Housekeeping

- Quiz answers
  - Add technical details to answers
  - Be sure you can answer last year's questions
  - Why agriculture isn't regulated
  - How it might be pushed to eco-awareness
- Change of Plans….
- How was the Municipal P2 viewing?
- State of the Art topics

1

		Average Scores			Max
		All	Grads	Under	Pts
1/11/2012	Intro to P2	9.0417	8.9667	9.1667	10
1/18/2012	Ind. Activity and Env.	10.239	10.036	10.556	10
1/25/2012	Municipal P2				10
1/31/2012	Field Trip - Cargill				
2/1/2012	Fuel Cells, Biogas, SOA, Pumps				10
2/8/2012	Life Cycle Assessment				10
2/15/2012	Design for Env. -- **Spiller**				10
2/22/2012	MSW Field Trip				10
2/29/2012	**P2 Economics**				10
3/7/2012	P2 Planning / Town Hall -- **Legare**				10
3/21/2012	Energy Conservation - **Walton**				10
	Field Trip - Zimmerman				
3/28/2012	**Fugitive Emissions -- Legare**				10
	Field Trip - Recycled Materials				
4/4/2012	P2 and BMPs in Industry				10
4/11/2012	Brewery and P2 -- **Smith**				10
	Field Trip - Coors				
4/18/2012	Metals Removal				10
4/25/2012	Water Resources, DNAPLs, and Fracking				10
	Personal Quiz Average				10
	Total Quiz and Homework Points				150

2

P2 Technologies
Biogas and Fuel Cells

Sidney Innerebner, PhD, PE
Indigo Water Group

What is Biogas and Where Does it Come From?

- A methane rich byproduct produced when organic matter breaks down anaerobically
- Sources of biogas:
  - Decomposing vegetation
  - Farm and ranch animals
  - Manure from farm and ranch animals
  - Wastewater plants
  - Landfills

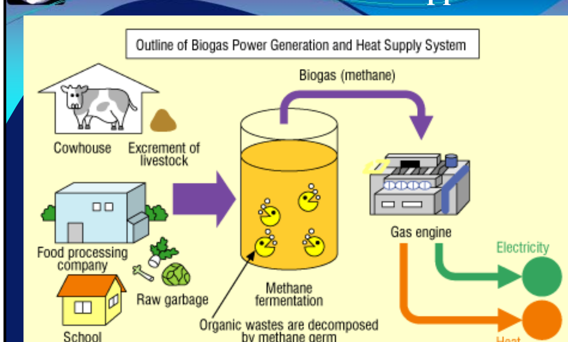
4

Typical Biogas Utilization

- As fuel for boilers (heat production)
- As fuel for combustion engines (electric energy production and heat recovery)
- After CO_2 separation, gas can be pressed into a gas grid (use like natural gas)
- Heating and cooking "off the grid"

5

Combined Heat and Power Applications



Source: http://www.inverter-china.com/blog/articles/green-energy/Definition-of-biogas.html

6

Advantages of Biogas

- Renewable resource
- Cheaper and simpler than other biofuels
- Well suited for small scale application
- Decentralized production
- Methane recovery is spontaneous
- Dilute waste materials can be used as substrate (2 – 10%)
- Any biodegradable material can be used
- *Reduced* explosion risk compared to pure methane
- Anaerobic digestion inactivates pathogens and parasites
- Converts methane to CO_2 and water

7

Tonight's Agenda

- A close look at anaerobic digestion
- Opportunities for biogas use
  - Combined Heat and Power
  - Biofuel?
- Case studies
- Discussion of SOA Project
- Fuel cell intro (time permitting)

8

Cooking with Biogas

- Ingredients for a single family anaerobic digester
  - Closed 800 gallon tank
  - 165 pounds per day of waste material
  - 5 to 8 cattle plus kitchen and bathroom waste
- Produces 106 cf of biogas per day
- 23 cf of biogas = 1 kw of electricity
- Results in about 5 to 6 kw per day

9

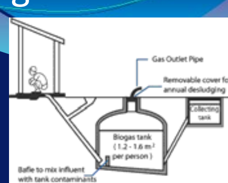
How much is 5 kw?

