Bioenergy Production from MSW by Solid State Anaerobic Digestion (SS-AD)

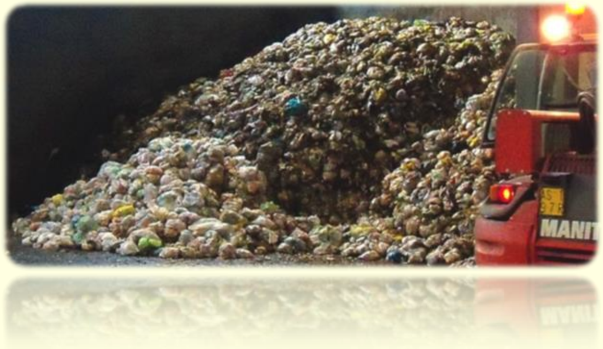
Sarina J. Ergas, PhD, PE, BCEE
Daniel H. Yeh, PhD, PE, LEED AP
George Dick, EI, (MSEV)
Greg Hinds, EI, (MSEV)
Ariane Rosario, (BSCE)

Dept. of Civil & Environmental Engineering
University of South Florida, Tampa, FL

Update to TAG
March 11, 2015

Introduction to SS-AD

- Recent increase in diversion of organic fraction of MSW (OFMSW) from landfills for separate anaerobic digestion in the US
  - Enhanced energy recovery
  - Reduced transportation costs
  - Extend landfill life
  - Decrease leachate strength
  - Reduced fugitive methane release
- Common practice in Europe



Introduction to SS-AD

- AD environmentally superior OFMSW management method based on Life Cycle Assessments

Comparison of GHG emissions (MT CO_2 / MT organic waste) from various organic waste management methods

Management Method	Minimum	Maximum	Median	Mean
Anaerobic Digestion	-0.74	-0.06	-0.14	***-0.25***
Aerobic Composting	-0.76	0.22	0.04	-0.07
Mass Burn WTE	-0.24	0.63	-0.02	0.02
Home Composting	-0.69	0.29	0.14	0.05
LFGTE	-0.31	1.00	0.11	0.16
LF Flaring	-0.06	-0.05	-0.06	-0.06

Jeffrey Morris, S.M., Clarissa Morawski, *Review of LCAs on Organics Management Methods & Development of an Environmental Hierarchy*. 2011, Alberta Environment Edmonton, AB.

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Introduction to SS-AD

- Wet: <10%TS
  - Most common (e.g. WWTP sludge; Harvest Power Orlando)
- Semi-dry: 11-19%TS
- Solid state: >20%TS
  - No excess leachate production
  - Quicker path to stabilized soil amendment
  - Reduced cost (decreased parasitic energy loss)
  - Facilities in CA (San Jose, Monterey, Sacramento, Davis), WI (Oshkosh); others in planning, permitting, or construction phases
  - Promising for Florida because: high availability of OFMSW, warm climate, high energy demand

Example - UW-Oshkosh

- Developed by BioFerm
- 10,000 tons of food and yard waste per year
- 3,300 MW/year
- 8% of campus electricity needs
- $5 million total cost
- Very simple system

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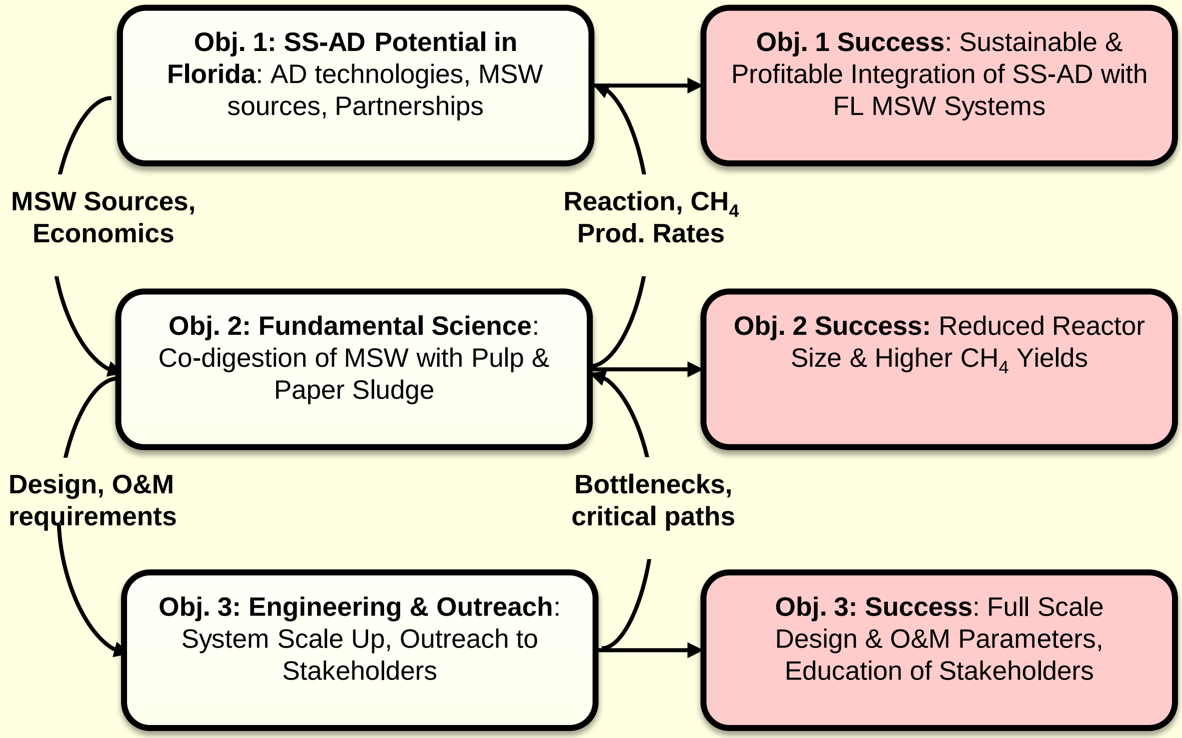
Challenges of SS-AD

- Substrate collection
- Separation of comingled organic wastes
- Breakdown of lignocellulosic substrates
  - Requires pretreatment or long retention times
  - Bioaugmentation is a novel alternative
    - Pulp & Paper Mill AD sludge

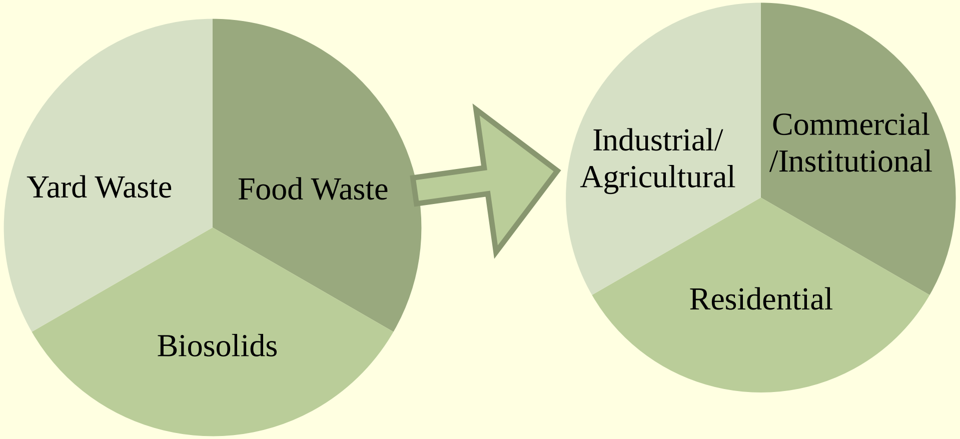
Overall Goal of Project

- To investigate the potential for biogas production in Florida from OFMSW using SS-AD



