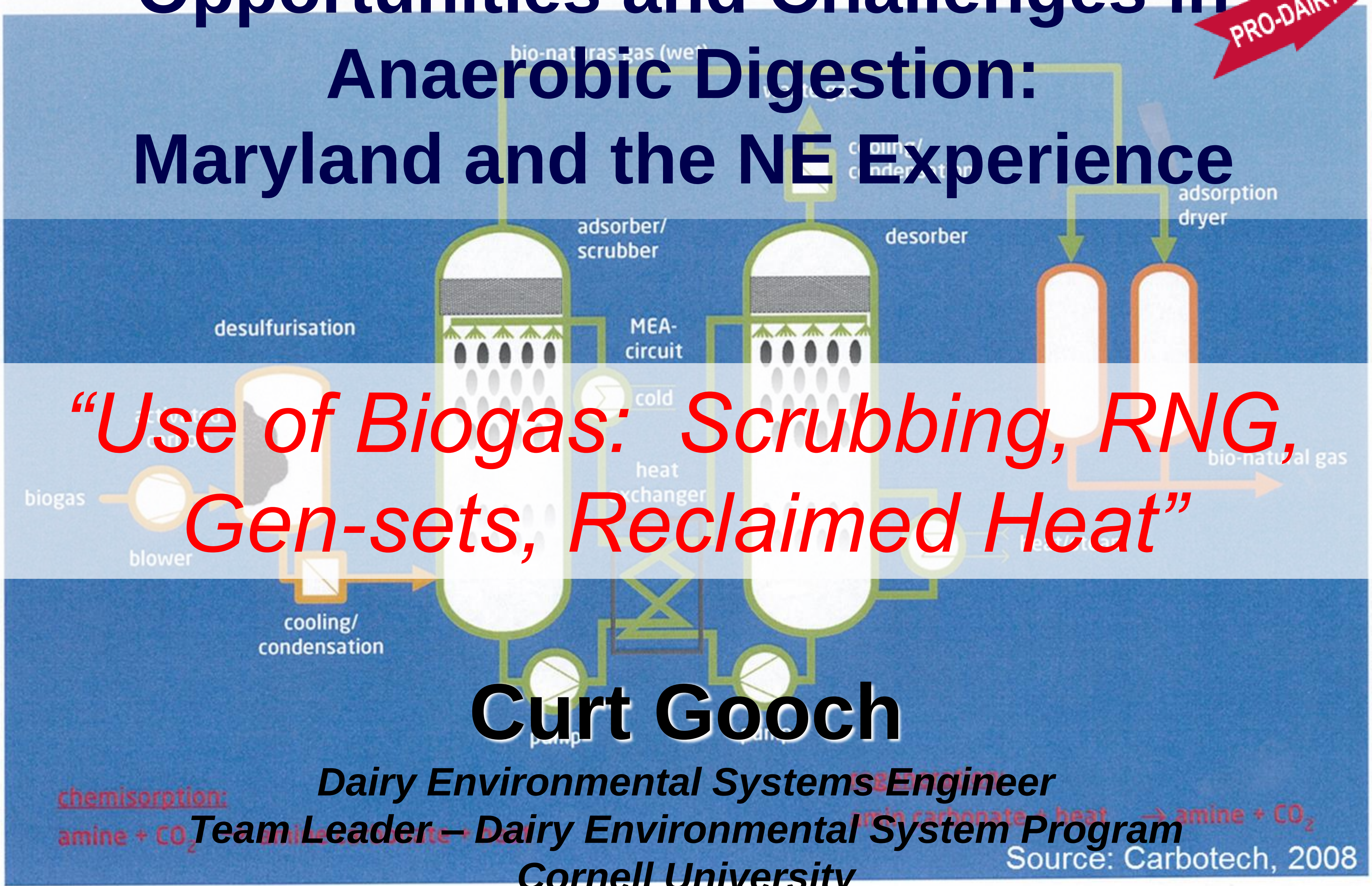
Opportunities and Challenges in Anaerobic Digestion: Maryland and the NE Experience

“Use of Biogas: Scrubbing, RNG, Gen-sets, Reclaimed Heat”



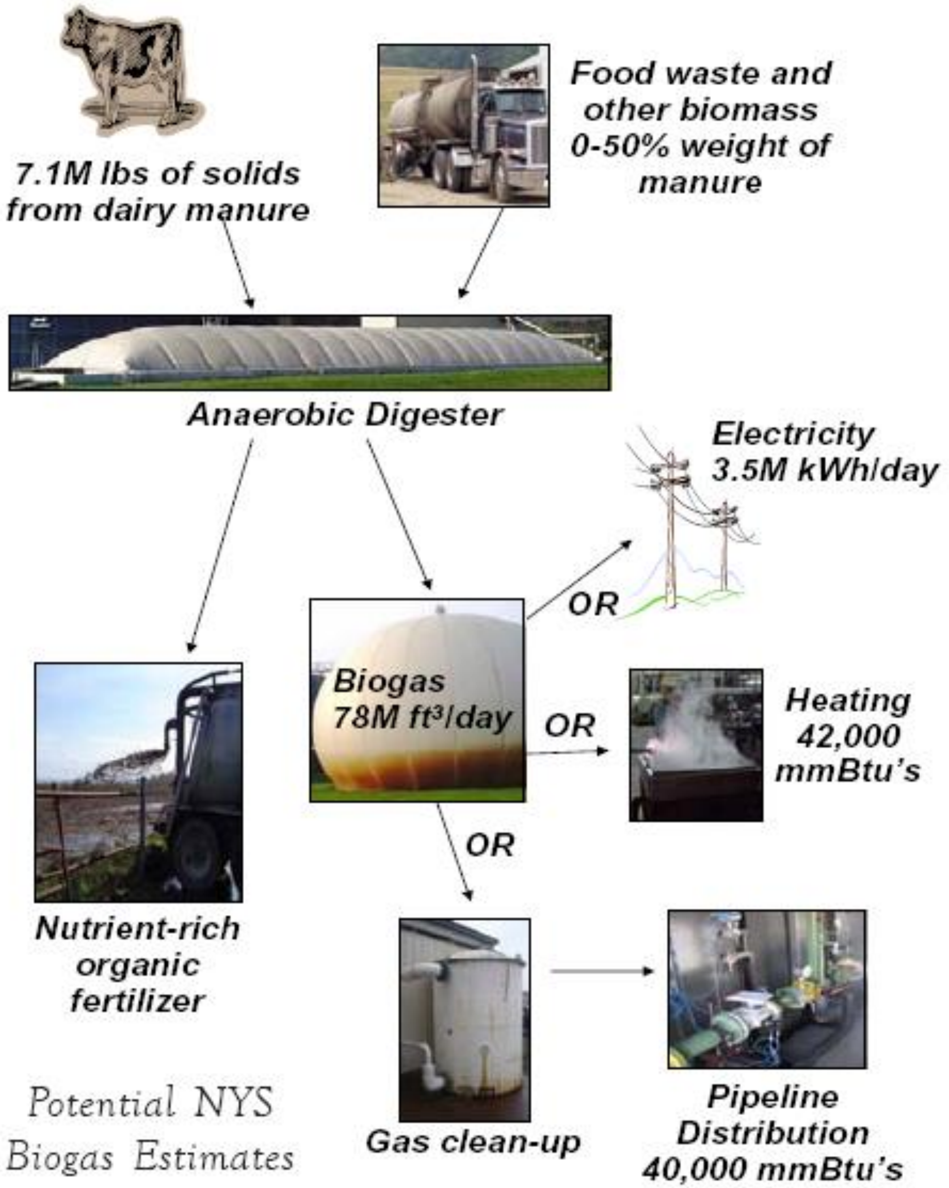
Source: Carbotech, 2008

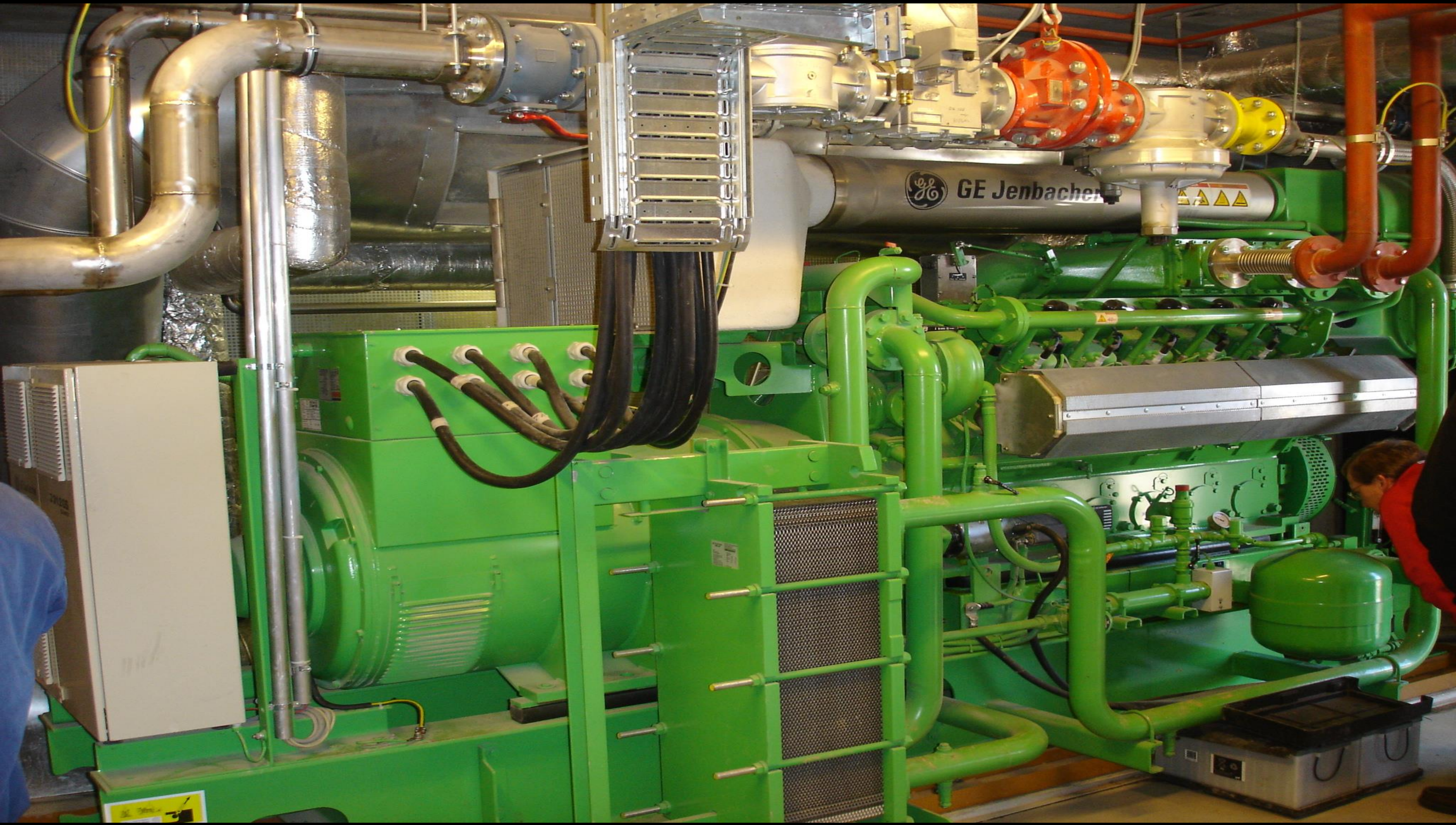
Curt Gooch

Dairy Environmental Systems Engineer
Team Leader – Dairy Environmental System Program
Cornell University

www.manuremanagement.cornell.edu

On-Farm AD: Linking Agriculture, Community and Industry toward a Sustainable Future