- 5,000 watts
- Enough to run
  - One 60 watt bulb for 83 hours
  - Charging a cell phone at 3.7 watts for 6 hours uses 22 watts of electricity
  - 19-inch CRT television for 55 hours
  - A 1,000 watt microwave for 5 minutes

10

Single Family Biogas Unit

- Gas may be burned directly for heating
- Send to 100% biogas generator followed by alternator ($800 - $1000)
- Payback on construction is 4 to 8 years
- Can sell excess biogas and electricity



Source: http://tianwai.wordpress.com/2009/10/29/hooray-poop/

http://khaoyai.wordpress.com/2007/11/20/sustainable-energy-project-reduces-logging/

Number of People Relying on Biomass for Cooking and Heating (Millions)

	2000	2030
China	706	645
India	585	632
Other Asia	420	456
Sub-Sahara Africa	**583**	**996**
Latin America	96	72

Mostly the rural poor.

Anaerobic Digestion

13

Digestion Processes

- Anaerobic Digestion
  - Ponds
  - Septic Tanks
  - Engineered Systems
- Bacteria break down in ***Endogenous Respiration***
- End products of digestion are carbon dioxide, water, and bits that don't degrade easily

$C_4H_7O_2N \rightarrow CO_2 + H_2O$

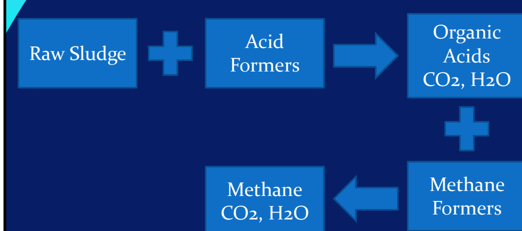
14

Anaerobic Digestion

- Absence of Oxygen and Nitrate
- Fermentation process
- Depends on two groups of bacteria
  - Acid Formers or Saprophytic Organisms
  - Methane Formers
- Generally not cost effective below 5 mgd - *changing*

15

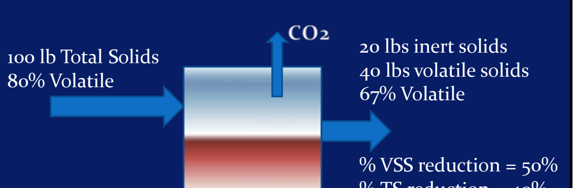
Anaerobic Digestion



16

Volatile Solids Reduction

$$\% \text{ VSS Reduction} = \frac{(\text{In} - \text{Out})}{\text{In} - (\text{In}*\text{Out})} * 100$$



If MLSS is 82% volatile and solids leaving the digester are 67% volatile, find the %VSS reduction.

$$\% \text{ VSS Reduction} = \frac{(\text{In} - \text{Out})}{\text{In} - (\text{In}*\text{Out})} * 100$$

$$\% \text{ VSS Reduction} = \frac{(0.82 - 0.67)}{0.82 - (0.82*0.67)} * 100$$

$$\% \text{ VSS Reduction} = 55.4\%$$

18

Types of Anaerobic Digesters

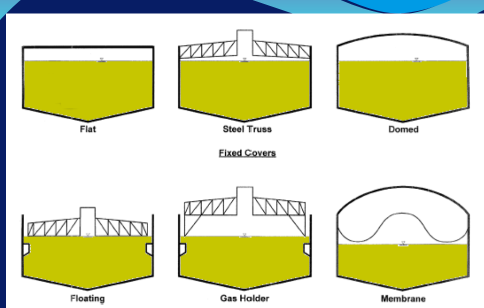
Type	Temperature Range, °F	Solid Retention Time, days
Psychrophilic	Unheated	60+
Mesophilic	68 – 113 (95°F)	25 - 30
Thermophilic	120 - 135	5 – 12

19

Anaerobic Digester Components

- Cylindrical, cubical, or egg-shaped tank
- Sloped floor (1:4 to 1:6 side slope)
- Fixed or Floating Cover
- Mixing Equipment
- Supernatant Tubes
- Sludge Draw Off Tubes
- Gas System

20



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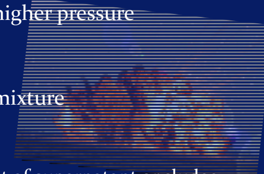
23

Fixed Cover Tank

- Designed to maintain 8-inch water column of gas pressure on tank roof
- Occasionally designed for higher pressure
- Flat versus Domed Cover
- Can develop explosive gas mixture
  - 5 – 15% gas/air mixtures
  - Add new sludge
  - Withdraw an equal amount of supernatant or sludge
  - Maintain constant level