Objective 1: SS-AD Potential in FL

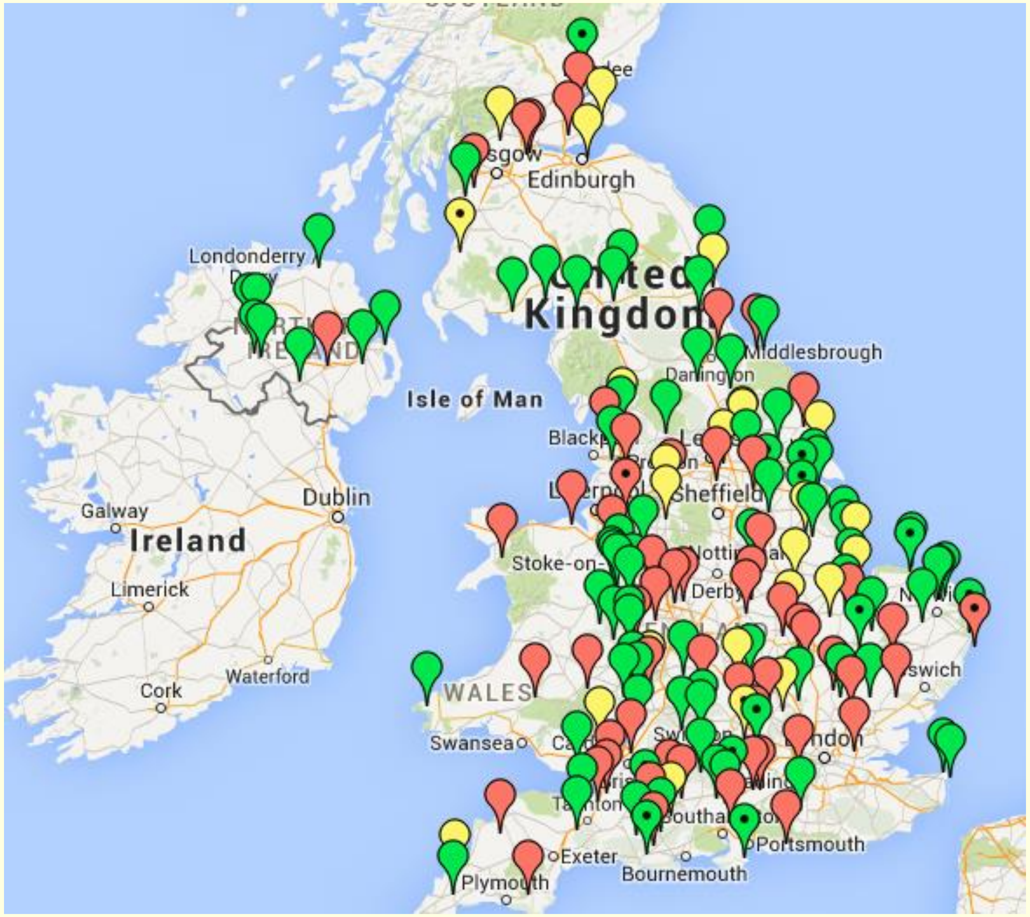
- AD technologies
  - Many vendors emerging in the US
- MSW sources
  - Industry survey

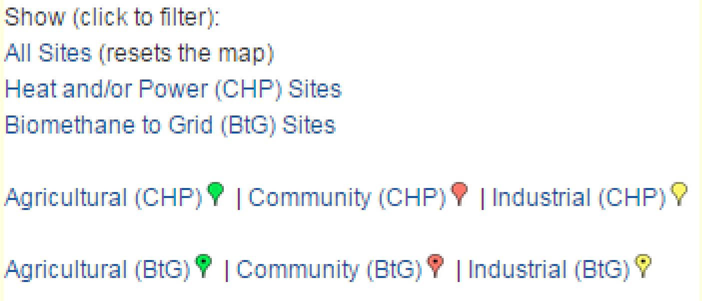


- Partnerships
  - Utility companies?
- Sustainable and profitable integration of SS-AD with FL MSW systems
  - What will it take?

Objective 1: SS-AD Potential in FL

- OFMSW Source Map with type and generation rate similar to the UK's biogas map





- http://www.biogas-info.co.uk/maps/index2.htm

Objective 1: Questions

- Origin of OFMSW sources?
- Generation rates of centralized OFMSW sources?
- Potential demonstration sites?
- Scale?
- Potential funding sources?
- Policy issues?
- Biogas uses?
- Tipping fees at landfills? (~$44 on average)

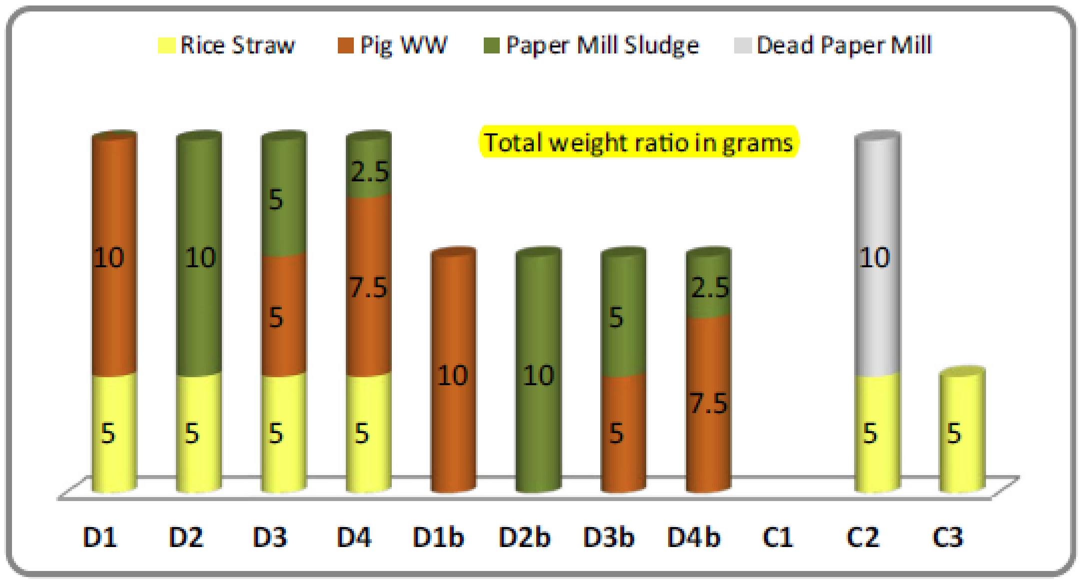
  *Required tipping fee for 5,000 tpy SS-AD:

  ~$10 (assuming 203 kWh/ton @ $0.10 used onsite)

  ~$50 (assuming no electricity production)

  *According to pro-bono cost analysis by SCS Engineers

Objective 2: P&P Sludge Bioaugmentation



Data from Dr. Wendy Mussoline

Methane production and specific methane yields for digesters.

	L_NCH_4[a]	L_NCH_4/kgTS[a]	L_NCH_4/kgVS[a]	L_NCH_4/kgCOD[a]
C1	0	0	0	0
C2	0.172	38	43	40
C3	0.183	41	46	43
D1	0	0	0	0
D2	1.351	301	340	314
D3	1.332	296	335	310
D4	1.198	267	302	279

[a] The values in this table represent methane produced from rice straw only (gas produced from sludge blanks (i.e. D1-b to D4-b) have been subtracted).

