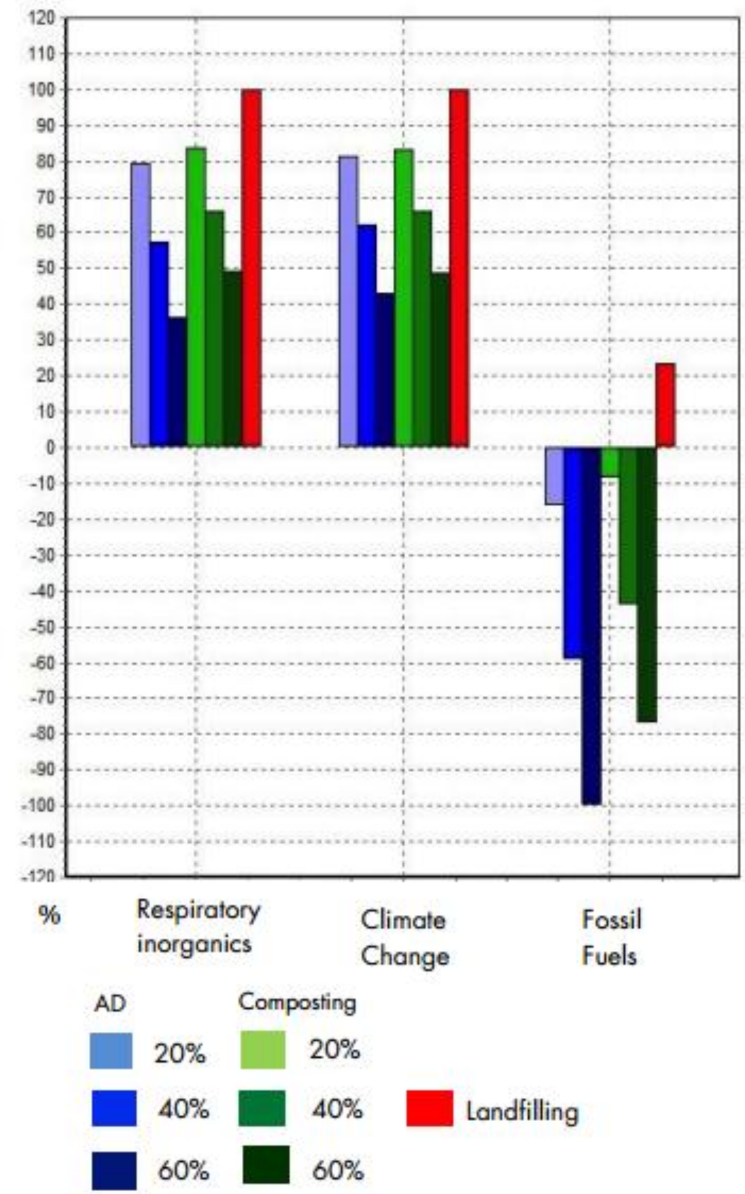


Figure based on Levis and Barlaz, 2011. Data was provided courtesy of the authors.

Sustainability of AD for OFMSW

- A high level of compliance is required to achieve environmental benefits of AD
- Biogas yield differences have only relatively minor impacts on AD sustainability
- Beneficial use of digestate (e.g., replacing commercial fertilizers) is key to maximizing environmental benefits



Results based on an LCA of management options for MSW for Fort Collins, CO (R. Santin, 2013).

Economics of AD for MSW

- Accurately predicting costs and revenues remains challenging due to lack of full-scale systems in the US.
  - Local factors (e.g., tipping fees, labor costs, site conditions etc.) vary.
- Costs to consider
  - Predevelopment: siting, permitting, land acquisition, planning and design, and environmental impact assessment
  - Construction: Infrastructure, buildings/reactors, equipment, and labor
  - Operations: Maintenance, manager training, labor, materials, water and energy, insurance, wastewater disposal, solids disposal, and regulatory fees
- Costs savings possible if incorporated with existing waste management facilities.
- Economies of scale apply.
- Maximizing all revenues is critical (energy, tipping fees, secondary products, and incentives).