24

Floating Cover Tank

- Cover moves up and down with tank level
- Vertical travel of 8 feet typical
- Total depth of 20 feet or more
- Stops or Corbels spaced every 10-16 feet around
- Roller Guides ensure even travel
- Maximum water level controlled by overflow pipe
- Water seal prevents air from entering tank

25

Source: http://i178.photobucket.com/albums/w263/queenjen136/Otsego.jpg

26

27

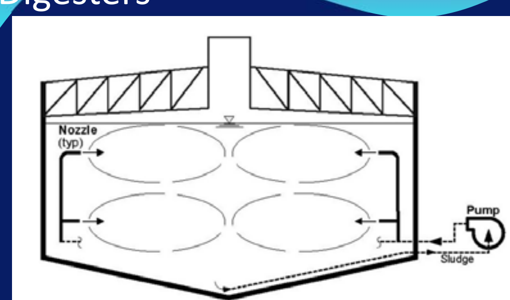
28

Mixing

- Utilizes entire digester volume
- Distributes raw sludge throughout tank
- Contacts microorganisms with food
- Distributes inhibitory byproducts
- Assists with pH and alkalinity control
- Distributes heat
- Minimizes separation of grit and scum

29

Pumped Mixing for Smaller Digesters



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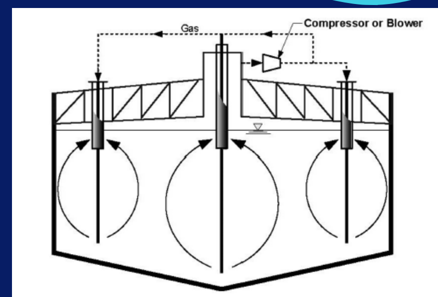
31

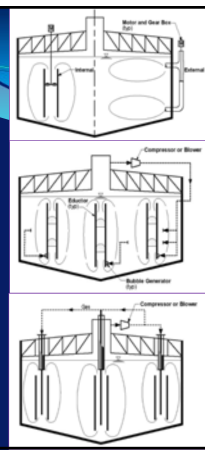
Gas or Lance Mixing



32

Other Types of Mixing

- Impeller Mixing
- Bubble Gun System
- Draft Tube



Supernatant and Sludge Withdrawal Tubes

- Three to five tubes set at different depths
- Multiple lengths
- Allow operator to draw supernatant and sludge from different depths
- Some digesters use a single, adjustable tube for supernatant

34

35

Gas System

- Digestion Process Produces
  - 8 to 12 cubic feet of gas for every lb VSS ADDED
  - 12 to 18 cubic feet of gas for every lb VSS DESTROYED
- Gas Mixture should be
  - 65 – 75 percent methane by volume
  - 30 – 35 percent carbon dioxide by volume
- Trace gases also present
  - Hydrogen, nitrogen, hydrogen sulfide, etc

36

Heating Value for Digester Gas

- 500 to 600 BTU per cubic foot
  - BTU = British Thermal Unit = Energy to raise 1 lb of water by one °F
- Natural gas has a heating value of 900 to 1,200 BTU per cubic foot
- Reuse to heat digester and/or buildings or "flare" for safety

37

38

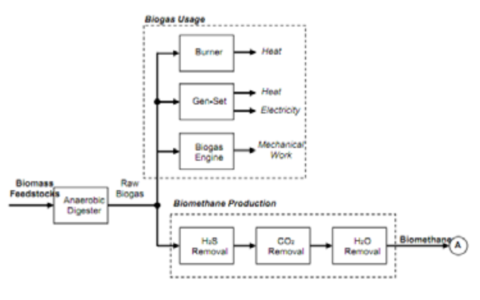


Figure 1: Schematic diagram of biogas and biomethane production and utilization (Part 1)

39

Digester Heating

- Heat required to raise temperature of incoming sludge
- Heat required to make up transmission losses
- Sludge Heating Formula
  - $Q = (S)(C_s)(T_o-T_i)$
  - Q = Heat requirement in BTU/hr
  - S = Solids flow rate in lb/hr
  - Cs = Specific Heat of Solids (1 BTU / lb * °F)
  - T = Temperature of operation and initial, °F

40

Digester Heating

- Digester gas scrubbed
- Sent to Boiler
- Recirculate digesting sludge through heat exchanger
- Internal or external to tank
- Recirculation pump keeps velocity at 4 fps to minimize fouling