Objective 2: Preliminary Research Questions

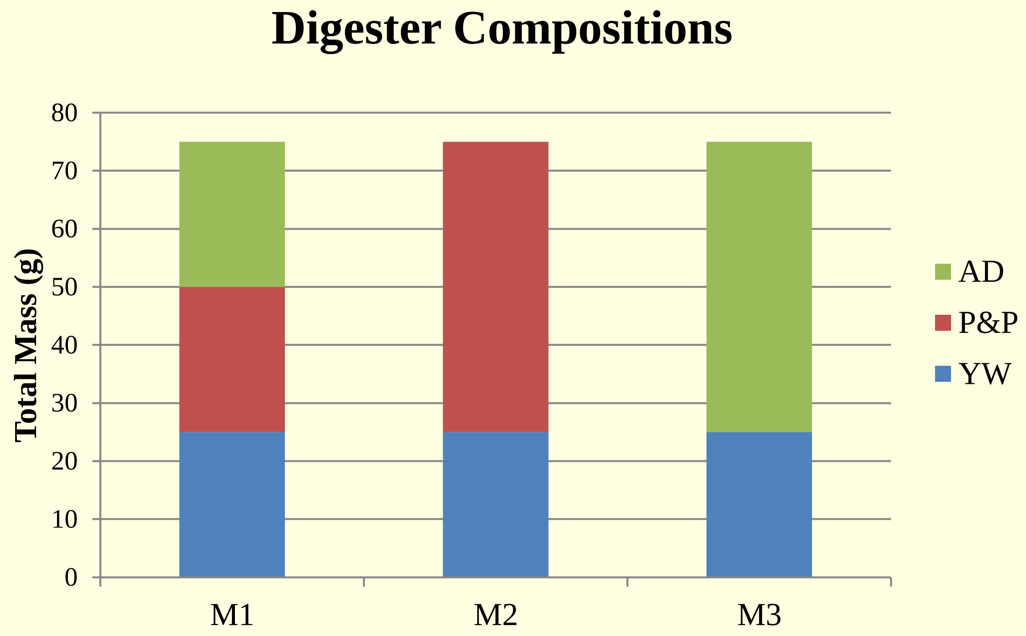
1) Does inoculation with P&P sludge enhance biogas production from yard waste in SS-AD?
   - To what degree?
   - How does it compare with other pretreatment methods?
   - Can enhancement be achieved through digestate recycle?
   - What other inoculum sources enhance lignocellulosic biodegradation?
2) What codigestion strategies provide a sustainable approach for Florida MSW facilities (e.g. various combinations and ratios of yard waste, food waste, and biosolids)?
   - Trade-offs between substrate collection and processing and bioenergy production?

Objective 2: Research Question 1 - Methods

- 3 'mixtures' M1) YW + AD
  M2) YW + P&P
  M3) YW + P&P + AD
- BMP Assays modified from Owens, 1993
  - 20% Total Solids
  - Inverted 3M, NaOH
  - Mesophilic conditions (35 °C)
  - Done in triplicate with 1 intermediate
  - Blanks to adjust methane yields
- Measure:
  - Gas production measured over 60 days
  - pH, alk., TN, TAN, COD, & VFA
  - Heavy metals in digestate – not yet determined
- Compare methane production (Total and Adjusted: L CH_4/kg VS)

Objective 2: Research Question 1 - Methods

- AD –Howard F. Curren Advanced Wastewater Treatment Plant
- P&P – Pulp and paper mill in Eerbeek, Netherlands
- YW – Yard waste from USF
  - sieve to a maximum particle size of one square centimeter



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Objective 2: Research Question 1 – Results

- Results from chemical analyses

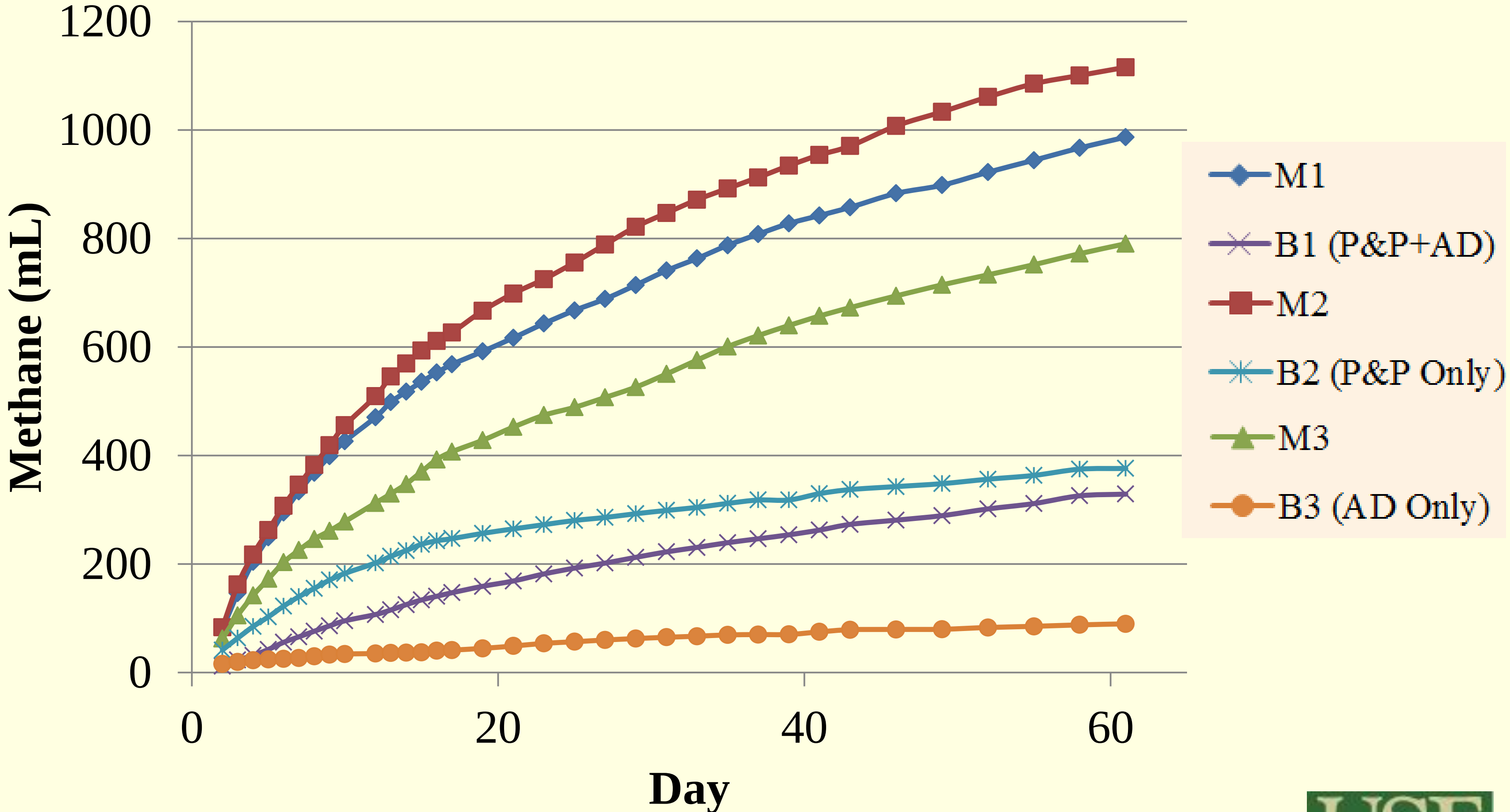
	pH	Alk. (mg/L)	COD (mg/L)	TN (mg/L)	TAN (mg/L)	VFA (mg/L)
			Raw Mixtures			
M1 (P&P + AD)	6.9	180	2200	160	78	1000
M2 (P&P)	7.1	240	2400	120	62	***710***
M3 (AD)	7.4	420	1500	170	100	760
			Final Digestate (60 days)			
M1 (P&P + AD)	8.2	3900	4300	410	440	790
M2 (P&P)	8.1	3300	3500	490	360	***730***
M3 (AD)	8.1	2700	1800	230	250	510