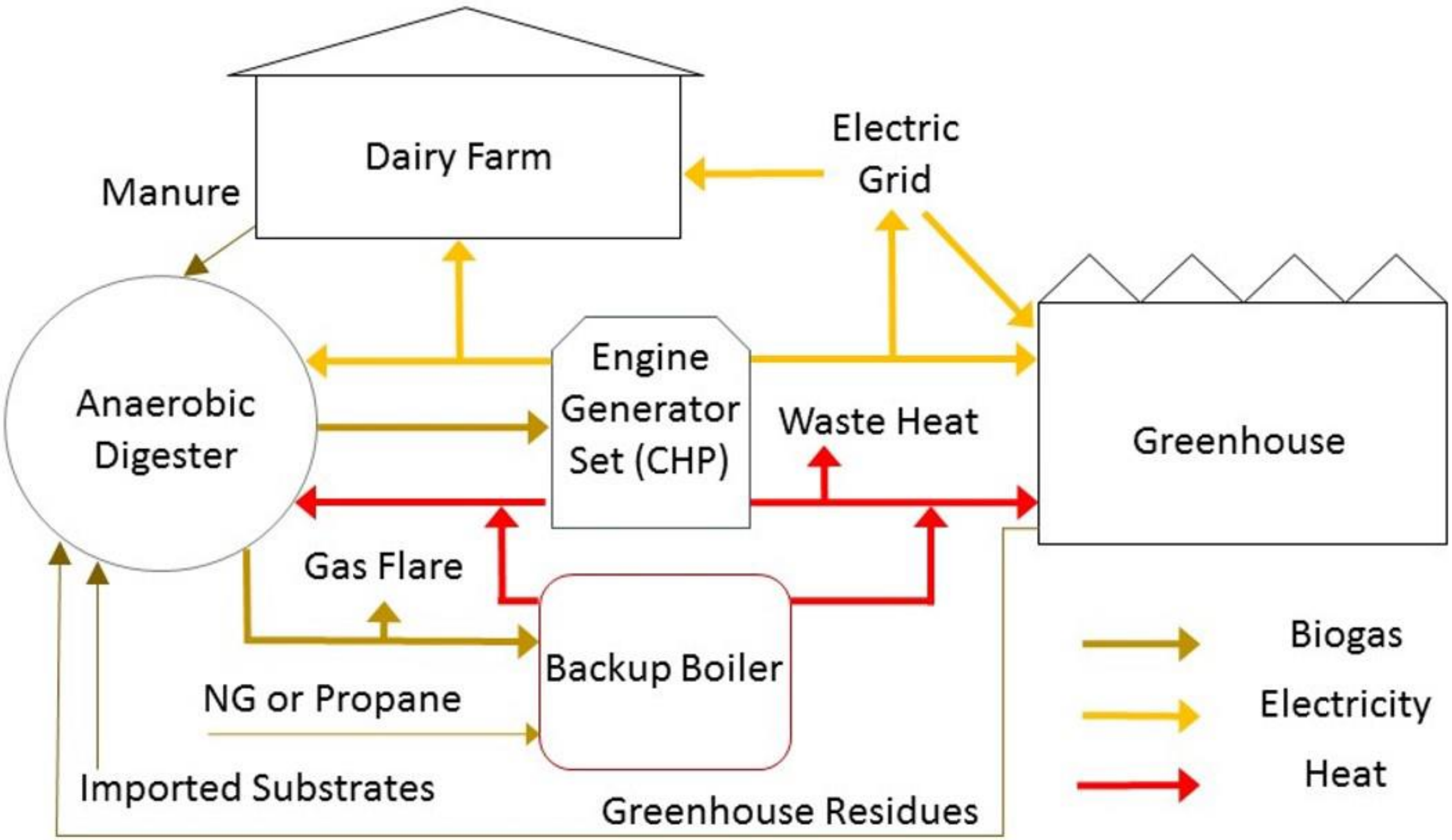

GE Jenbacher

AD: Heat Production

- As much as 75% of the produced heat is wasted
- Excess heat is typically dumped to the ambient using large radiators

- Some (few) farms use recovered heat in a beneficial manner…
- Waste heat usage represents a valuable opportunity for farms


Coupling Dairy Manure Anaerobic
Digesters with Commercial Greenhouses:
An Assessment of Technical and
Economic Feasibility


Dairy Farm
Manure
Electric Grid
Anaerobic Digester
Engine Generator Set (CHP)
Waste Heat
Greenhouse
Gas Flare
Backup Boiler
NG or Propane
Imported Substrates
Greenhouse Residues
Biogas
Electricity
Heat

Phase I - Project Goals:

- Develop user friendly computer programs to:
  - Predict the surplus heat and electricity available from digesters of user specified size, design and operational characteristics. Cornell Anaerobic Digester Simulation Tool
  - Predict the required heat and electricity for a greenhouse of user specified size, design and operational characteristics. Cornell Greenhouse Simulation Tool
  - Use the output from the AD computer program, and determine the size of greenhouse that could be supported by the specified digester, or the portion of the energy usage of a specified greenhouse that could be digester supported.

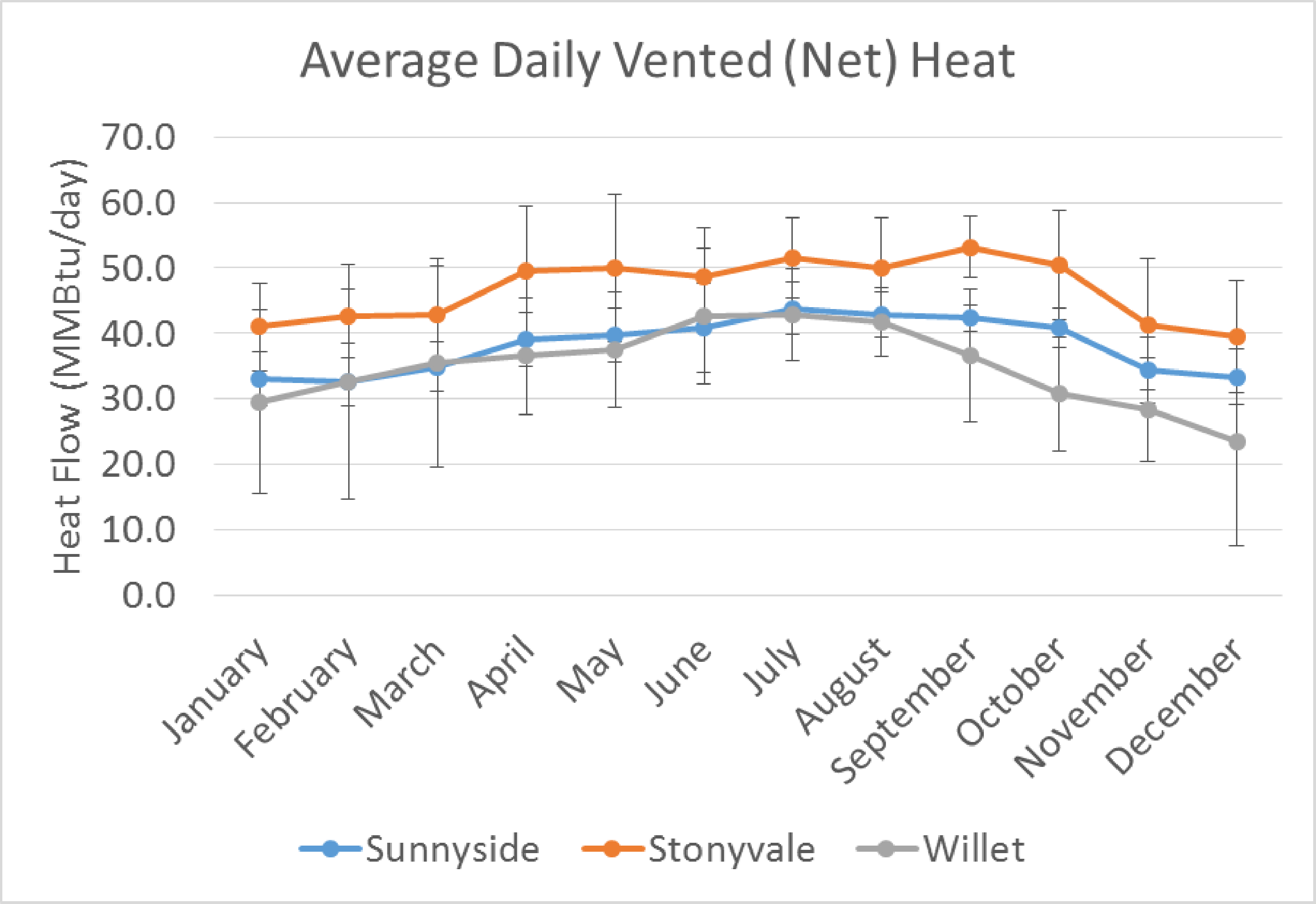
    Cornell AD/GH Synergy Simulation Tool

Monitoring Surplus Heat Of Digesters

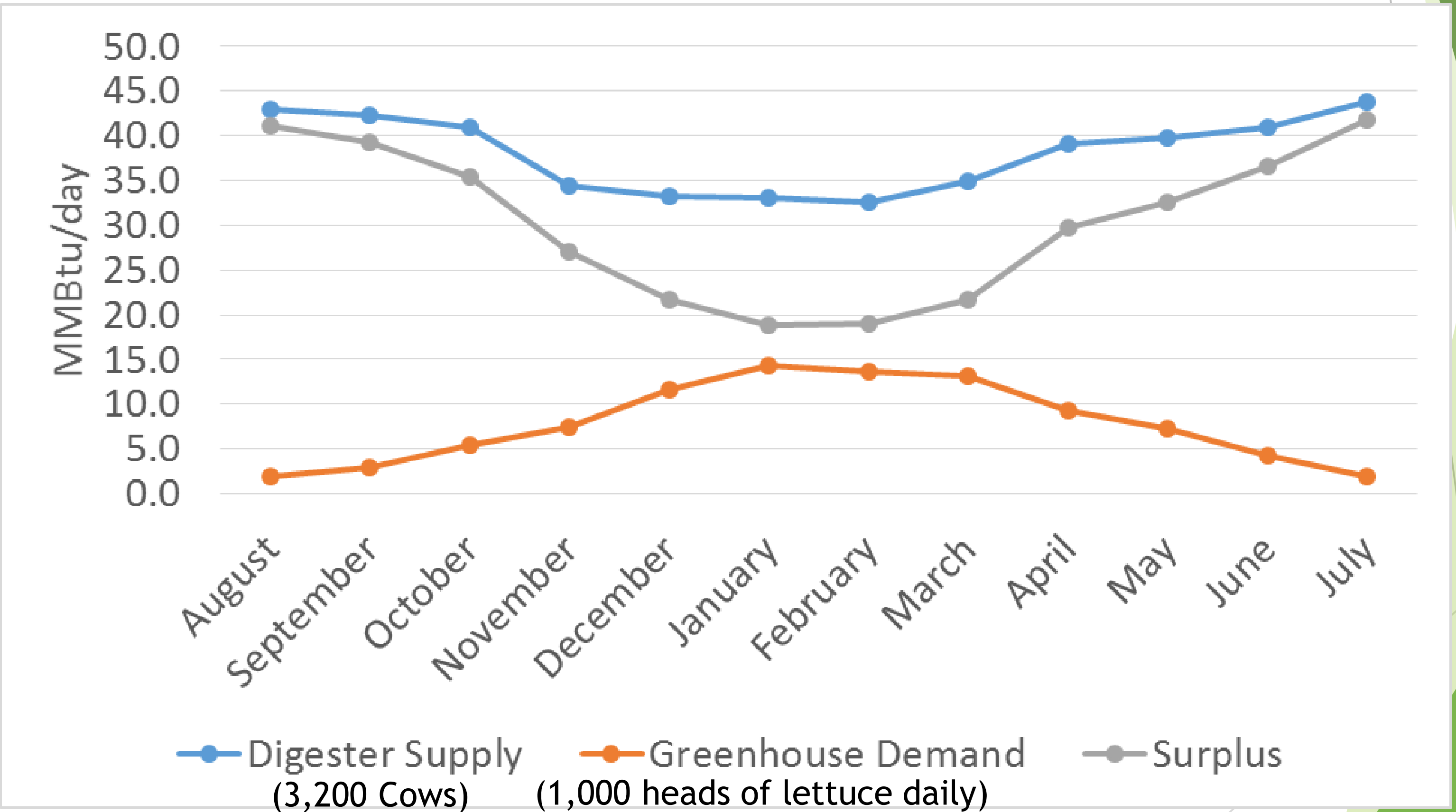
Thanks to:

- Dairies
  - Synergy Dairy (Covington, NY)
  - Stonyvale Farm (Exeter, ME)
  - Sunnyside Dairy (Venice, NY)
  - Willet Dairy (Locke, NY)
- Commercial Greenhouses
  - Challenge Industries (Ithaca, NY)
  - Durham Foods (Port Perry, ON)

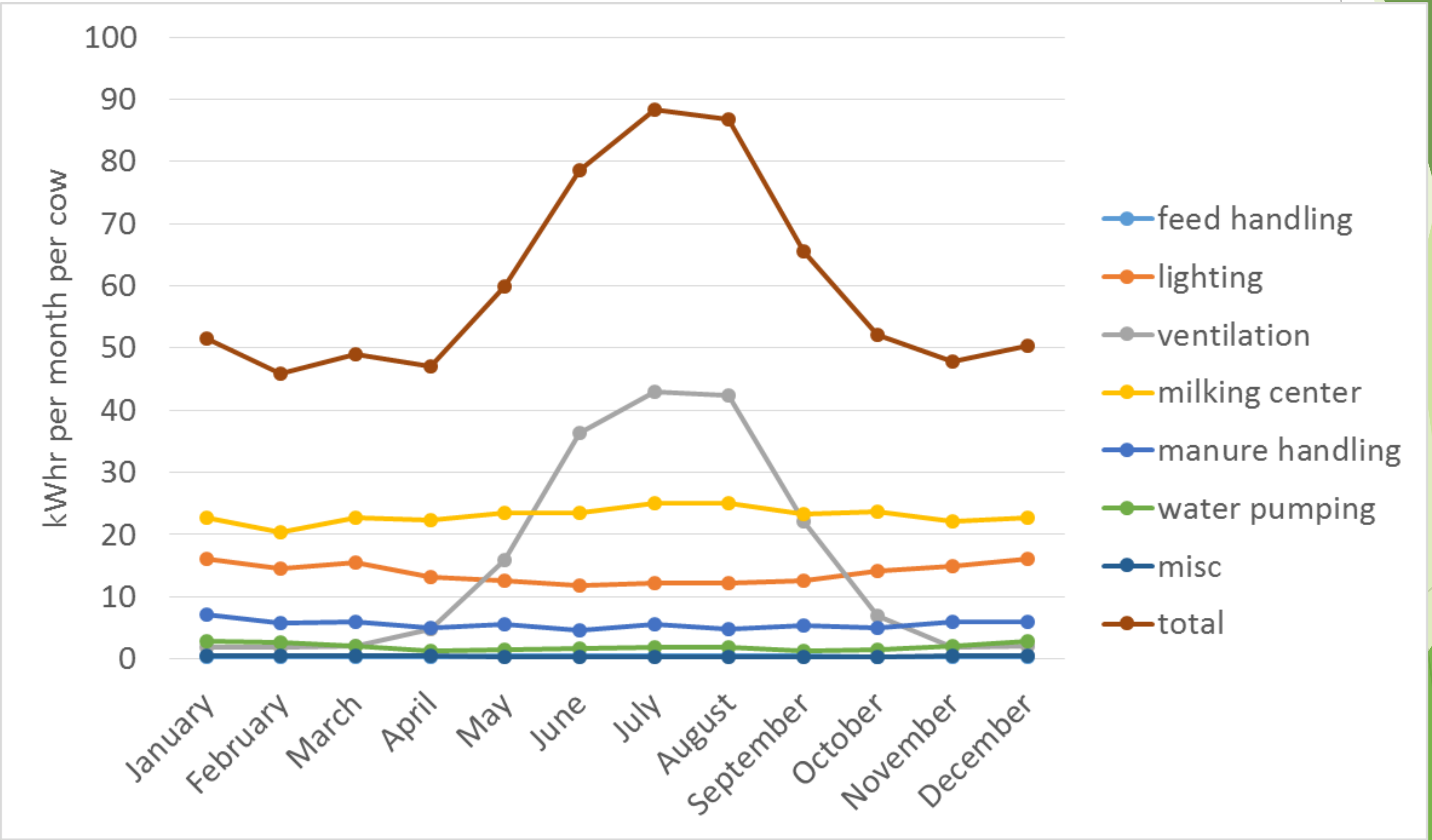
Anaerobic Digester Surplus Heat



Out of Sync Heat Production and Consumption

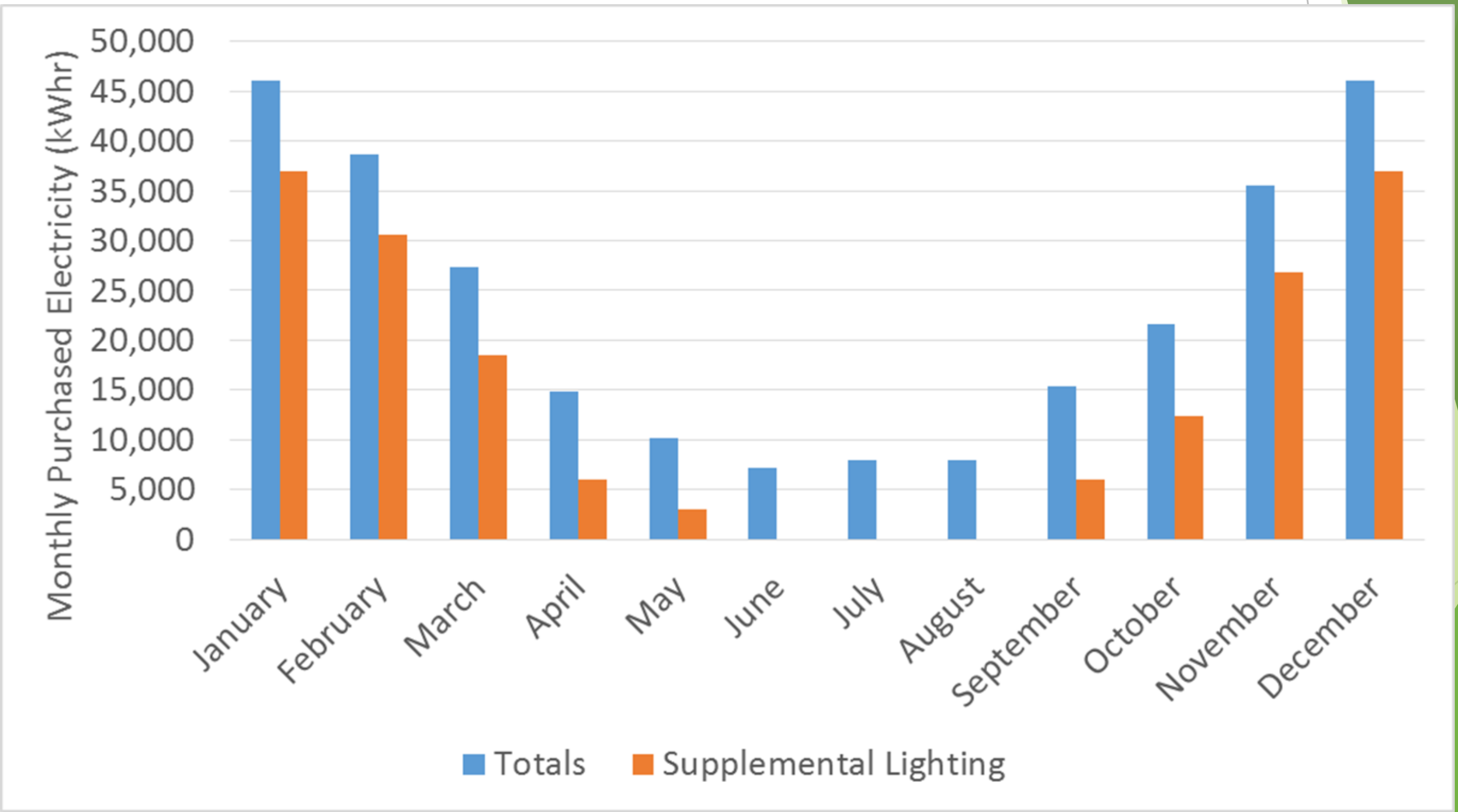


New York Freestall Barn Dairy Monthly Electricity Use

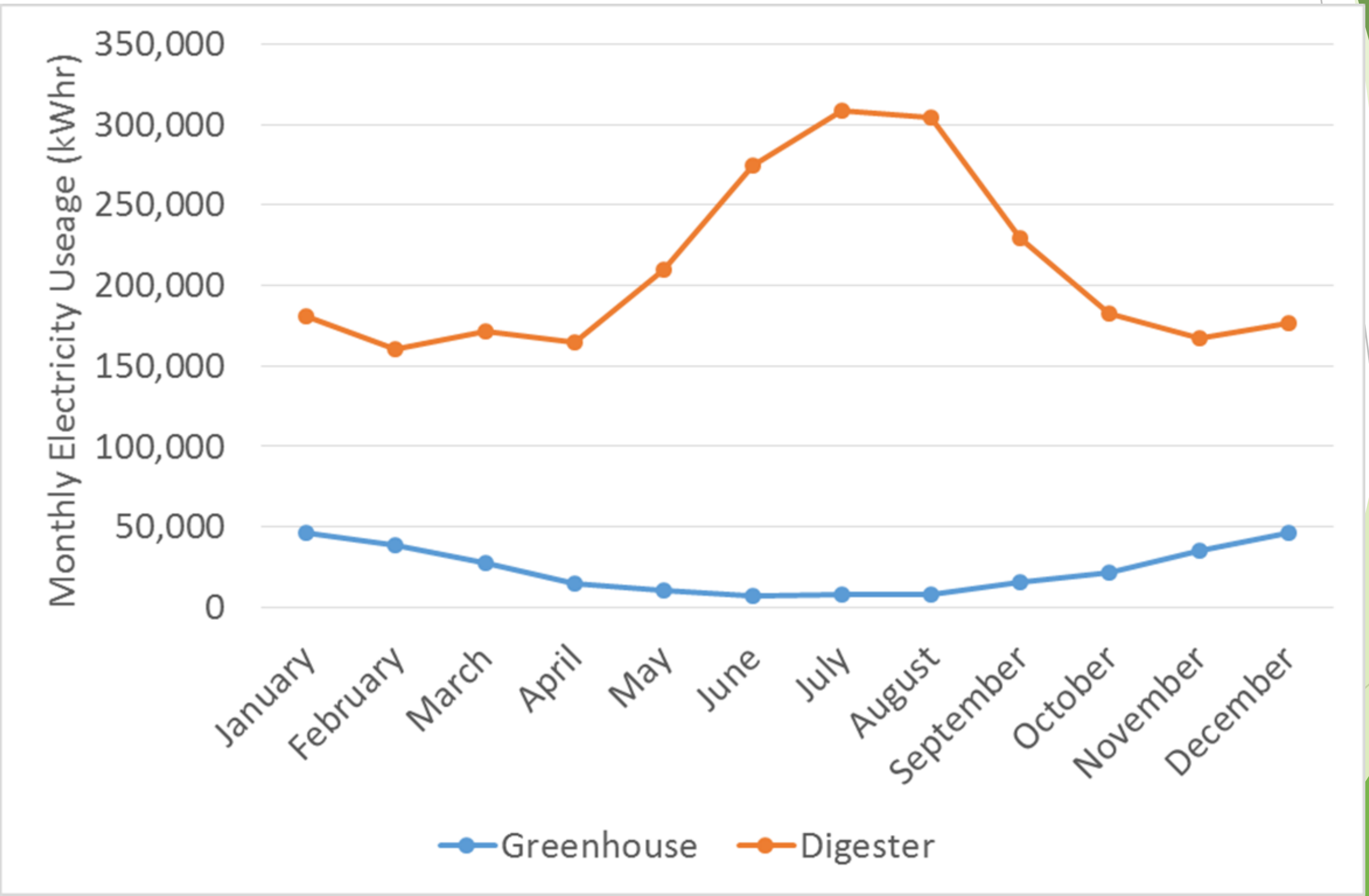


Source: Adapted from Peterson, Northeast Agriculture Technology Corporation 2014

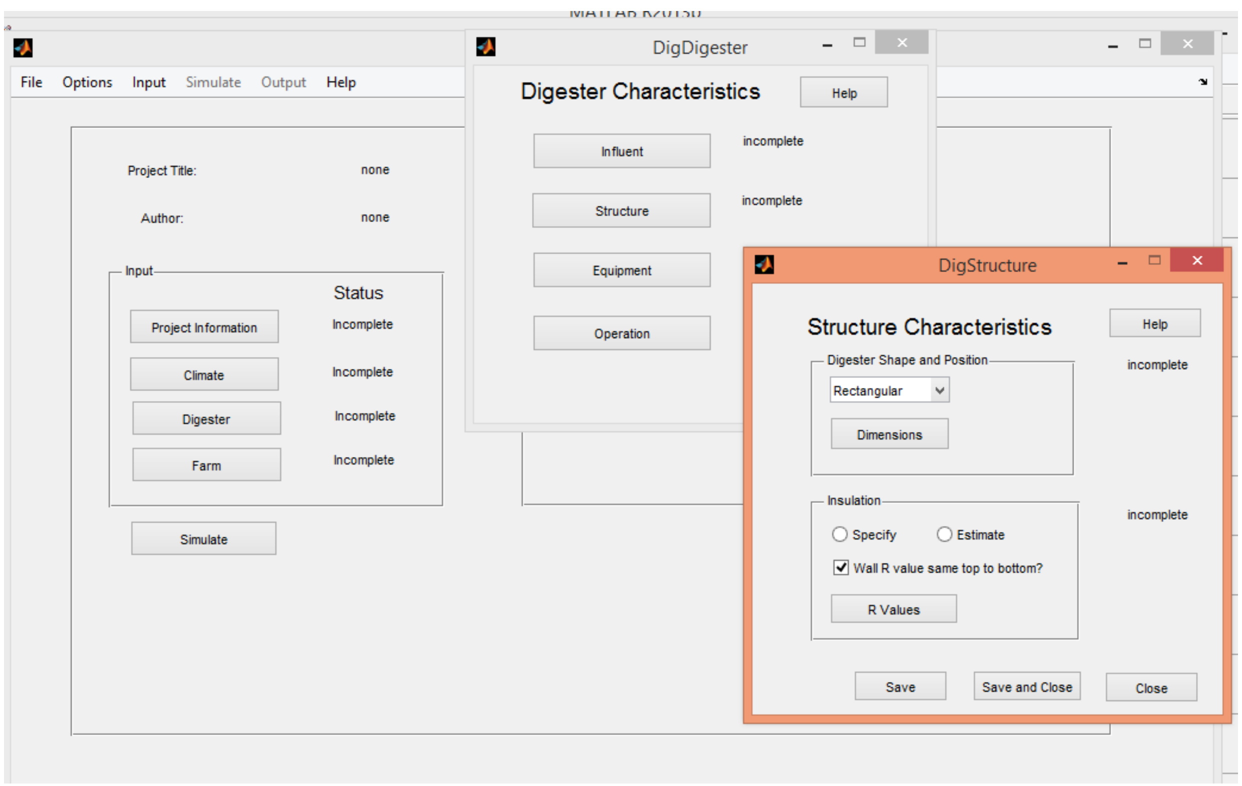
NY Greenhouse Yearly Electricity Usage



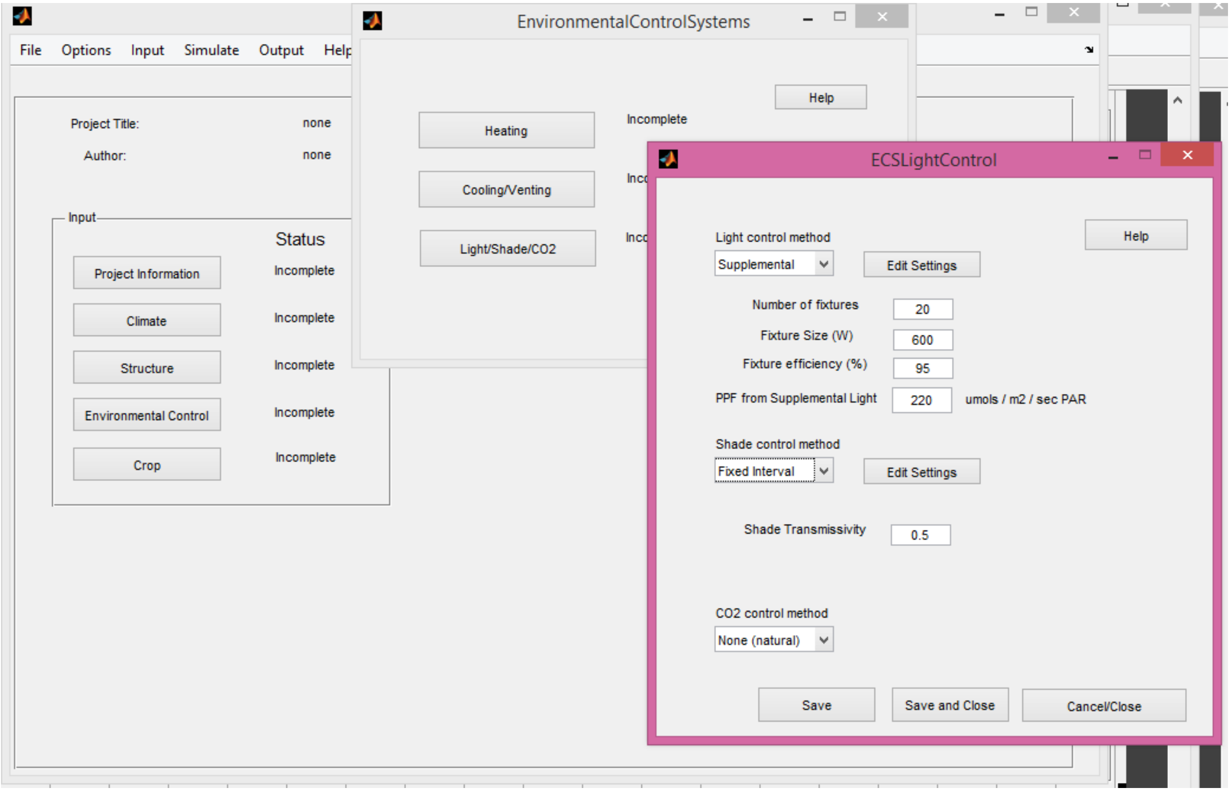
Complementary Electricity Use



Digester Simulation Computer Program

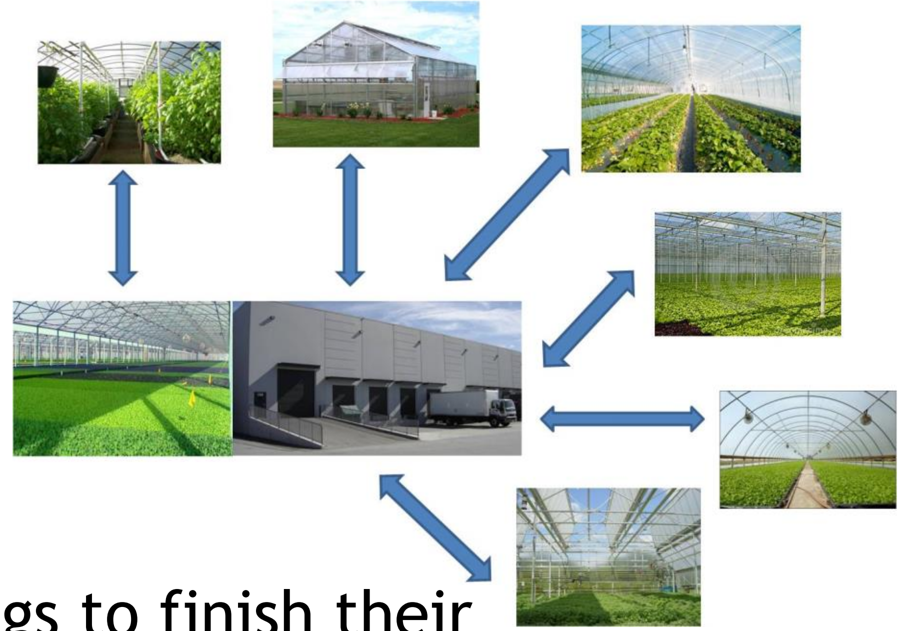


Greenhouse Simulation Computer Program



Farm Size (LCE[1])	Co Digestion[2]	Greenhouse Size (ft²)	Value of Heat[3] ($/year)	Value of Electricity[4] ($/year)	Benefit[5] ($/year)
500	none	580	$9,975	$1,650	$11,625
	10% whey	720	$11,548	$2,100	$13,648
	25% whey	1,325	$17,035	$3,900	$20,935