41

Anaerobic Digester Operation

- Pump as thick as sludge to digester as possible
- Thin sludge is < 3.5% solids
- Excess water causes
  - Additional heating capacity to maintain temperature
  - Reduction in retention times
  - Reduces buffering capacity by forcing out supernatant
  - Increased decant frequency
- Sludge concentrations greater than 10% don't digest well

42

Anaerobic Digester Operation

- Air entering tank creates explosive gas mixture
- Adjust sludge withdrawal rate to
  - Maintain positive pressure in digester
  - Prevent vacuum formation
- Monitor Volatile Acid to Alkalinity Ratio
  - Generally less than 0.1
  - Volatile acids less than 500 mg/L
  - Problem when ratio gets to 0.5
- pH should be near 7.0 or a little higher

43

Anaerobic Digester Operation

- Loading rate of 0.15 – 0.35 lb VSS per cubic foot OR
- 150 – 300 lbs of VSS per day per 1,000 cubic feet
- Primary and secondary digesters often used
- Primary digester receives raw sludge
- Secondary digester
  - Digests at a slower rate
  - Settles digested sludge
  - Provides seed sludge for Primary when needed

44

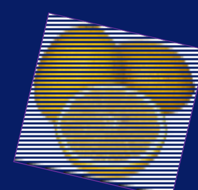
Operating Parameter Cheat Sheet

Parameter	Units	Target
Temperature	Degrees F	90 – 100
Volatile Acids	mg/L	50 – 330
Alkalinity	Mg/L as $CaCO_3$	1500 – 5000
VA/Alk Ratio	none	0.1 – 0.2
pH	S.U.	6.8 – 7.2
Gas Production	cfd	12 – 16 cf/lb VS destroyed

45

Common Operational Problems

- Souring of Digester
  - Acid formers out-pace methane formers
  - Neutralize with 1 lb lime per 1,000 gallons sludge
  - Jar test for accurate dosing
- Foaming
  - Often caused by over feeding
  - Methane formers grow rapidly
  - Reduce feeding and mix gently to release gas



46

Control Strategy

- Stop or reduce solids feed
- Determine the cause of the imbalance
- Correct the cause
- Provide pH control until balance returns

47

Advantages of Anaerobic Digestion

- Methane Gas Utilization
- Better VS Reduction than Aerobic Digestion
- Reduces Total Solids Mass
- Good Pathogen Deactivation
- Low Net Energy Requirements
- Decreases Sludge Volume
- Less Sludge Storage Required
- Lower Annual Operating Costs

48

Anaerobic Digestion Disadvantages

- High Initial Capital Costs
- High Operator Attention
- *May* Experience Foaming
- Grit Removal
- Supernatant Can Have Significant Ammonia Recycle Load
- High Cleaning Cost
- Struvite Potential

49

Class "A" With Respect to Pathogens

- Fecal < 1000 MPN/g or Salmonella s.p. < 3 MPN/4g (based on seven samples per event) AND
- Use one of 5 approved methods to Further Reduce Pathogens:
  - Time/temp depending on solids content
  - pH/time then dry to at least 50% solids
  - Testing for enteric viruses/viable helminth ova
  - Testing
  - PFRP: composting, heat drying, heat treatment, TAD, beta ray irradiation, gamma ray irradiation, pasteurization, other as approved by EPA Region 8

Class "B" With Respect to Pathogens

- 7 samples - Geometric Mean <2,000,000 MPN/g or CFU* (based on seven samples per event) OR
- Use 1 of 5 Approved Process to Significantly Reduce Pathogens (PSRP) methods:
  - Aerobic Digestion: 40 days @ 20 C no less than 60 days @15 C
  - Air Drying: 3 months with two months above 0 C
  - Anaerobic Digestion: 15 days @ 35-55 C no less than 60 days at 20 C
  - Composting: Minimum 40 C for 5 days with min 4 hours at 55 C
  - Lime Stabilization: Add lime to raise pH to 12 after two hours of contact
  - Other as approved by EPA Region 8

52

53

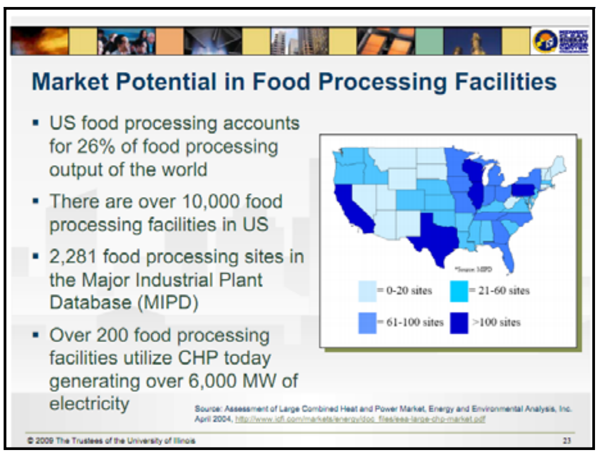
MWRD - Metro Wastewater Reclamation District