- Ammonia inhibition concentration = ~2,500 mg/L
- VFA decrease = acetogenesis is outpacing hydrolysis; hydrolysis is limiting
- VFA increase = hydrolysis is outpacing acetogenesis; hydrolysis is not limiting

Objective 2: Research Question 1 – Results

Objective 2: Research Question 1 - Results

Cumulative Methane Production



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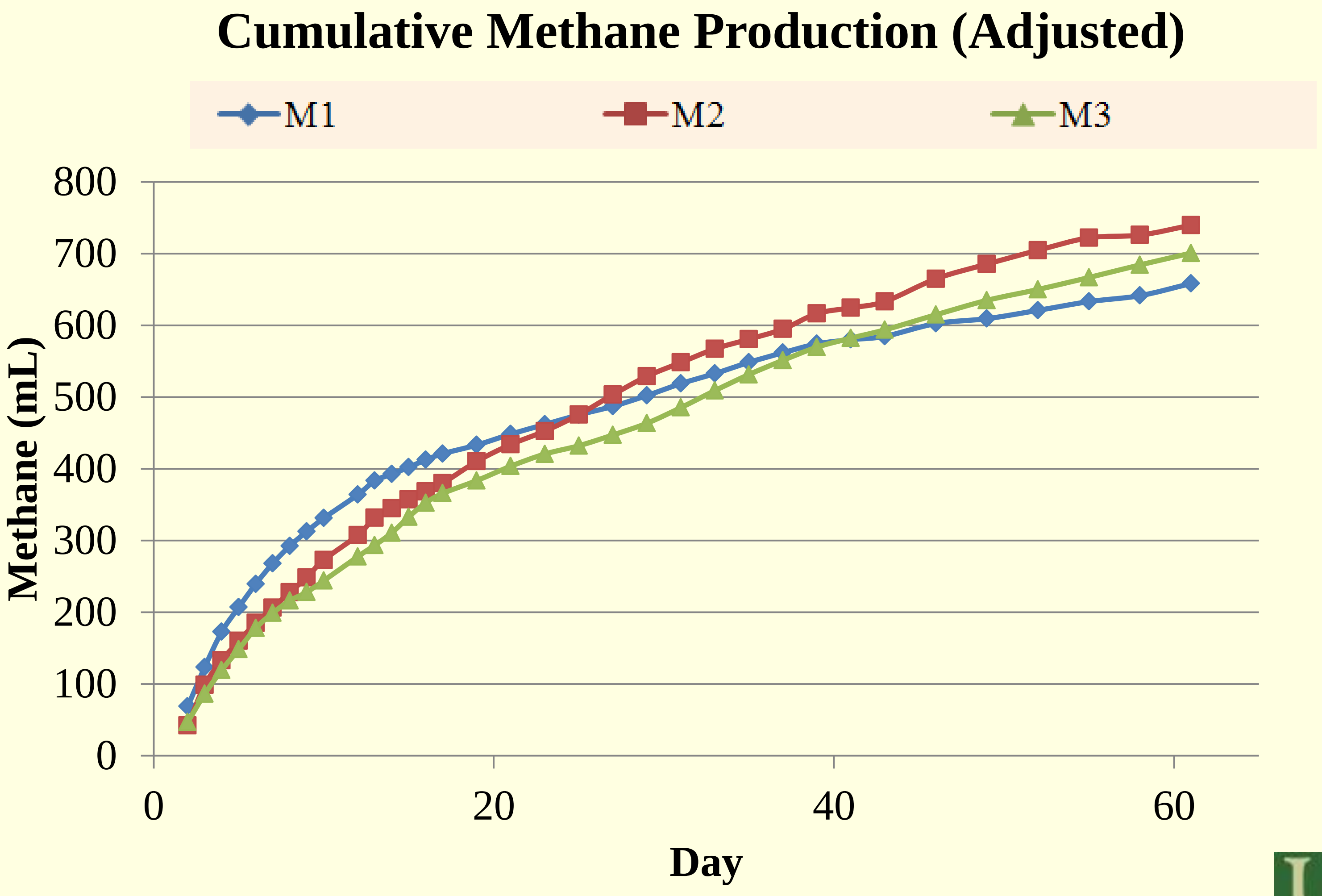

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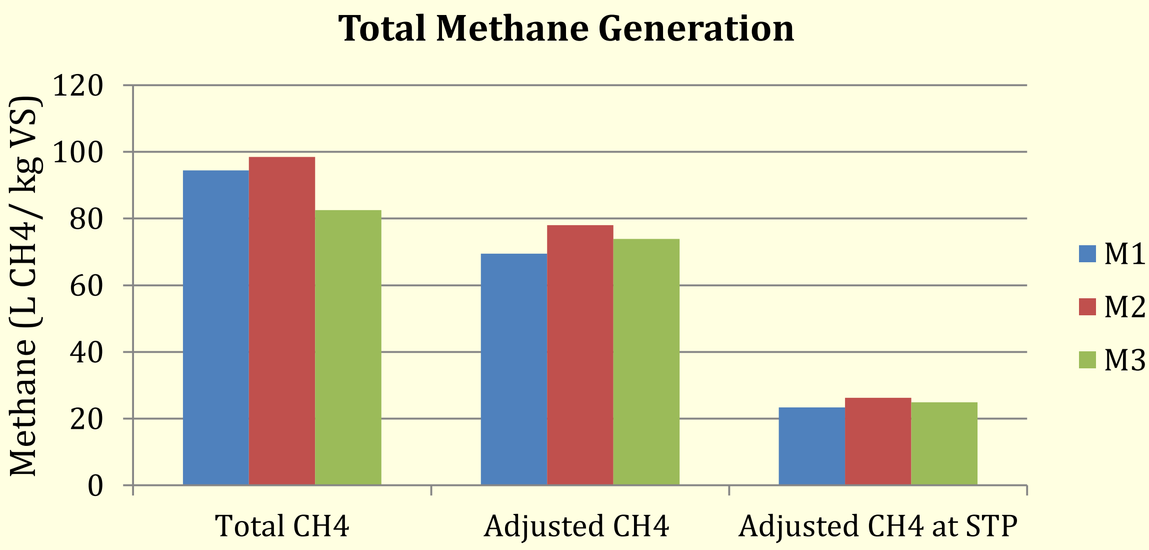

		Total CH_4		*Adjusted CH_4*		*Adjusted CH_4 at STP*	
		L	L CH_4/ kg VS	L	L CH_4/ kg VS	L	L CH_4/ kg VS
M1 (P&P + AD)		1.0	94	0.66	69	0.22	23
M2 (P&P)		1.1	99	0.74	78	0.25	26
M3 (AD)		0.8	83	0.70	74	0.24	25
% Increase	M1 vs. M3	25%	14%	-6%	-6%	-6%	-6%
	M2 vs. M3	***41%***	***19%***	***5%***	***5%***	***5%***	***5%***

Objective 2: Research Question 1 - Discussion

Zheng Y., Zhao J., Xu F., Li Y. 2014. Pretreatment of lignocellulosic biomass for enhanced biogas production. Prog Combust Sci; 42: 35-53

Biological pretreatment	Results	Feedstocks
Fungal pretreatment	15% to 5 folds increase of methane yield	• Agricultural residuals: sweet chestnut leaves/hay and sisal leaf decortications residue (SLDR) • Hardwood: Japanese cedar wood chip
Microbial consortium	Methane yield improvement by 25–96.63%	• Agricultural residuals: corn straw, corn stalks, cotton stalks, cassava residues, and manure biofibers
Enzymatic pretreatment	0–34% increase of methane yield	• Agricultural residuals: Sugar beet pulp, spent hops, and manure biofibers • MSW: pulp and paper sludge • Grass: jose tall wheatgrass
Ensilaging	15% increase of methane yield, but negative effect was also found	• Agricultural residuals: maize

Objective 3: Engineering and Outreach

- System scale-up
  - Pilot system constructed
  - SS-AD at USF
    - Conducting feasibility study and LCA for SS-AD at USF with interdisciplinary team for reapplication to SGEF
- Outreach to Stakeholders
  - *Talking Trash* spring newsletter article
  - Proposal submitted to *Biocycle*
- Education of stakeholders
  - Abstract submitted to WASTECON
  - Engineering EXPO demonstrations
  - Poster presentations
    - AEESP Lecture at UCF, USF Research Symposium, Presenting at NAWTEC and USF Undergrad Research Colloquium

Objective 3: Engineering and Outreach

Questions, comments?