	5% FOG	1,125	$15,107	$3,300	$18,407
	10% FOG	1,500	$18,874	$4,350	$23,224
1,000	none	3,250	$23,170	$9,600	$32,770
	10% whey	4,000	$26,500	$11,700	$38,200
	25% whey	6,750	$31,865	$19,800	$51,665
	5% FOG	6,000	$29,479	$17,550	$47,029
	10% FOG	7,500	$34,316	$21,900	$56,216
1,500	none	7,875	$35,344	$22,950	$58,294
	10% whey	9,375	$39,613	$27,450	$67,063
	25% whey	15,500	$49,345	$45,300	$94,645
	5% FOG	13,000	$43,712	$37,950	$81,662
	10% FOG	16,500	$51,725	$48,300	$100,025
2,000	none	14,500	$46,967	$42,450	$89,417
	10% whey	16,500	$51,725	$48,300	$100,025
	25% whey	20,000	$60,224	$58,350	$118,574
	5% FOG	19,000	$57,424	$55,500	$112,924
	10% FOG	21,000	$62,879	$61,350	$124,229
3,000	none	21,000	$62,879	$61,350	$124,229
	10% whey	28,125	$69,628	$82,200	$151,828
	25% whey	43,750	$84,545	$127,800	$212,345
	5% FOG	33,750	$73,909	$98,700	$172,609
	10% FOG	50,000	$89,050	$146,100	$235,150

Food Hub Operations Model



- Transport seedlings to finish their finish their growth at smaller, distributed operations, located to take advantage of inexpensive heat and power.