- MetroGro
- About 52,000 dryland farm and pasture acres where they apply biosolids.
- Crop variety includes winter wheat, sorghum/sudan grass, and corn.
- Pasture areas are often used for sheep and cattle grazing.

54

Combined Heat and Power - CHP
55

Digester / Reactor
Gas Treatment Module
Cogeneration - Power Module
Transformer Station
56



Market Potential in Food Processing Facilities
US food processing accounts for 26% of food processing output of the world
There are over 10,000 food processing facilities in US
2,281 food processing sites in the Major Industrial Plant Database (MIPD)
Over 200 food processing facilities utilize CHP today generating over 6,000 MW of electricity
= 0-20 sites
= 21-60 sites
= 61-100 sites
>100 sites
Source: Assessment of Large Combined Heat and Power Market, Energy and Environmental Analysis, Inc. April 2004
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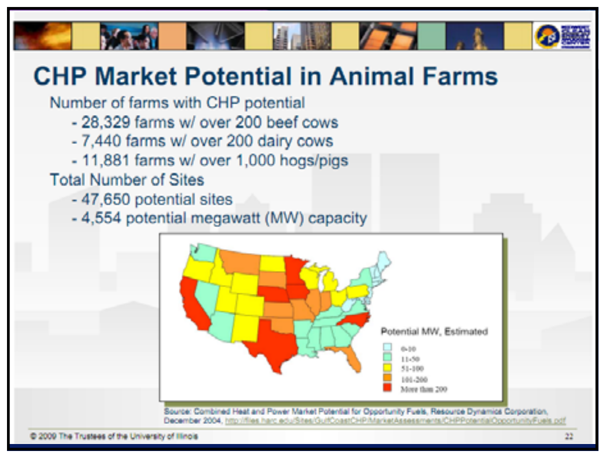

CHP Market Potential in Animal Farms
Number of farms with CHP potential
- 28,329 farms w/ over 200 beef cows
- 7,440 farms w/ over 200 dairy cows
- 11,881 farms w/ over 1,000 hogs/pigs
Total Number of Sites
- 47,650 potential sites
- 4,554 potential megawatt (MW) capacity
Potential MW, Estimated
Source: Combined Heat and Power Market Potential for Opportunity Fuels, Resource Dynamics Corporation, December 2004
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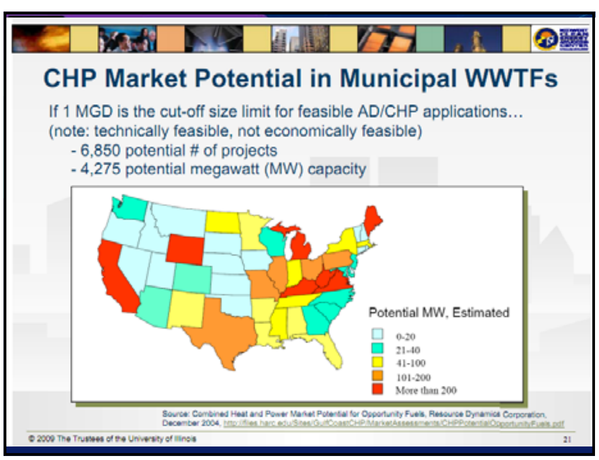

CHP Market Potential in Municipal WWTFs
If 1 MGD is the cut-off size limit for feasible AD/CHP applications…
(note: technically feasible, not economically feasible)
- 6,850 potential # of projects
- 4,275 potential megawatt (MW) capacity
Potential MW, Estimated
0-20
21-40
41-100
101-200
More than 200
Source: Combined Heat and Power Market Potential for Opportunity Fuels, Resource Dynamics Corporation, December 2004
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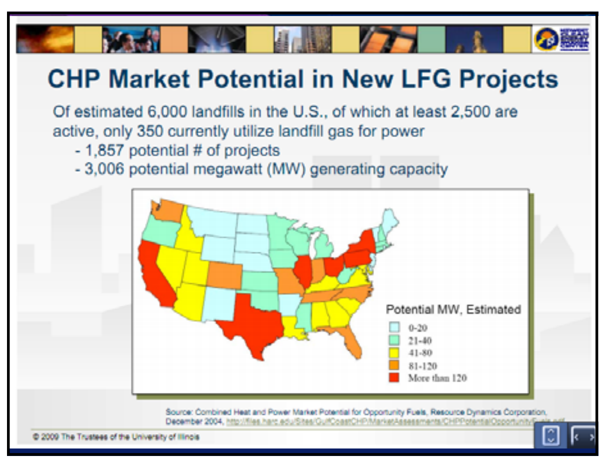