Thank you TAG and Sponsors

NSF

Hinkley Center
for Solid and Hazardous
Waste Management

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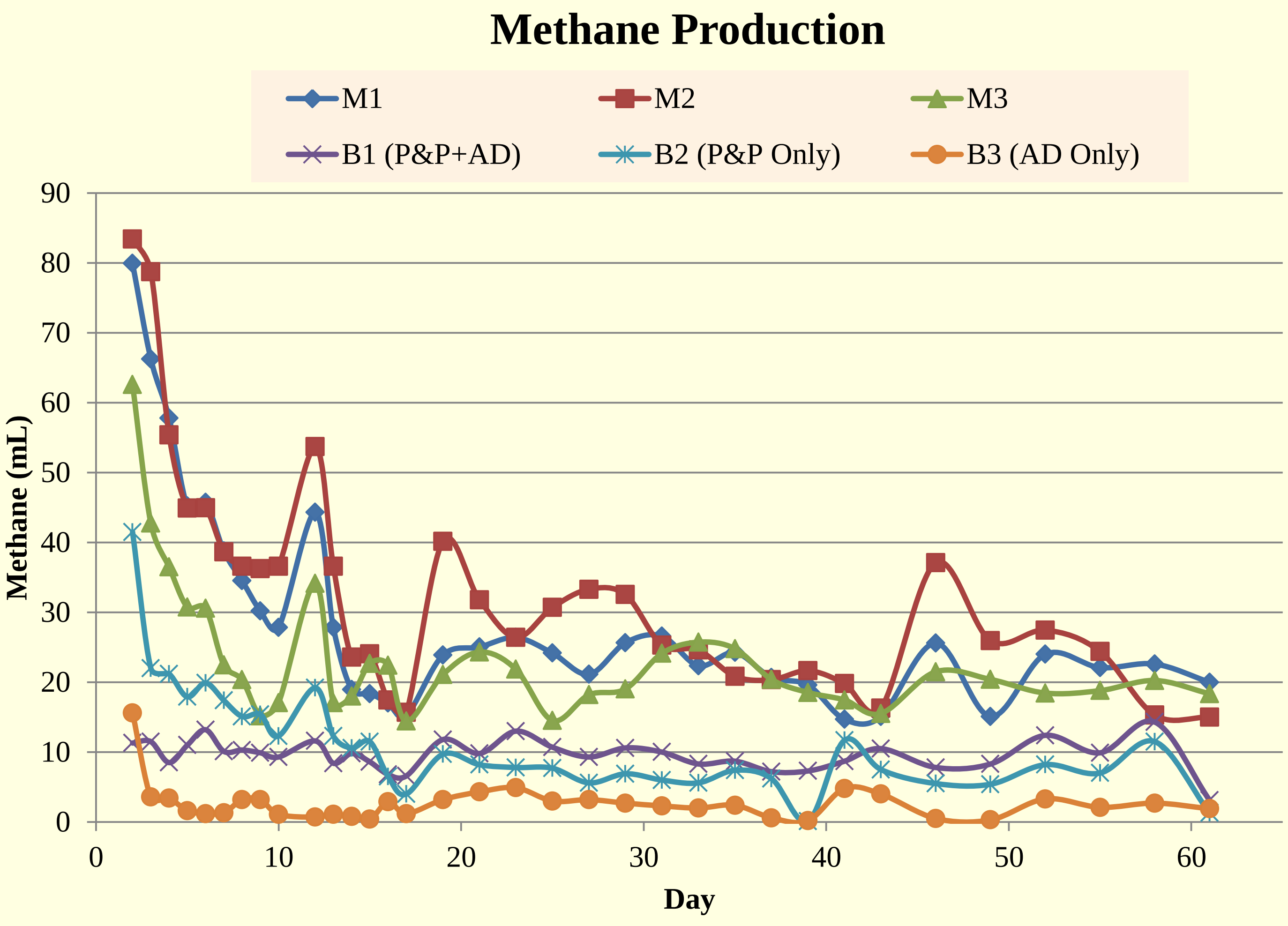
Objective 1: Questions

- Origin of OFMSW sources?
- Generation rates of centralized OFMSW sources?
- Potential demonstration sites?
- Scale?
- Potential funding sources?
- Policy issues?
- Biogas uses?
- Other challenges?

GRAVEYARD

Objective 2: Research Question 1 - Results



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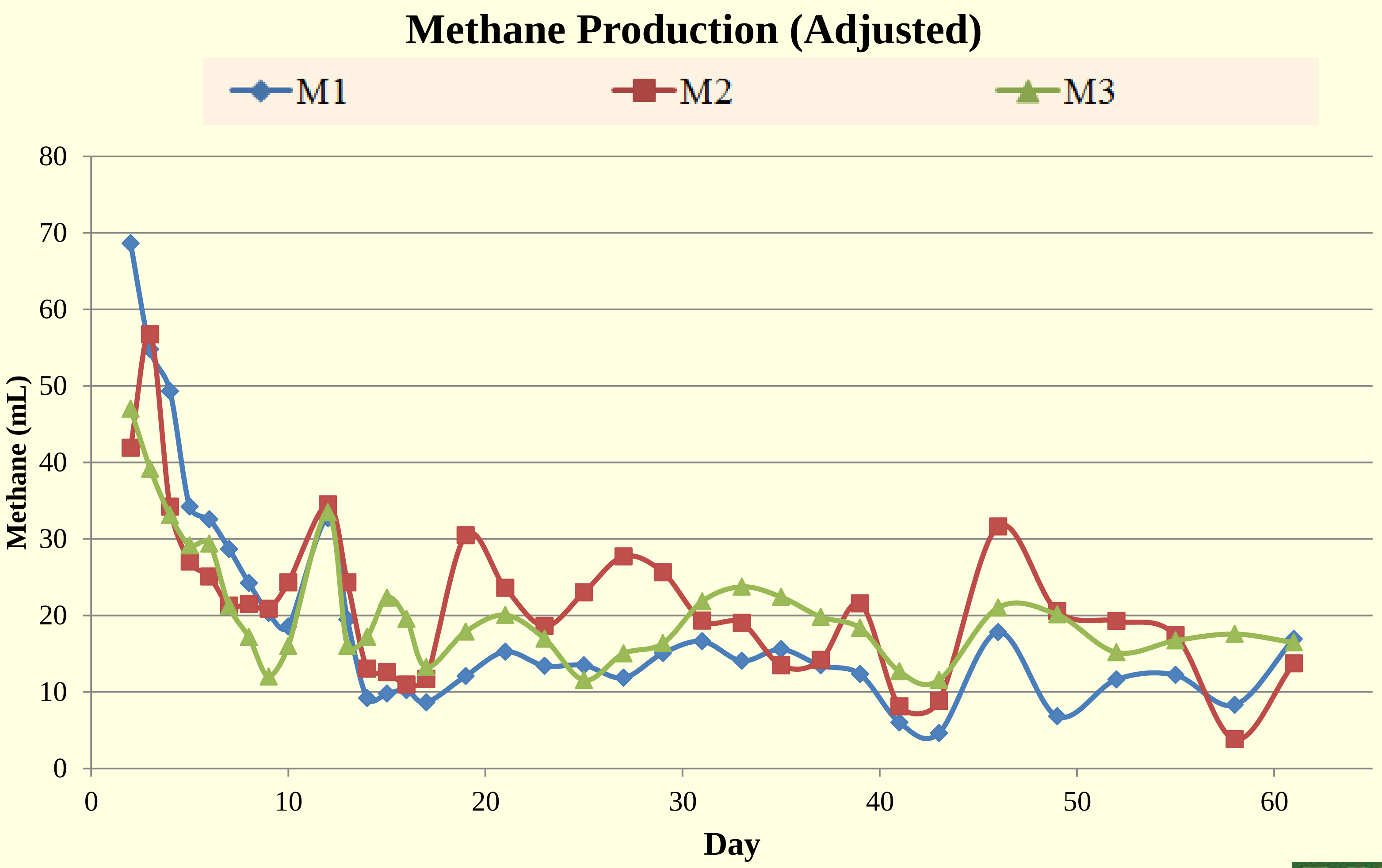