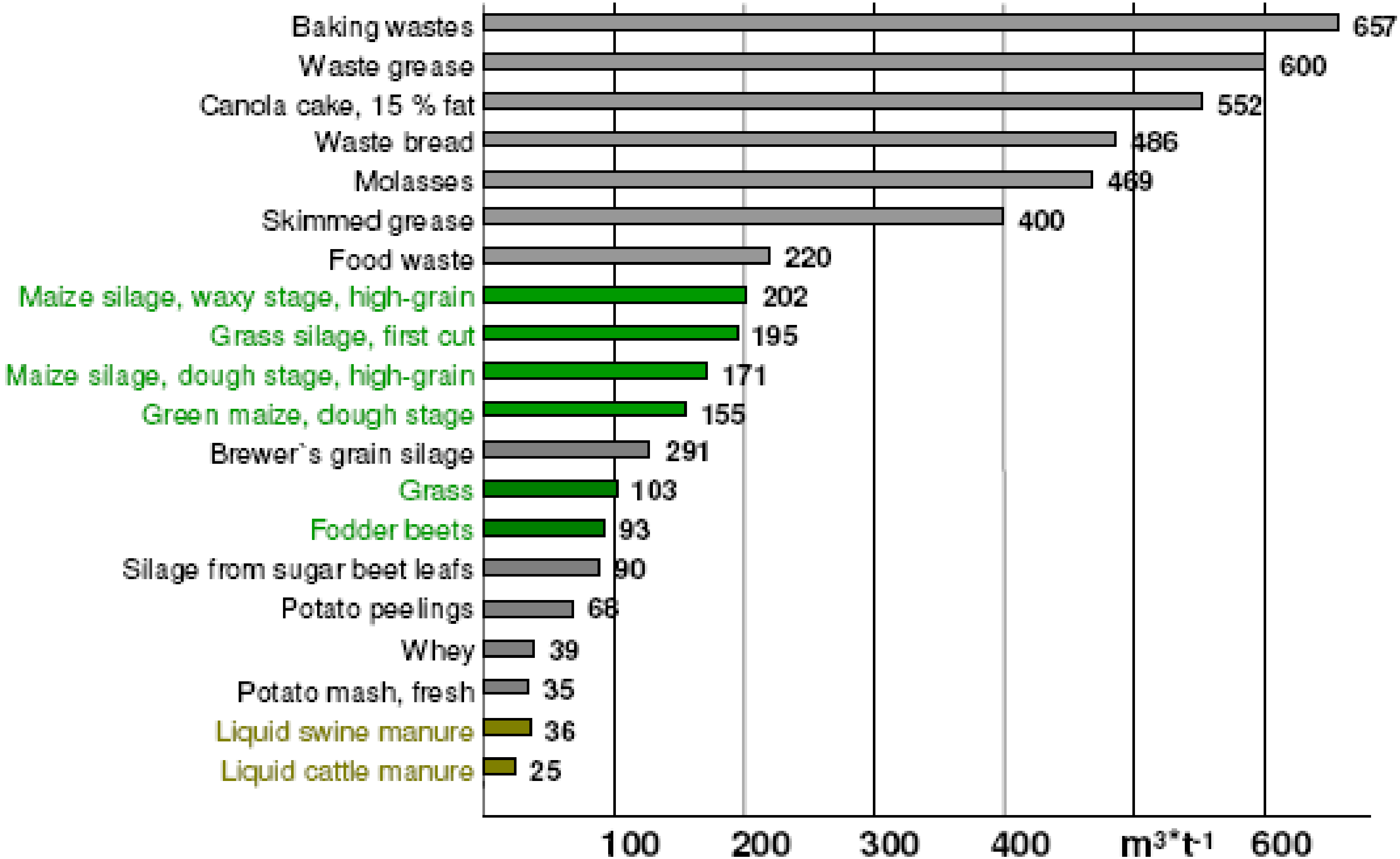
Dairy Manure Derived Biogas: Raw Composition

- Methane (CH_4); 55 to 68 percent → 60%
- Carbon Dioxide (CO_2); 32 to 45 percent → 40%
- Hydrogen Sulfide (H_2S); 1,500 – 5,000 ppm
- Ammonia (NH_3); 0 – 300 ppm
- Water Vapor (H_20); saturated gas: ~4%

Biogas Yields for Sizing Clean-up System

- Cow manure only anaerobic digester systems: 60 to 100 ft^3 biogas per lactating cow equivalent on a volatile solids basis ($LCE_{vs\ basis}$)
- Co-digestion anaerobic digester systems: 2 – 3x cow manure only systems on a $LCE_{VS\ basis}$ <u>or more</u>
- For existing systems, use gas meter data to size

Potential Biogas Yields



Source: Mathias Effenberger, 2006

Landfill Biogas: Raw Composition

Dairy Manure Derived Biogas Components plus various other contaminates such as:

- Siloxanes
- CFCs
- S-compounds
- Oxygen
- Nitrogen

Important Considerations

- End use of biogas/rng and its requirements
- Requirements can drive clean up system method selected
- Clean up systems require energy: electricity and sometimes heat
- CAPEX and OPEX

Important Considerations

- Sometimes no cleanup is cheapest option
- Some methods need redundancy
- Most appropriate solution may include multiple methods arranged in series

Biogas clean-up/upgrading

– Level 1 of 3: Moisture removal

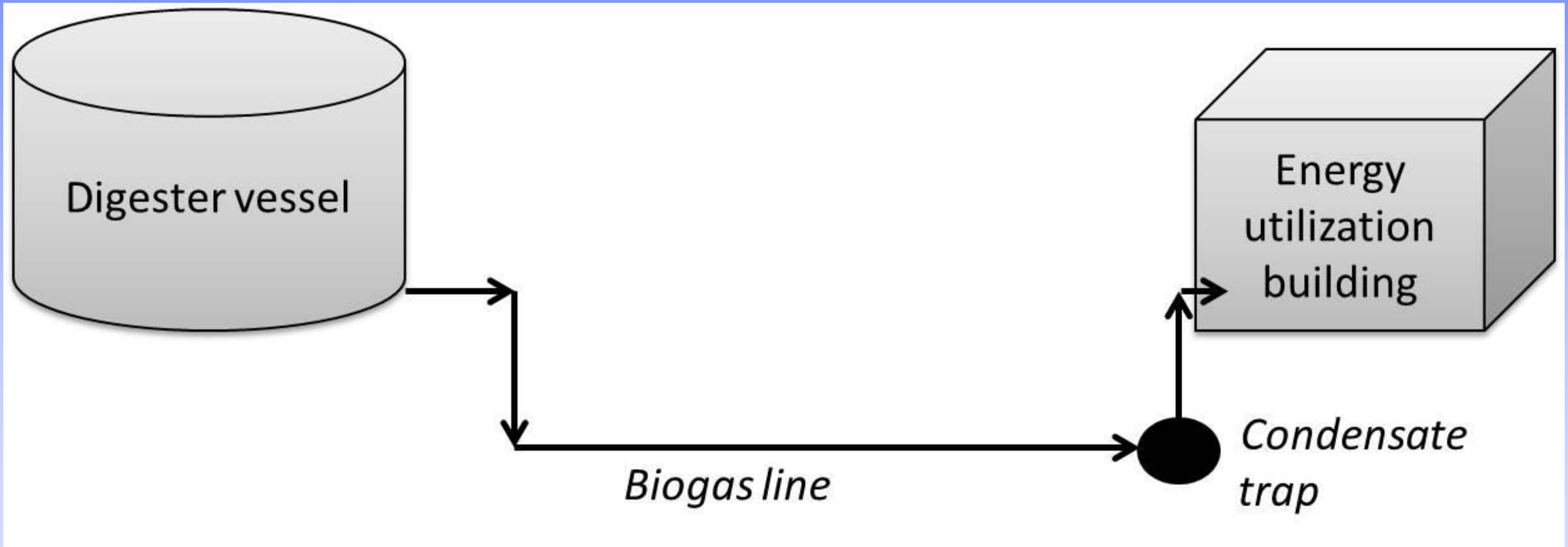
– Level 2 of 3: Hydrogen sulfide removal

– Level 3 of 3: Carbon dioxide removal

Biogas Cleanup – Level 1 of 3

Moisture removal for local use/pipeline transport

Level 1 - Moisture Removal: *Passive Condensation*



Level 1 - Moisture Removal: *Refrigeration*

- Heat exchangers used to cool biogas to desired dew point

- Biogas pressurized to increase further dryness

- Condensate removed from system and disposed of as wastewater

Level 1 - Moisture Removal: *Adsorption*

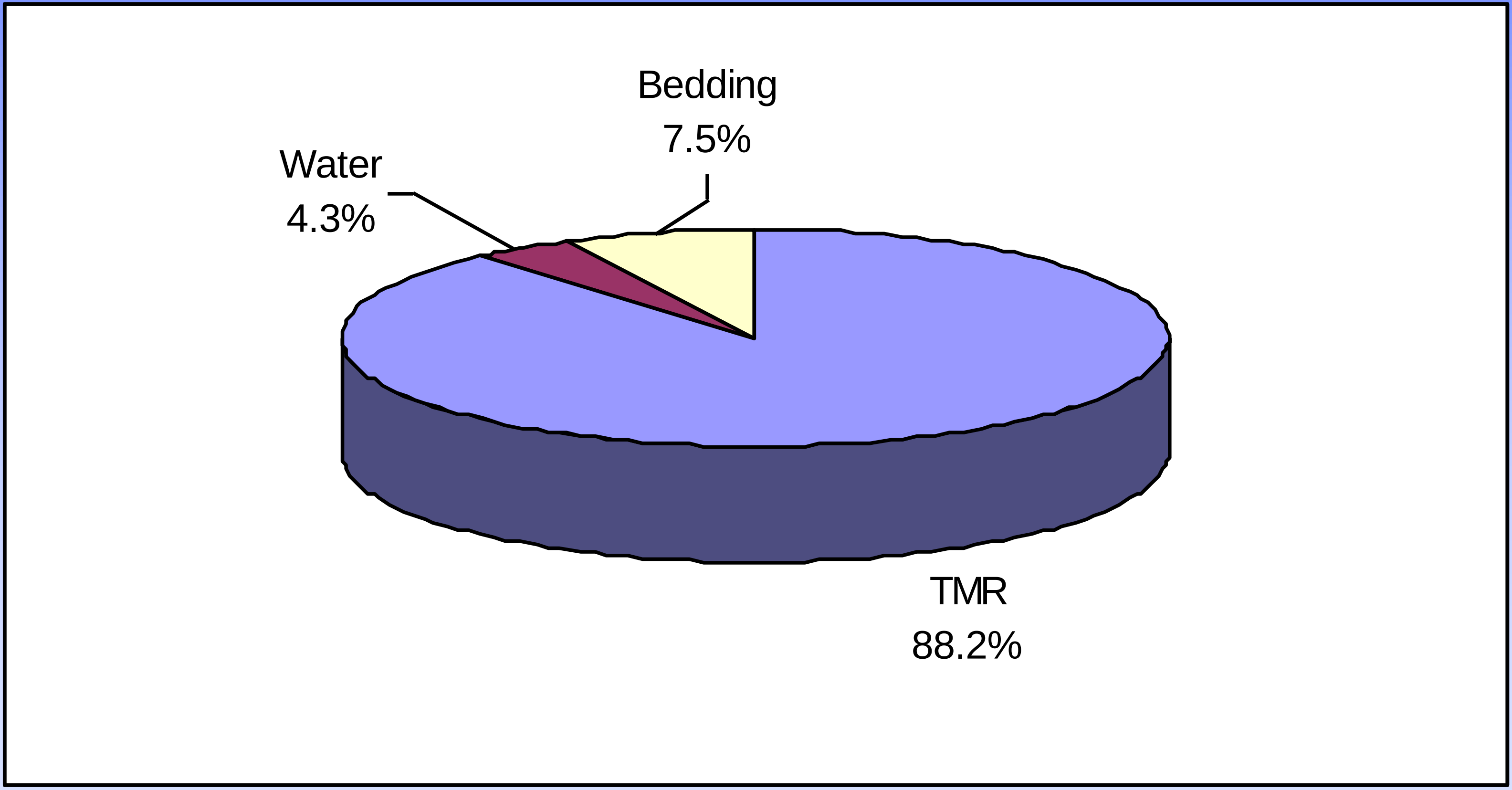
- Adsorption agents used to capture moisture
- Silica gel or aluminum oxide used when biogas used for vehicle fuel
- Two vessels are used for continuous treatment