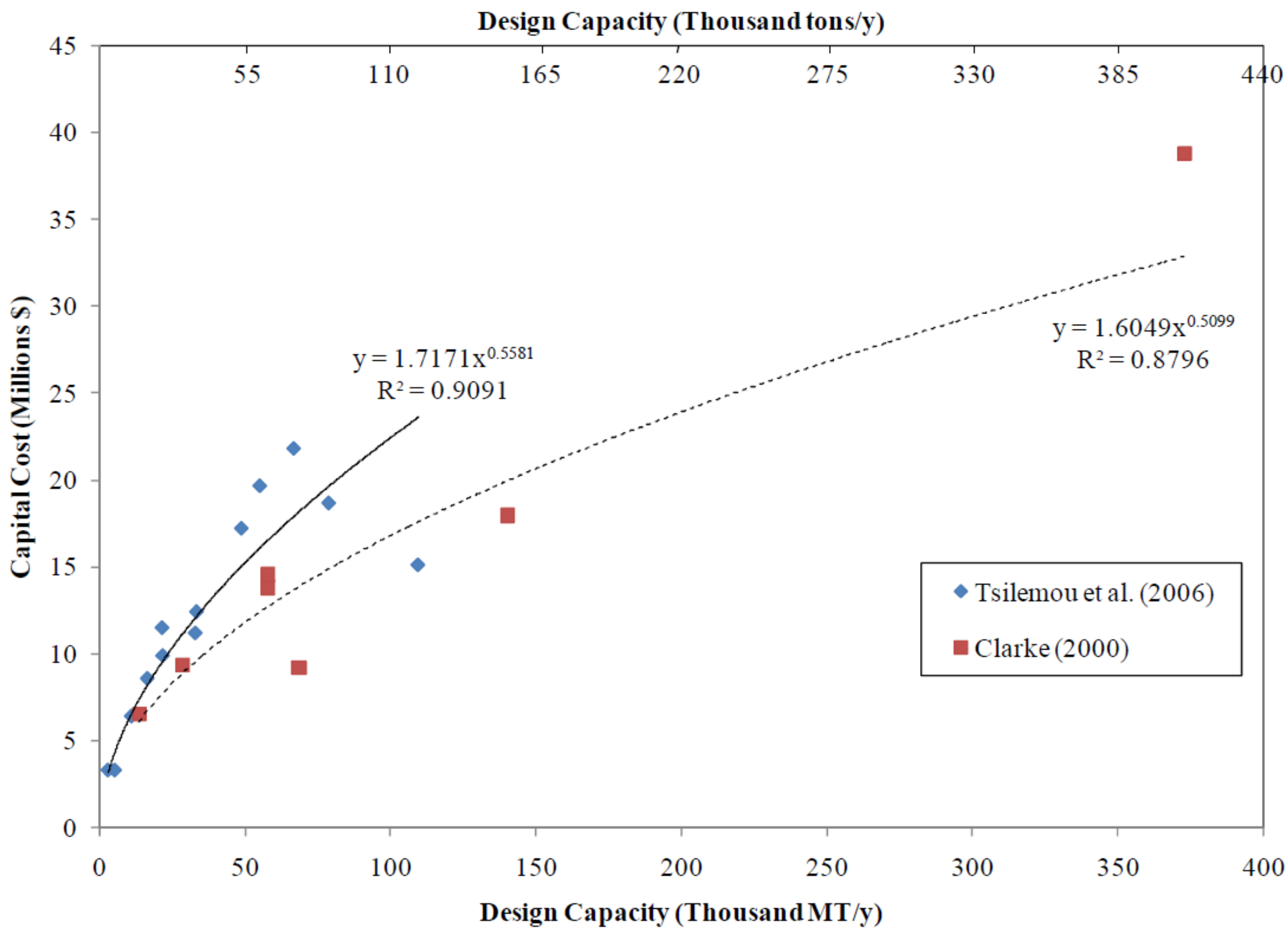


Figure 31. Capital cost curves for European MSW digesters
PPP and inflation-adjusted to 2007 dollars [120, 121].

Figure from Rapport et al., 2008

Carbon Credits and Low Carbon Energy

- CH_4 has 21 times the global warming potential as CO_2
- 1 carbon credit = 1 metric ton of CO_2 = 0.05 metric ton of CH_4
- AD installation can result in ability to gain carbon credits
  - May improve economics
  - Methane capture must be measured
  - Regular inspections on measurement devices
- Can produce a low carbon fuel

Co-digestion at WWTPs

- Co-digestion at existing WWTPs can be economic
- East Bay Municipal Utility District (EBMUD) – Oakland, CA
  - Implemented program in 2004 and processes approx. 20 tons/day of food waste with plans to increase
  - Generates an annual savings of $10 million
- Central Marin Sanitation Authority (CMSA) – San Rafael, CA
  - Program initiated in March 2014
  - Designed their process based off EBMUD
  - Potential to process 109 tons/day of food waste
    - Currently 4-5 tons/day processed
  - Supplies 75% of Marin Sanitation Service