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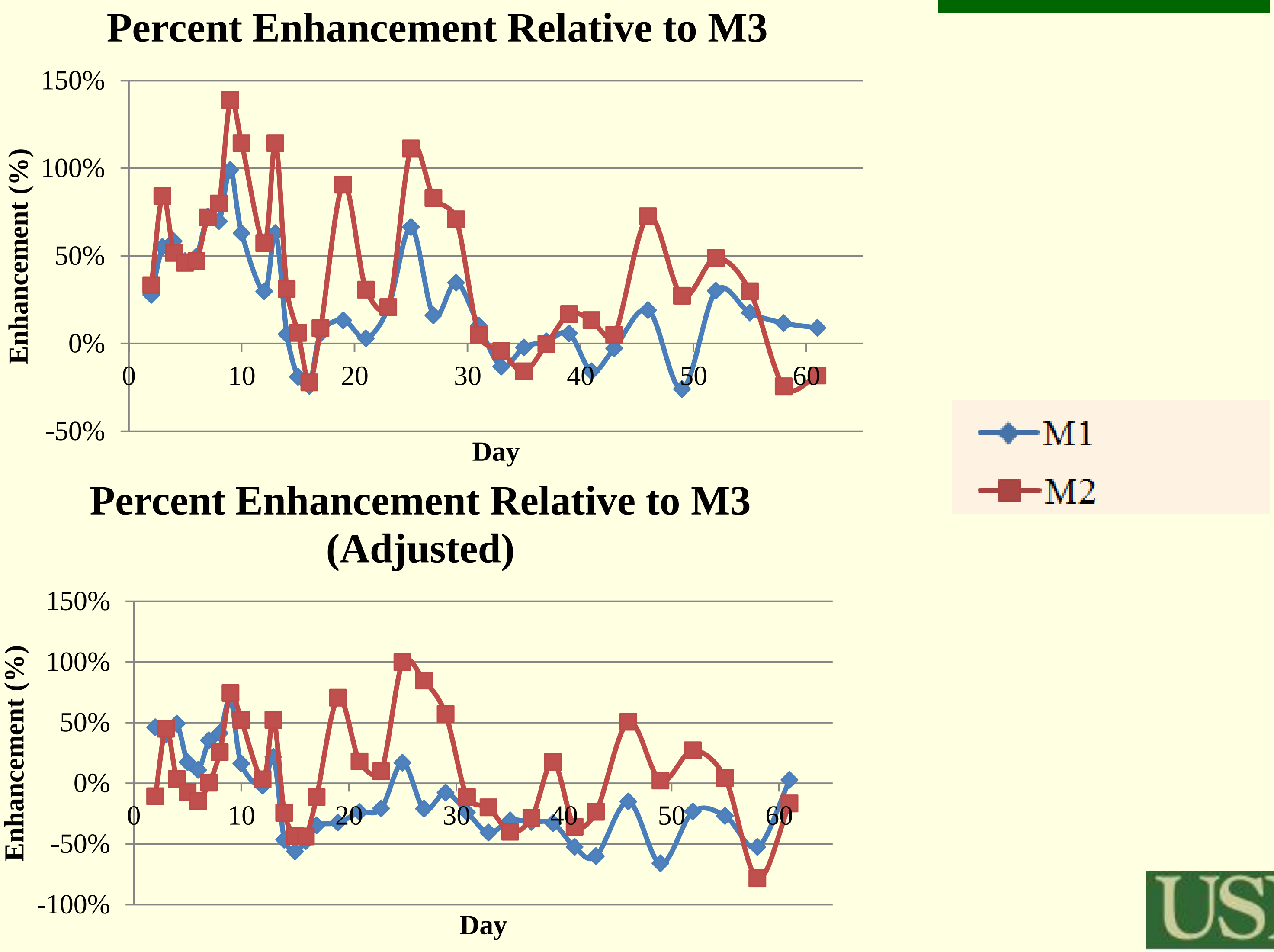
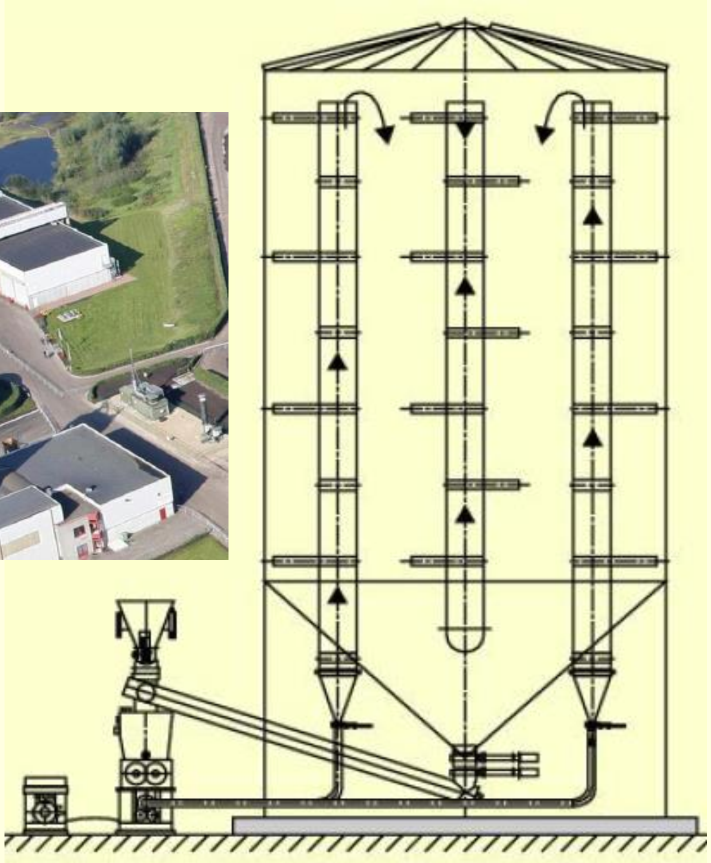


Objective 2: Research Question 1 – Results

- Results from chemical analyses are shown below

	pH	Alk. (mg/L)	COD (mg/L)	TN (mg/L)	TAN (mg/L)	VFA (mg/L)
			Raw Mixtures			
M1	6.9	180.0	2213.3	160.0	78.0	1025.0
M2	7.1	240.0	2388.9	122.2	61.6	710.0
M3	7.4	420.0	1486.7	168.9	105.4	757.5
			Blanks			
B1	7.5	925.0	1001.7	721.7	5523.3	992.5
B2	7.2	233.3	1670.0	590.0	6123.3	374.8
B3	7.7	1350.0	880.0	485.0	5126.7	260.0
			Intermediates (25 days)			
M1	7.8	1600.0	1998.3	293.3	249.8	550.0
M2	7.6	1550.0	2626.7	391.7	249.5	455.0
M3	7.6	1175.0	2163.3	170.0	240.2	359.3
			Final Digestate (60 days)			
M1	8.2	3890.0	4280.0	412.0	444.0	790.0
M2	8.1	3260.0	3542.0	486.0	356.5	730.0
M3	8.1	2700.0	1772.0	230.0	250.5	506.0