Biogas Cleanup – Level 2 of 3

H_2S and moisture (sometimes) reduction for on-site combustion

Level 2 - Hydrogen Sulfide

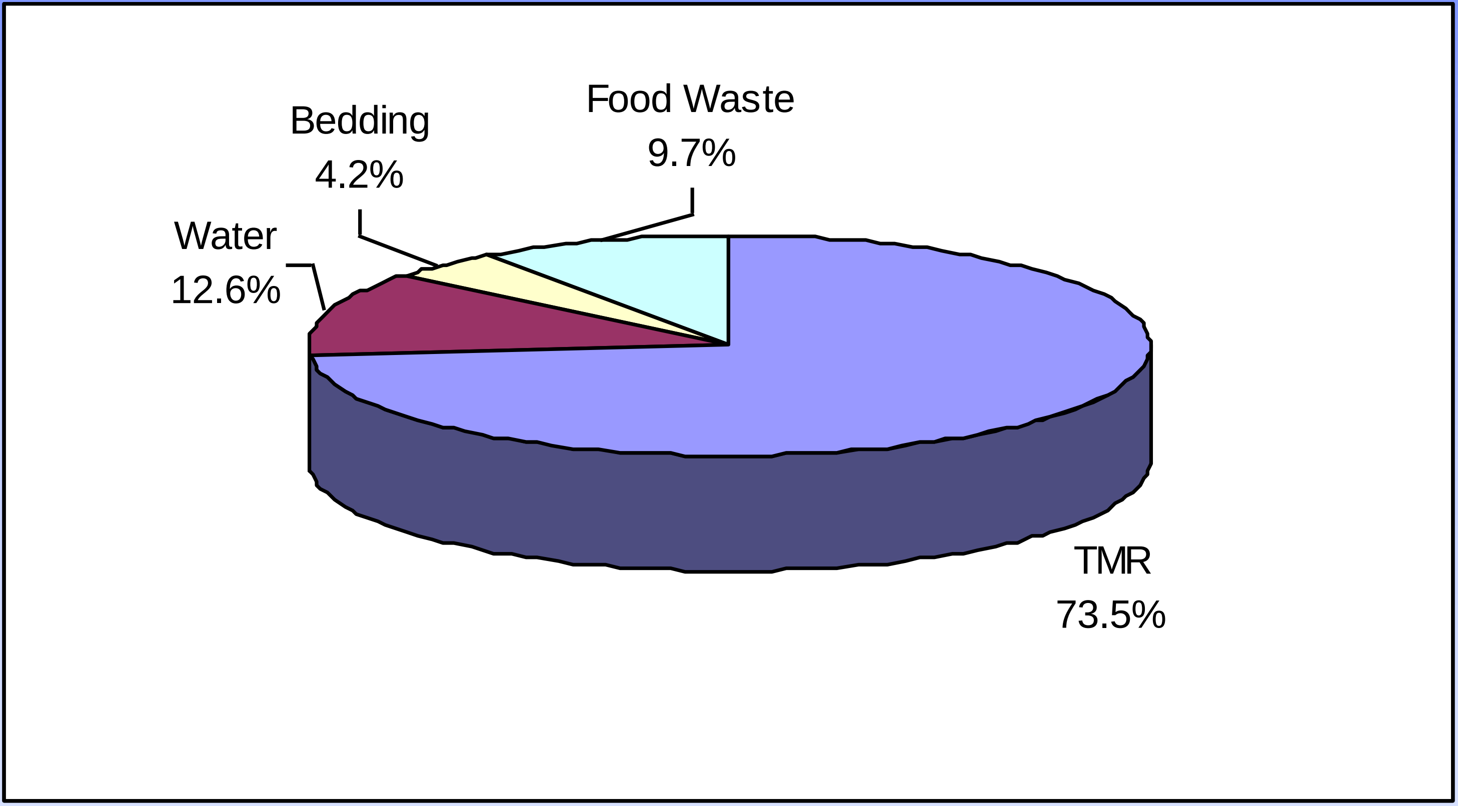
Sources of Sulfur on Farms Not Importing Food Waste for Co-digestion



Source: Ludington and Weeks, 2009

Level 2 - Hydrogen Sulfide

Sources of Sulfur on Farms Importing Food Waste for Co-digestion



Source: Ludington and Weeks, 2009

Level 2 - Hydrogen Sulfide

Max. Concentration for Various Biogas End Uses

Designated End Use	Max. [H_2S], ppm
Boiler	1,000
Engine-Generator	500
Vehicle Fuel	23
Pipeline Injection	4
Fuel Cell	1

Source: Electrigaz Report, 2008

Level 2 - Biogas Hydrogen Sulfide Reduction Options

- Digester Influent Additives
  - Iron Chloride Dosing
  - Ferric Hydroxide Dosing
- Biogas: Physical/Chemical
  - Iron Sponge
  - Activated Carbon
- Biogas: Microbial
  - Biological Fixation

Digester Influent Additive: *Iron Chloride ($FeCl_2$)*

- Liquid form - Injected directly into digester by an automated dosing unit
- Good for high initial [H_2S] as a first stage of a multistage H_2S removal process
- Comparatively low CAPEX
- Comparatively high OPEX due to chemical cost


09/18/2009

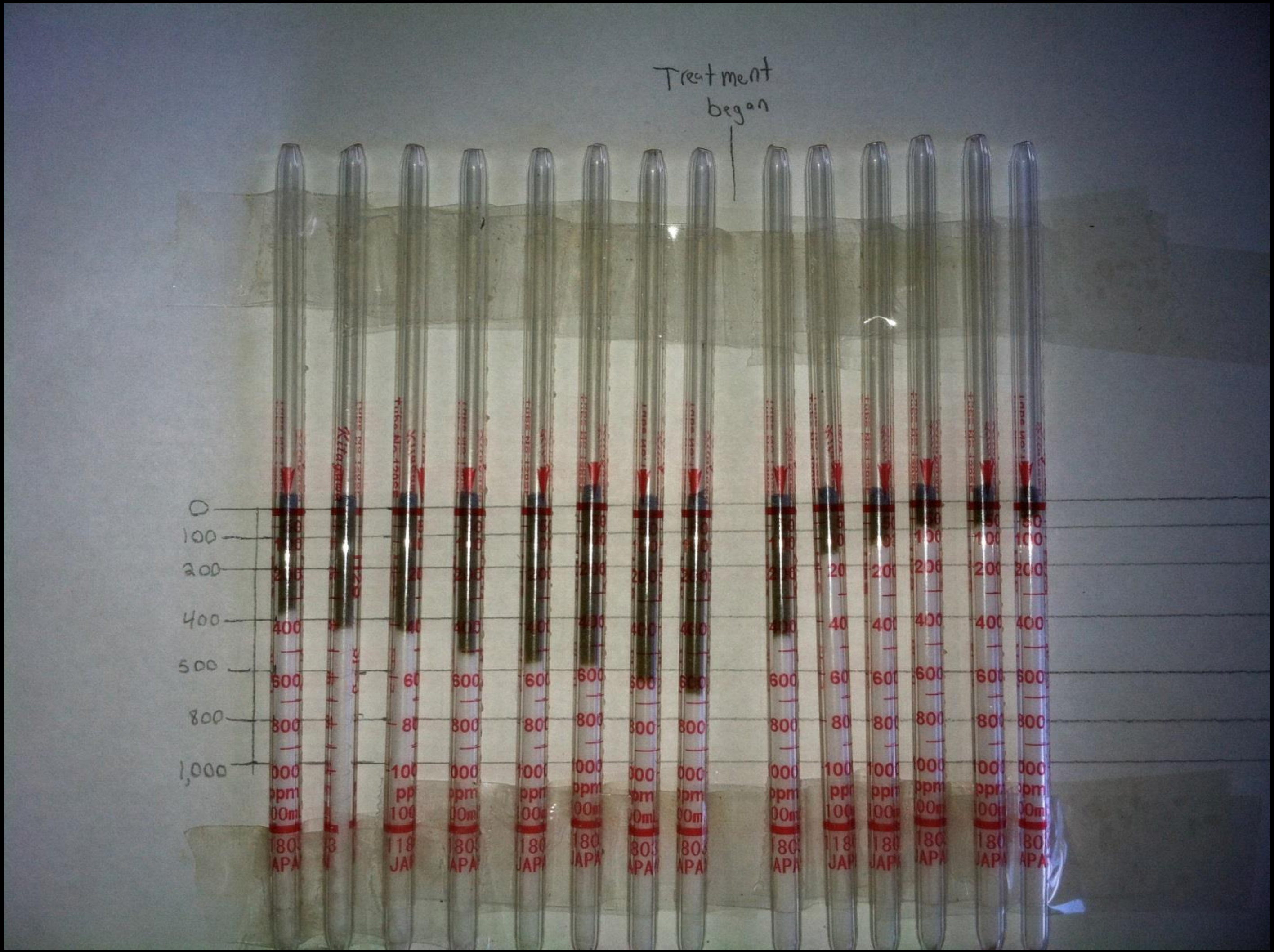

09/18/2009

Digester Influent Additive: *Ferric Hydroxide - Fe $(OH)_3$*

- Granular, powder, and liquid forms
- Application rate – nonlinear, depends on $[H_2S]$ and digester size
- Use started (2013) by NE farm with very good results (3.5 bags/day)
- Google Search reveals price $600 - $1,500/tonne

Ferric Hydroxide
NE Dairy Farm AD

Ferric Hydroxide - Results



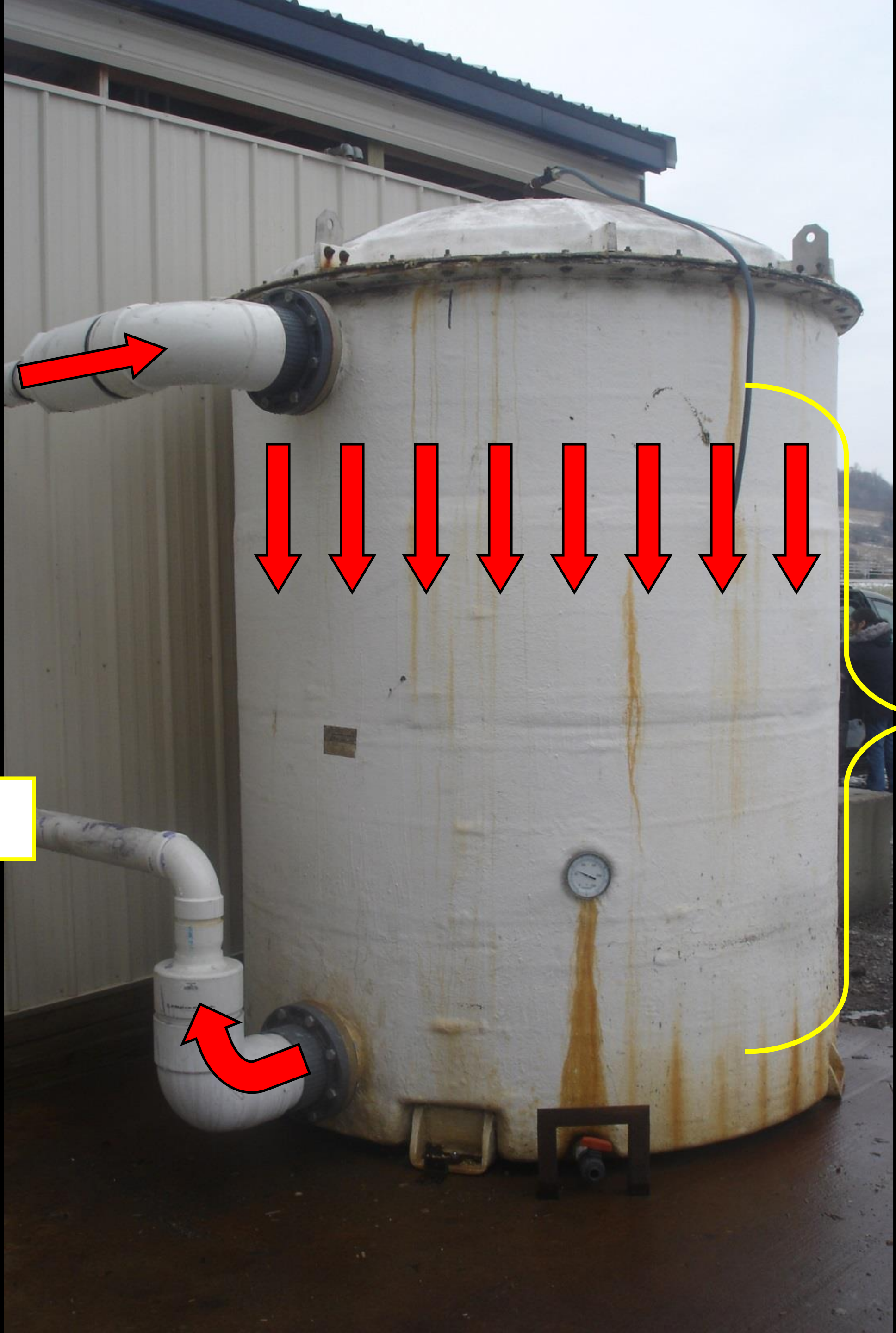
Chemical Removal of H_2S: *Iron Sponge*

- Chemical reaction bonds sulfur to iron oxide
- Reaction occurs at ambient temperatures
- Must be in alkaline conditions, pH > 7.5 w/ 8-10 preferred; caustic soda added as needed
- Temperature < 110F

Chemical Removal of H_2S: *Iron Sponge* (con't)

- Each pound of $Fe_2 0_3$ can remove 0.56 lbs. sulfide
- Iron oxide is impregnate in wood bark: 15 lbs. $Fe_2 0_3$ per bushel of bark (1 bushel in-place = 1 cu. ft.)