CHP Market Potential in New LFG Projects
Of estimated 6,000 landfills in the U.S., of which at least 2,500 are active, only 350 currently utilize landfill gas for power
- 1,857 potential # of projects
- 3,006 potential megawatt (MW) generating capacity
Potential MW, Estimated
0-20
21-40
41-80
81-120
More than 120
Source: Combined Heat and Power Market Potential for Opportunity Fuels, Resource Dynamics Corporation, December 2004
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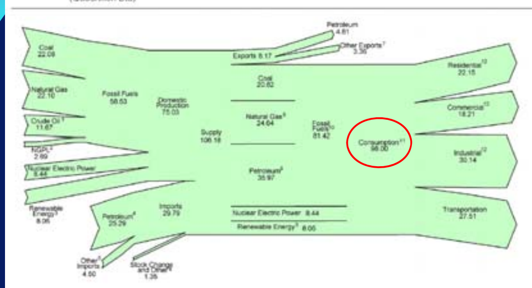
Energy Flow In The U.S., 2010

Figure 1.0 Energy Flow, 2010
(Quadrillion Btu)



(US Department of Energy, 2010) - http://www.eia.doe.gov/

Putting it into perspective

- 2010 Energy Consumption was 98 Quadrillion BTUs
- 98,000,000,000,000,000 BTUs (15 zeros!)

- 1 MW = 3414425 BTUs per hour
- 98 Quad BTU's is then about 3,276,456 MW

- Totals from previous slides is 17,835 MW
- About 0.5% of our total energy use each year

62

Example #1 – Seasonal CHP and Boiler Operation

- Site: Rochester Water Reclamation Plant
- Location: Rochester, MN
- Began Operation: 1982
- Operation Description:
  - 24 MGD wastewater treatment facility utilizing anaerobic digesters
- Project Description:
  - Biogas is utilized seasonally in
    - CHP system (2 MW capacity)
    - Boilers

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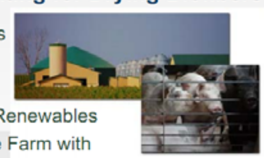
Example #3 – Biogas Heating for Drying Biofibers

- Site: Geerlings Hillside Farms
- Location: Overisel, MI
- Began Operation: 2008
- Project Developer: Phase 3 Renewables
- Operation Description: Swine Farm with 8,000 spaces wean to finish
- Project Description: Anaerobic digestion
  - Biogas utilized in two (2) 65 kW engines (CHP system) and one (1) 1 MMBtu Boiler
  - Recovered heat from engines and heat from boilers is used to dry biofibers to enable pelletization
  - Pellet mill can produce 1.5 tons per hour; pellets can be used for fertilizer, boiler fuel or horse bedding



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Example #5 – Gasification for Air Turbine and Steam

- Site: Sietsema Farms Feeds
- Location: Howard City, MI
- Began Operation: 2009
- Project Developer: Phase 3 Renewables
- Operation Description: Turkey Grower & Feed Mill
  - 1.5 million birds, five separate farm sites, 11,000 tons litter
  - Feed mill produces feed for turkeys and swine
- Project Description: Gasification, Electricity Generation, Heat and Steam
- Heat Application:
  - Syngas produced in SALT gasification facility
  - Advanced ceramic heat exchanger recovers air for use in 500kW air turbine generator
  - Metal heat exchanger recovers heat for 8,600 lbs/hr steam @ 150 psig for feed pelleting process

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Europe Takes the Lead

- Europe has about 200 biogas plants in the early 1990's
- Today they have more than 16,000
- 60% are located in Germany
- Estimated to have 30,000+ by year 2015

- Older models only about 28% efficient or less

66

Other Applications for Biogas

- Syngas – gasification of biomass
- Hydrogen Production from Methane
- Fuel Cells

68