DRANCO (Belgium)

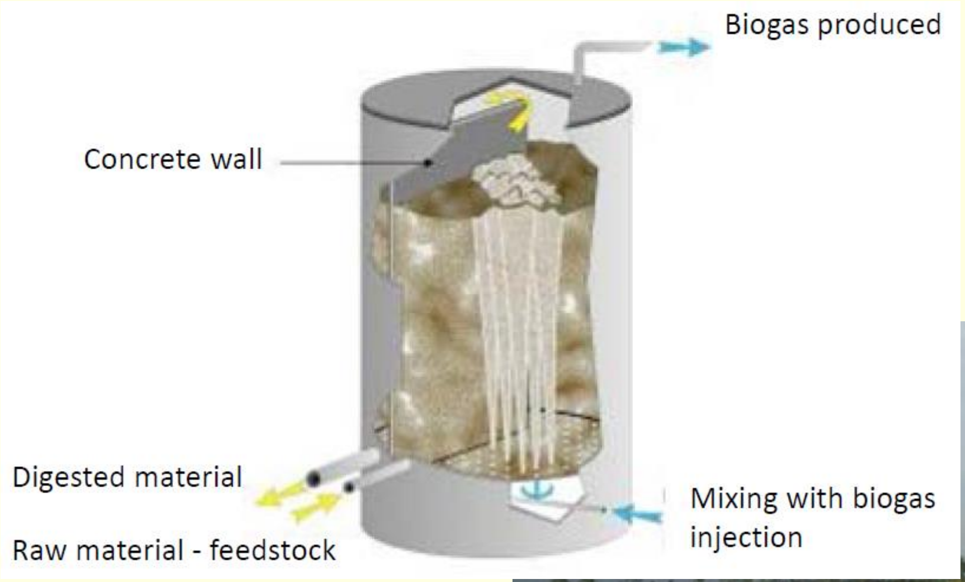


- No internal mixing
- 30 – 40% solids
- Mixing outside the tank with digestate (up-to 1:6)
- Extremely simple - reliable

Kompogas (Switzerland)

- Horizontal steel reactors
- Slowly rotating axial mixers (mixing, moving solids towards output, degassing)
- 23 – 28% solids
- Feed stream mixed with recycled digestate

Valorga (Germany/France)



• Plug-flow Improved by concrete baffle

• 25 – 35% total solids

• Mixing by high-pressure biogas

• Inoculation with finished product is not necessary

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BioFerm Batch Reactors – Garage Type

•**Simple!**
•Minimum maintenance
•Low energy losses
•Minimum capital costs
•Used especially for small farms (economy important)
•Inoculation with leachate (percolate)
•Drawback - low process control (no mixing)

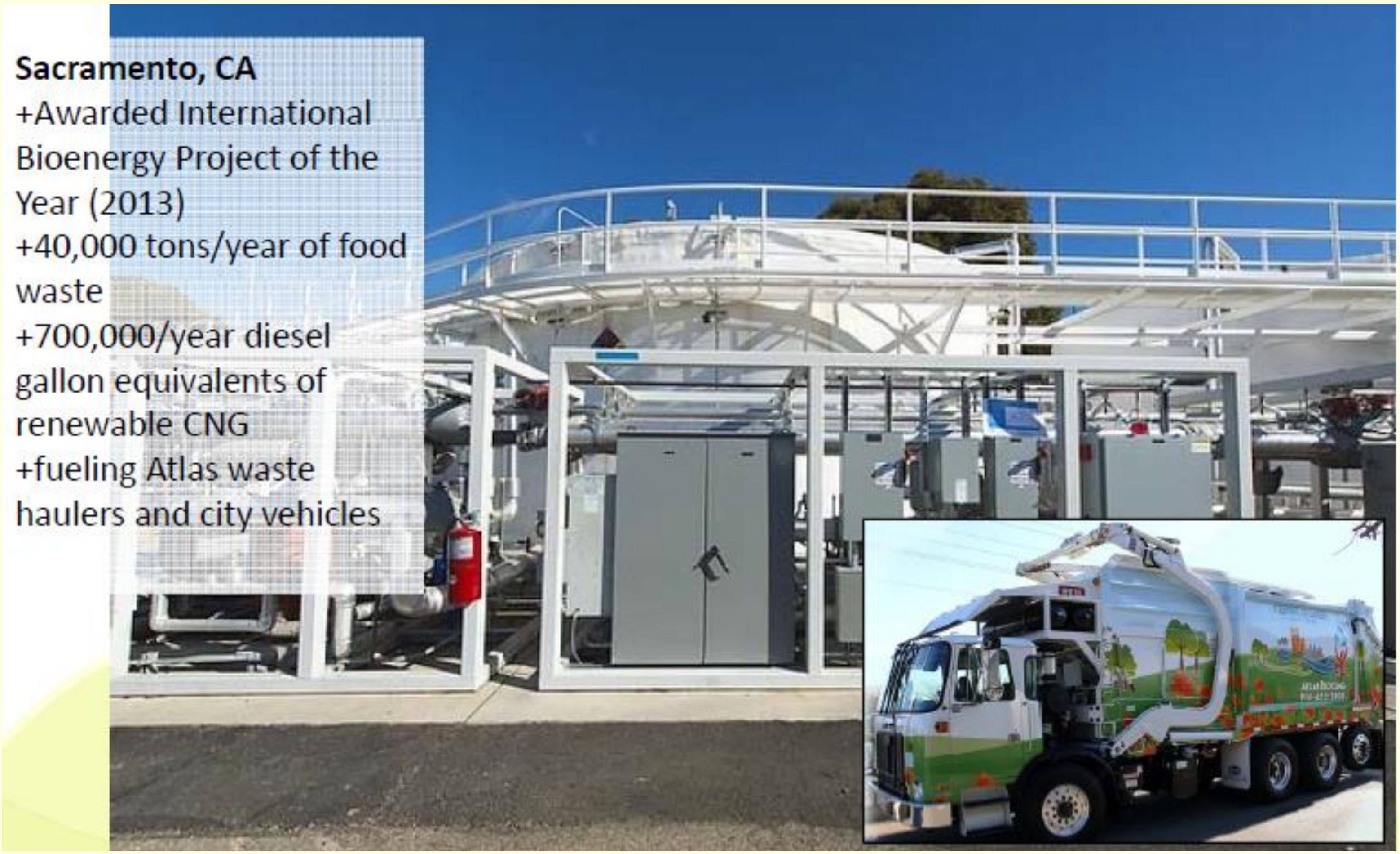
•Typically 30 – 40% solids
•Gas-tight container/room with gas tight door
•Loading by wheel loader
•Need to evacuate oxygen at the start (explosive)
•Inoculation with digestate (only 1/3 exchanged for each batch)
•Retention time around 90 days

UC Davis – Food and Yard Waste

- Invented by UC Davis Professor
- 50 ton per day capacity
- 1 MW
- Reduce loading to landfills by 20,000 tons/year
- Reduce GHG emissions by 13,500 tons/year
- 4 million gallons of low cost fertilizer and soil amendments/year