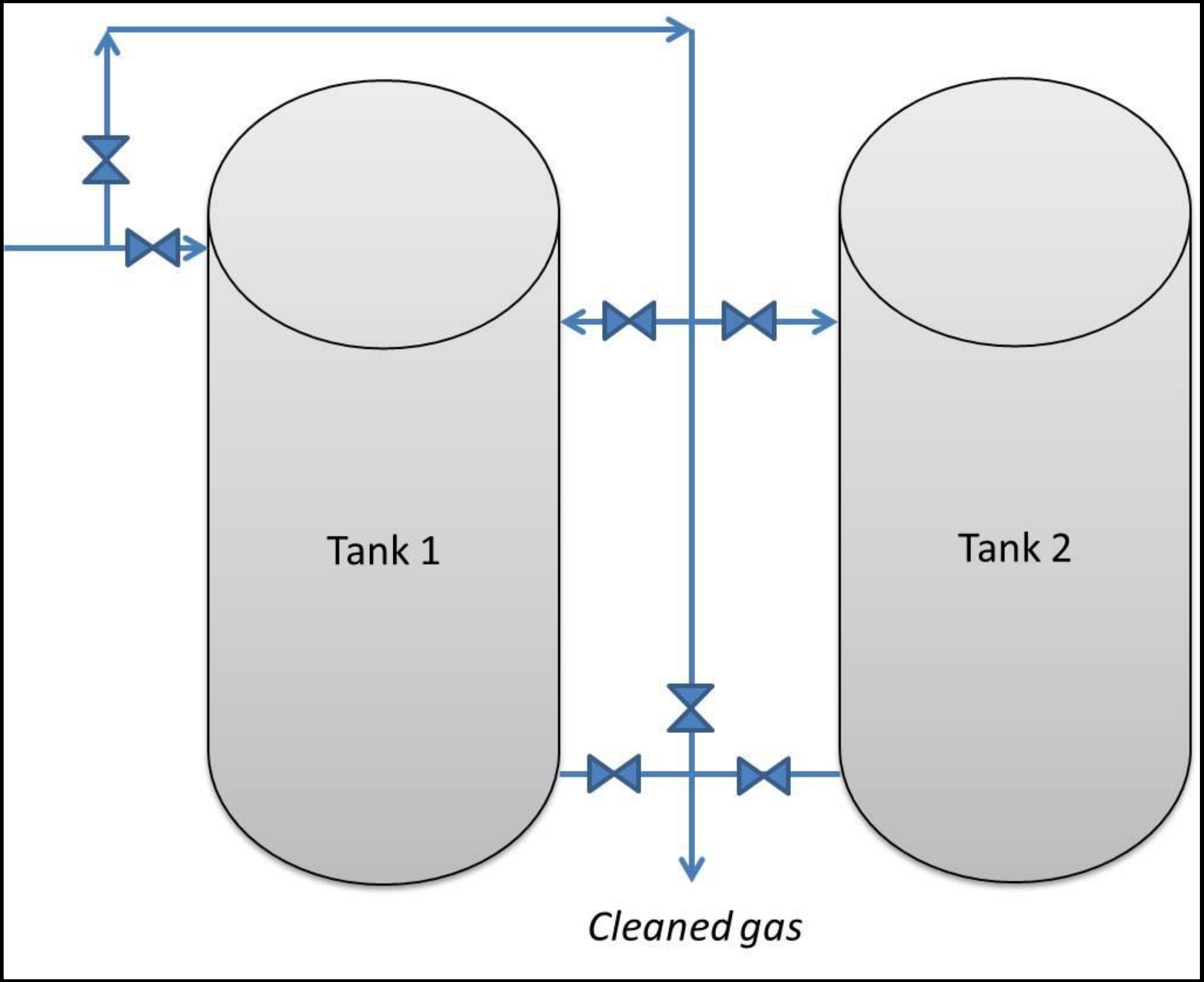
$$3H_2S + Fe_20_3 + H_2O \rightarrow 4H_2O + Fe_20_3$$



$[H_2S]_{in}$ = 1k to 4k ppm
$[H_2S]_{out}$ = 50 ppm
Δp:
2 - 3" wc initially
8 - 10" over time

Iron Sponge – MSU AD System

Two Tank System for Biogas Clean-up



Iron Sponge Scrubbers – Janesville WWTP, Janesville, WI

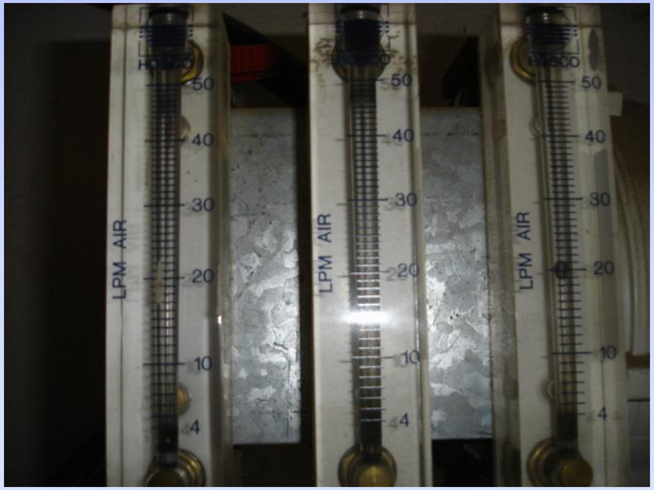
Chemical Removal of H_2S: *Activated Carbon*

- Activated carbon impregnated with potassium iodine or sulfuric acid
- Air injected into biogas to promote carbon adsorption of H_2S
- Carbon also regenerated with injected air
- $H_2S \rightarrow$ elemental S

Microbial Removal of Biogas H_2S

Biological Fixation

- 2 to 4% air injected into biogas
- Operative microbes grow on surfaces
- Reductions to 60 - 200 ppm
- Reduces NH_3 as well
- Final $[0_2]$ 0.5 to 1.8% by volume with also Some N due to the injection process



Microbial Removal of H_2S

Biological Fixation

$$H_2S + 0.5\ O_2 \rightarrow S + H_2O$$

(Partial Oxidation)

$$H_2S + 2O_2 + 2OH \rightarrow SO_4 + 2H_2O$$

(Total Oxidation)

Thiobacillus sp.

Microbial Removal of Biogas H_2S
Biological Fixation

Two Possible Locations:

Digester Biogas Head Space

Separate Vessel

Microbiological Scrubber – Synergy Farm, Covington, NY

Total Annual Cost or Benefit

$\sum$Total Annual Costs – ($\sum$Annual Cost Savings + $\sum$Annual Revenues)

If a positive No., then the system is an economic cost to the farm

If a negative No., then the system is *likely* an economic benefit to the farm

Biogas Cleanup – Level 3 of 3

H_2S, H_2O, CO_2, & NH_3 removal for pipeline injection or transportation fuel → "biomethane" or often called "Renewable Natural Gas (RNG)"

Level 3 - Carbon Dioxide (CO_2) Removal – Options

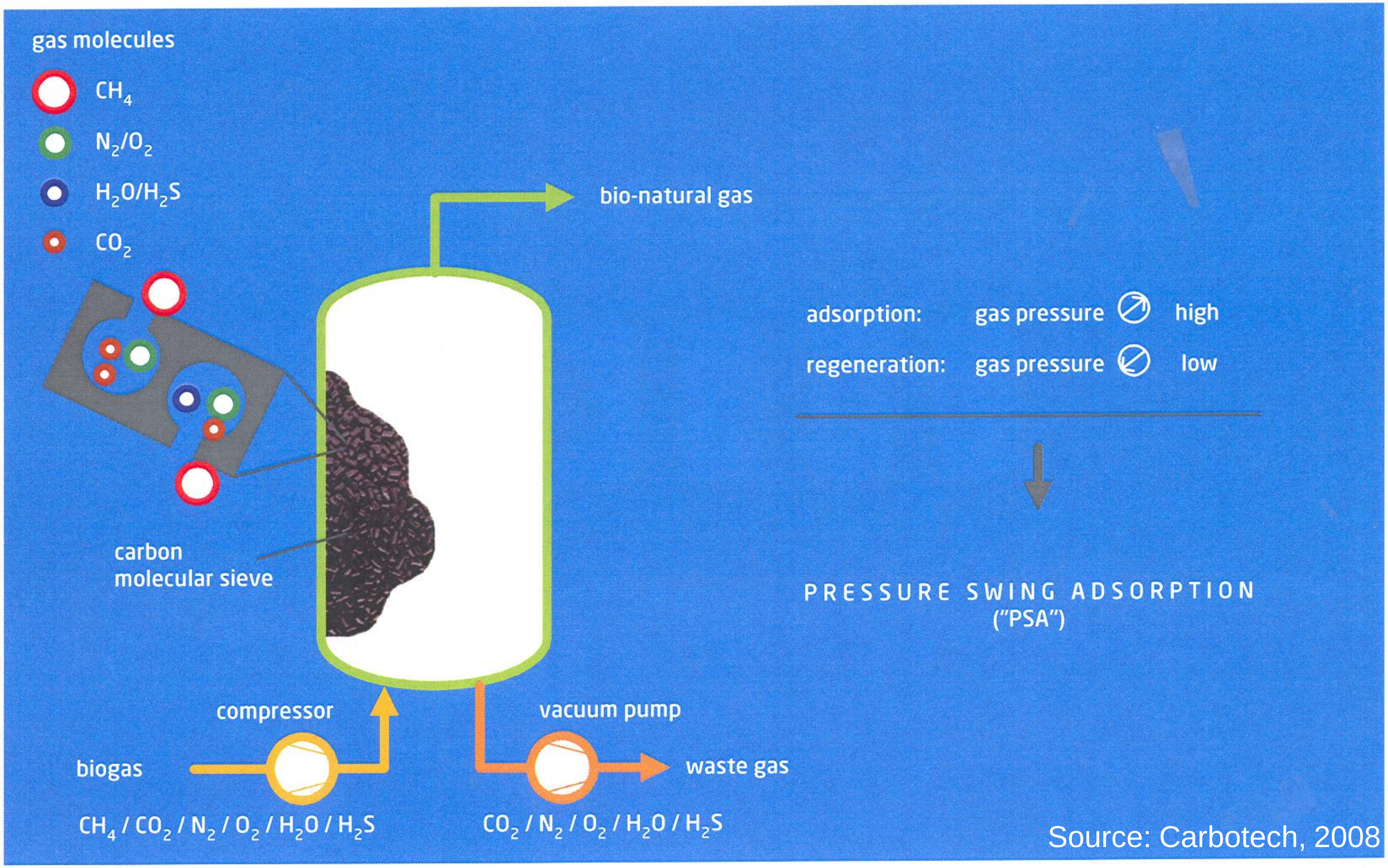
1. Regenerative Water Wash
2. Regenerative Amine Wash (Amine)
3. Pressure Swing Adsorption (PSA)
4. Membrane Separation
5. Cryogenic Distillation