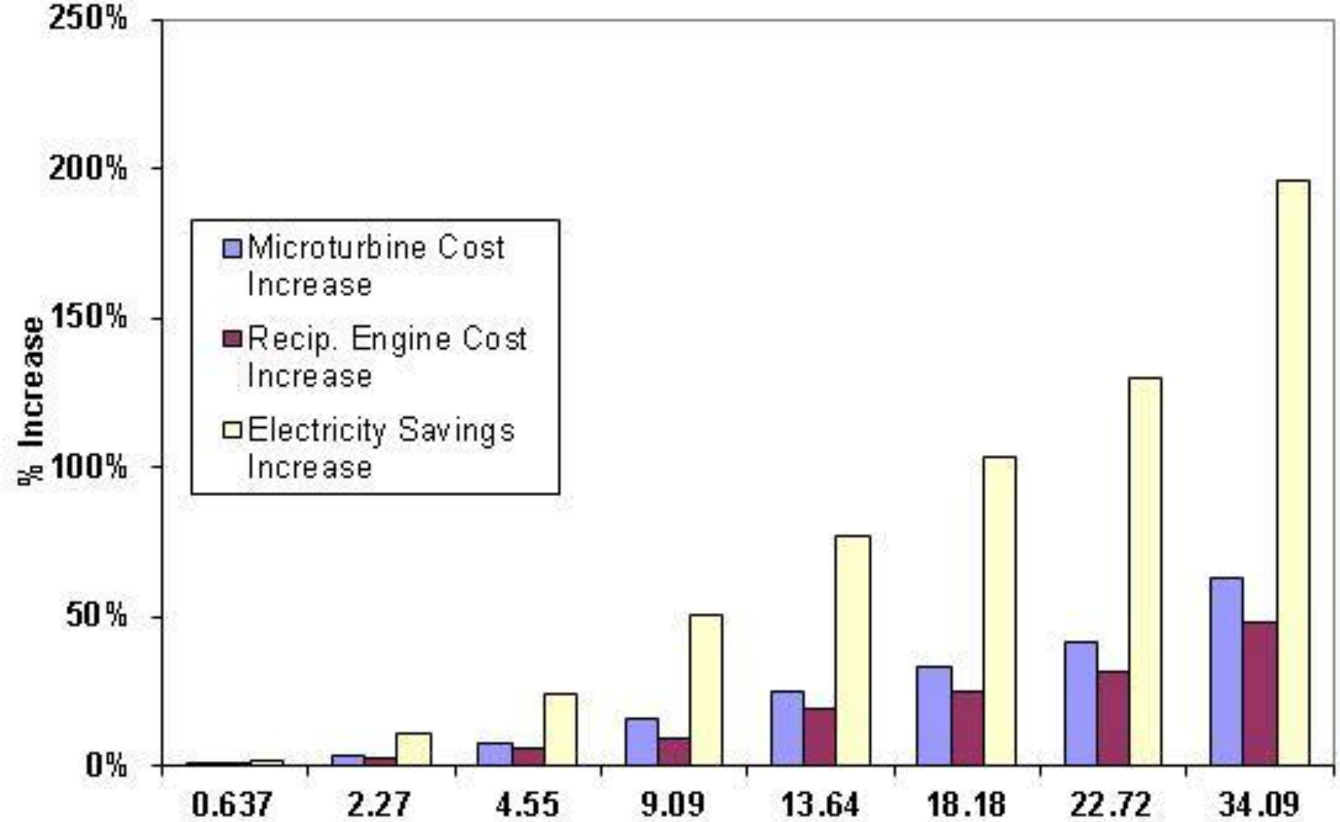
Economics of WWTP Co-digestion

- Feasibility Study at Drake Water Reclamation Facility: 13.6 tons additional food waste per day
  - Not financially feasible based on Fort Collins WWTP average energy charge for 2012 was $.0358 per kWh
  - Financially feasible based on July 2012 national average $0.1010 per kWh for commercial users (Energy Information Adminsitration)

Anaerobic Digesters at Drake Water Reclamation Facility

Mass of Waste Matters

- From City of Fort Collins Feasibility Study



Food Waste Added (Tons/day)

Source: (Robbins and Sharvelle, 2013)

Summary and Conclusions

- Digester performance is best compared on a volume of methane produced per gram of BOD.
- Biogas generation rates are more useful for evaluating financial viability.
- There are a range of options for biogas applications and the best option is case specific.
- Life cycle analysis has shown that AD is the most environmentally-beneficial waste management option.
- Economics remain challenging, but may shift with regulatory changes and changing energy prices.

Selected References

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