San Jose, CA – Food and Yard Waste

Sacramento, CA – Food Waste



Progress in California

Project Name	City or County	Feedstocks	Digestion Type	Status
East Bay Municipal Utilities District	Oakland	Food, Biosolids, & fats, oils, and grease	Wet	Operational
Inland Empire Utilities Agency - Environ	Chino	Food Waste	Wet	Operational
Monterey Zero Waste Energy	Marina	Green and Food waste	Dry	Operational
Sacramento Regional Sanitation	Elk Grove	Food waste, Biosolids, & fats, oils, and grease	Wet	Operational
Clean World - American River Packaging	Sacramento	Food Waste, cardboard & other	High Solids	Operational
Kroger/Ralphs - Compton Distribution Center	Compton	Food Waste	Wet	Operational
Central Marin Food to Energy	San Rafael	Food Waste	Wet	Operational
Clean World - Sacramento Digester	Sacramento	Green and Food waste	High Solids	Operational
Zero Waste Energy Development	San Jose	Green and Food waste	Dry	Operational
North State Rendering	Oroville	Agricultural, food waste and grease	Wet	Operational
Los Angeles Sanitation Districts AD Pilot	Carson	Food waste & Biosolids	Wet	Operational
UC Davis Renewable Energy Anaerobic Digester	Davis	Green and Food waste & manure	High Solids	Operational
Blue Line Zero Waste Energy	South San Francisco	Green and Food waste	Dry	Commissioning
CR&R Material Recovery Facility	Perris	Green and Food waste and MRF Residuals	High Solids Plug-flow	Construction

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Progress in California

Project Name	City or County	Feedstocks	Digestion Type	Status
Colony Energy Partners	Tulare	Waste Organics - TBD	Wet	Permitting
Agromin Zero Waste Energy	Oxnard	Green and Food waste	Dry	Permitting
Tajiguas Landfill	Santa Barbara County	Green and Food waste	TBD	Permitting
City of Napa Materials Recovery Facility	American Canyon	Green and Food waste	Dry	Permitting
Anaergia - Republic Material Recovery Facility	Anaheim	Green and Food waste	Wet	Permitting
Tracy Material Recovery Facility	Tracy	Green and Food waste	NA	Permitting
Tulare Harvest Power	Tulare County	Green, Food and Agricultural waste	Dry	Permitting
Recology Hay Road AD project	Solano County	Green and Food waste	Dry	Permitting
Encina Waste Water Plant	Carlsbad	Food, Biosolids, & fats, oils, and grease	Wet	Permitting

http://www.calrecycle.ca.gov/organics/conversion/ADProjects.pdf

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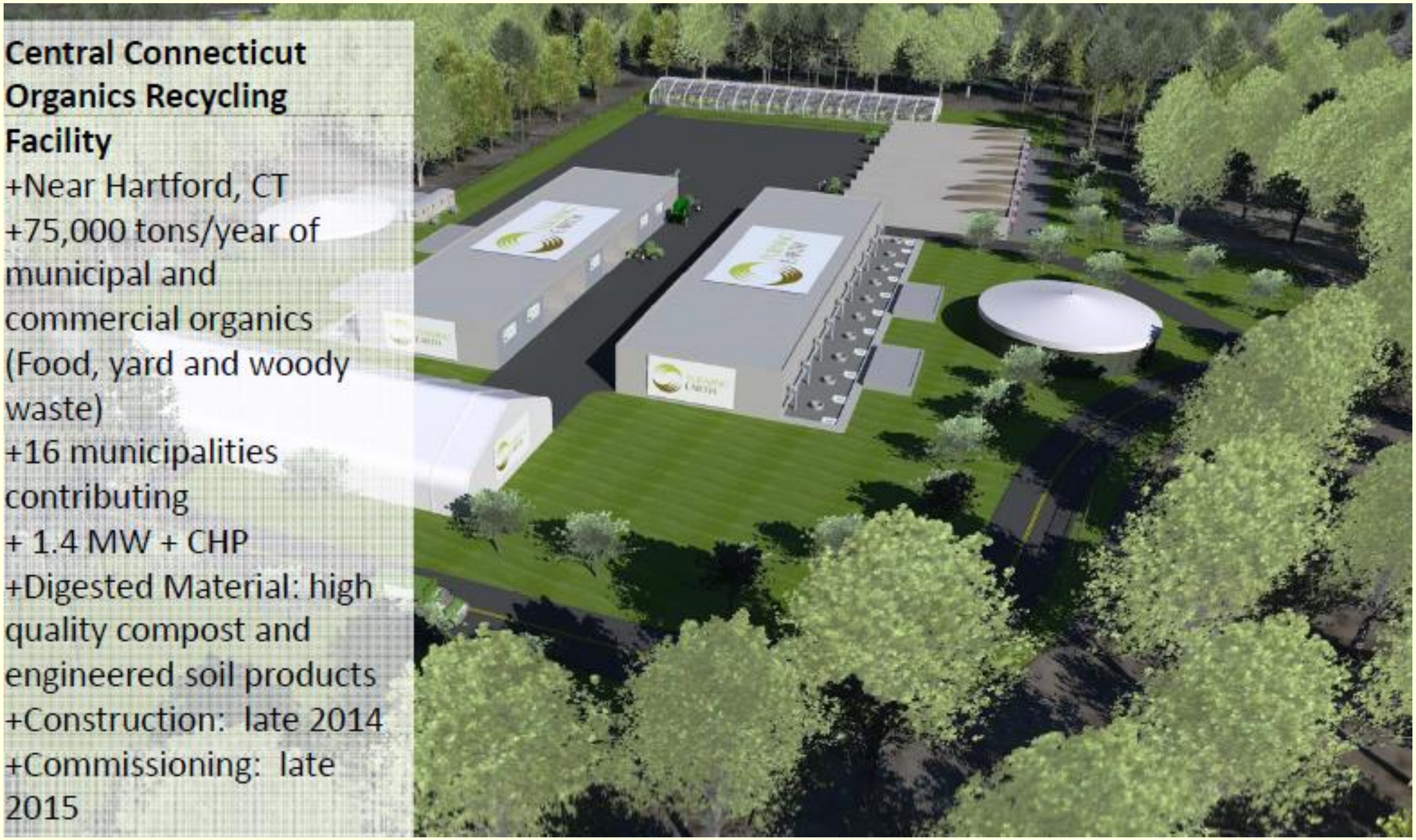
Hartford, CT - Food and Yard Waste



Digestate from SS-AD

- Concern – heavy metals…

Wet-AD in Florida

- WWTP Sludge (Biosolids)
- Harvest Energy in Orlando

Recent Legislation

- Florida Legislature enacted House Bill 7135 (2008) - established a new statewide recycling goal of 75% to be achieved by the year 2020.
- Examples of legislation for food waste recycling:

Municipalities: San Francisco, Seattle, Austin, Vancouver, New York City, most starting in 2009-10

2011: CT, Public Act 11-217 (updated in 2013)

2012: VT, Universal Recycling Law, Act 148—all organics, largest generators first, effective 7/1/2016

2013

- CT: Public Act 13-285 (update to 2011)—Commercial organics, **effective 1/1/14**
- NYC: Local Law 146-2013—Commercial organics, effective 7/1/2015

2014

- MA: 310 CMR 19.000 regulations—Commercial organics, effective 10/1/14
- RI: An Act Relating to Health and Safety—Commercial organics, effective 1/1/2016
- *CA AB 1826: Mandatory Commercial Food Waste Recycling (awaiting Gov's signature)*
- *MD: Composting and Anaerobic Digestion Facilities-Yard Waste and Food Residuals (pending)*

From American Biogas Council – americanbiogascouncil.org

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Year 2 (projected)

- Design, construct and operate a continuously-fed demonstration SS-AD
  - USF campus (Botanical Garden), or
  - Hillsborough County solid waste facilities
    - South County Landfill
    - Yard waste processing centers
- Life cycle assessment (LCA) and Life cycle cost analysis (LCCA)
  - Cradle-to-gate
  - MSW processing, transportation, conversion
- Evaluate Developing World Application