Physical Removal of CO_2: *Pressure Swing Adsorption (PSA)*

- CO_2 is absorbed by means of adsorption materials (molecular sieve)

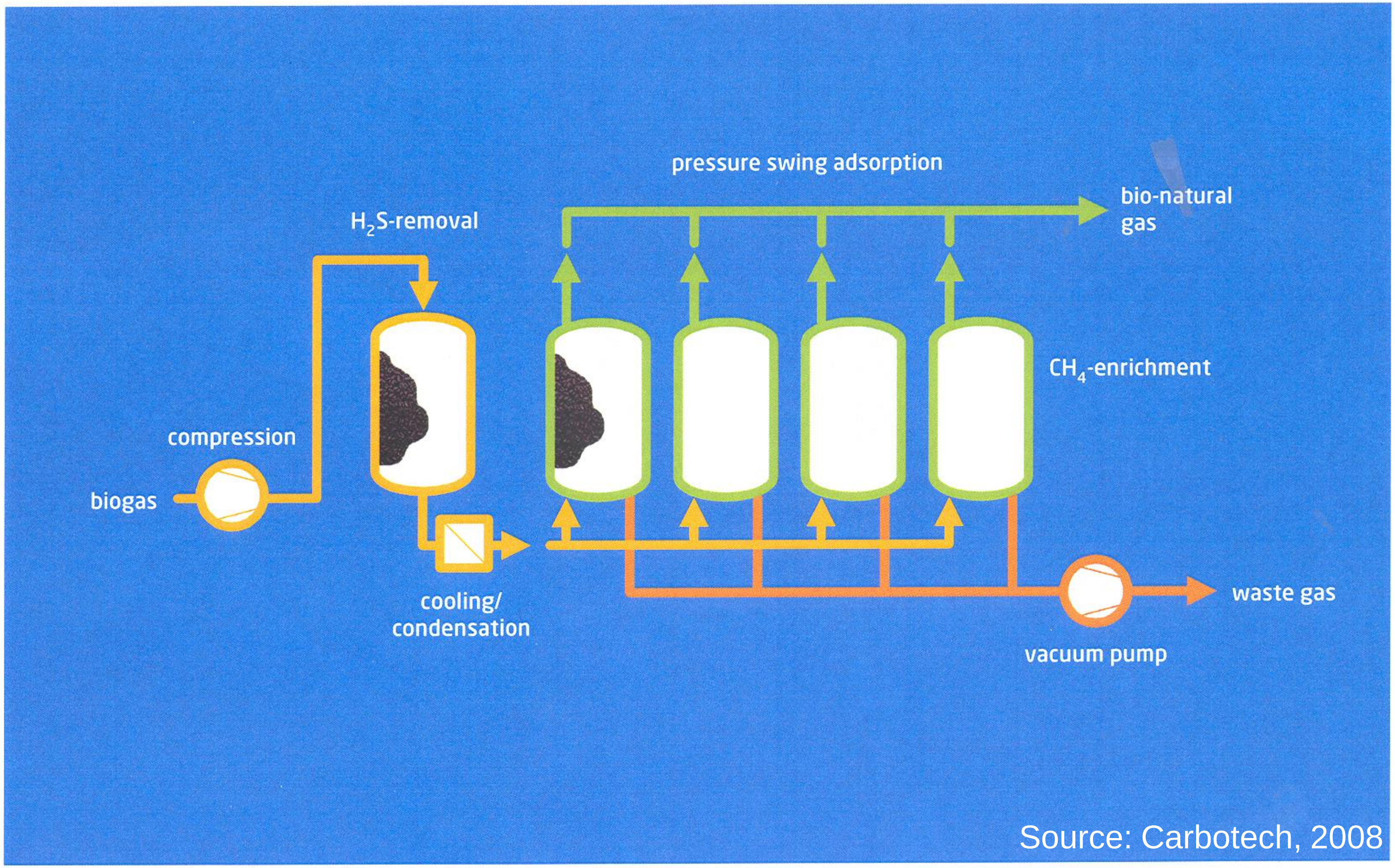
- This system is used extensively in Germany and Sweeden

Biogas Clean Up - PSA



Source: Carbotech, 2008

Biogas Clean Up - PSA



Source: Carbotech, 2008

PSA

- No process water
- No wastewater treatment
- No chemicals
- Removal of H_2O to dew point -90°C

PSA

- N_2 and O_2 removal
- Hydrocarbon, VOC, and Silicon Compounds removed
- Flexible system, containerized

PSA

- Efficient; 97% CH_4 capture
- Off-the-self components
- Very low maintenance

Biogas Clean Up - PSA

(cofermentation sewage slurry/organic waste)

Biomethane Energy Content

100% CH_4

- LHV = 896 Btu's/scf
- HHV = 960 Btu's/scf

Wobbe Index:

- Used to compare the combustion energy output of different composition fuel gases in an appliance
- An indicator of the interchangeability of gaseous fuels

WI = higher heating value/(square root of gas SG)

Average Cost of Biogas Upgrading

Vendor	Biogas Flow (cfm)	Year	Cost ($/MMBtu)	Technology
Metener	118	2006	6.22	Water Wash
Molecular Gate	142	2008	7.08	PSA
Carbotech	148	2008	10.73	PSA
QuestAir 1 Stage	142	2008	6.73	RPSA
QuestAir 2 Stages	142	2008	7.54	RPSA

Source: Electrigaz Report, 2008

Biogas as Liquid Fuel Replacement

Source: Mike McCloskey, 2012

Biogas Thermal Energy Value and Diesel Volume Equivalents

Farm	CH_4 (%)	CH_4 (lbs./day)	Annual Heating Value (mmBtu/yr.)	Diesel Eq. (gal/yr.)
AA Dairy	57	900	7,068,663,000	50,781
New Hope View	58	1,837	14,427,926,590	103,649
Ridge Line	65	3,663	28,769,458,410	206,677
Noblehurst Cell 1 and 2	56	1,069	8,396,000,830	60,316
Patterson	56	3,894	30,583,748,580	219,711
Sunny Knoll	64	1,691	13,281,232,370	95,411


NATURAL GAS
KWIK TRIP
CNG 1.59 9/10
LNG 2.69 9/10
DIESEL 3.99 9/10
PREMIUM DIESEL 4.02 9/10
B5 BIO-DIESEL 4.04 9/10
B20 BIO-DIESEL 4.19 9/10
OFF-ROAD DIESEL 3.54 9/10
DEF 2.69 9/10
PROPANE 3.29 9/10
E85 3.25 9/10
PUBLIC WELCOME


EMERGENCY
SHUT-OFF
PHASE 3


Mobil


DOLLARS
CNG
COMPRESSED
NATURAL GAS
PHASE 3


HILARIDES
TRANS CO
LINDSAY, CA - 67854
Peterbilt
27
DEC
California
2017
COWGAS1

2007 – Dairy Manure Derived Biogas Injection to Natural Gas Pipelines in US

- Few locations attempting this; ID, WI
- Natural gas companies (NGC) very interested
- 17 NGC project investors funded a project in 2007 to develop a US <u>guideline</u> for <u>dairy-based</u> biogas injection

US Guideline for Dairy-Based Biogas Injection (continued)

Biogas testing for:

- ✓ Basic composition
- ✓ Dissolved metals
- ✓ Dust
- ✓ Microbes – MIC
- ✓ Others

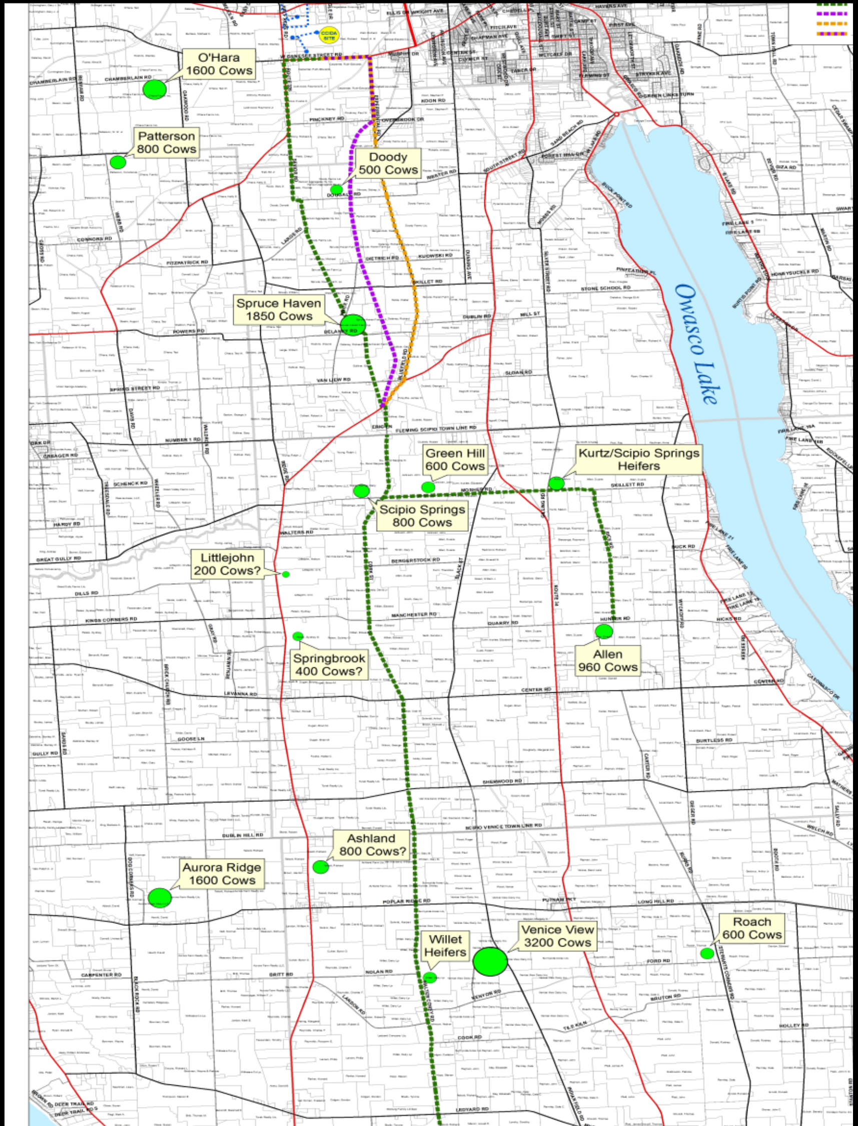
US Guideline for Dairy-Based Biogas Injection (continued)

Biogas testing for:

- ✓ Basic composition
- ✓ Dissolved metals
- ✓ Dust
- ✓ Microbes – MIC
- ✓ Others

Guideline Completed 8/2008

2005-2010 Cayuga Renewable Energy, LLC AD/Pipeline/End Use Project



Vision for Agricultural Community Development

Luftbild der Bioenergieanlage in Jühnde

Why are you here? Perhaps…

- ✓ For networking opportunities
- ✓ To share knowledge
- ✓ Looking for new opportunities
- ✓ Representing products/services for sale
- ✓ To learn
- ✓ Seeking a business opportunity