Biomass Waste-to-Energy 101:

Methane Digestion and Biomass Gasification

Dan Moring
Arizona Department of Environmental Quality

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Presentation Overview

- Basic Science:
  - What’s happening physically?
- Technology Overview
  - How do we control those processes?
- Economic Considerations
  - What are the costs and benefits?

Scope of Presentation

- No Biofuels discussion
- Focus: Science & technology of converting organics to gas for electricity and heat production
- Broad overview of issues:
  - Scientific
  - Technological
  - Economic
- Connect with experts in breakout sessions

Big Picture

- Make agricultural by-products ready for energy recovery by converting to a gas to burn for electricity and heat
- Provide information at “ Why?” threshold
- Both are <u>Scientifically Possible</u>
  - Biological Pathway: Methane Digesters
  - Thermochemical Pathway: Biomass Gasifiers
- Both are <u>Technologically Feasible</u>
- May be <u>Economically Feasible</u>

Basic Science

- Fundamental Concepts
  - Thermodynamic Free Energy:
    - Ability to extract work from a system
  - Biomass:
    - “Organic matter in trees, agricultural crops and other living plant material” (Western Governors’ Assn)
    - “Any organic material not derived from fossil fuels” (18 CFR 292.202)
  - Biological and Chemical Conversion Pathways of biomass to fuel gas

Free Energy

- “Mechanical work that can be extracted from a system”
- The “system” is the particular area of the planet we inhabit
- Sun is the source of all energy in our biological systems
- Convert through photosynthesis in ag.

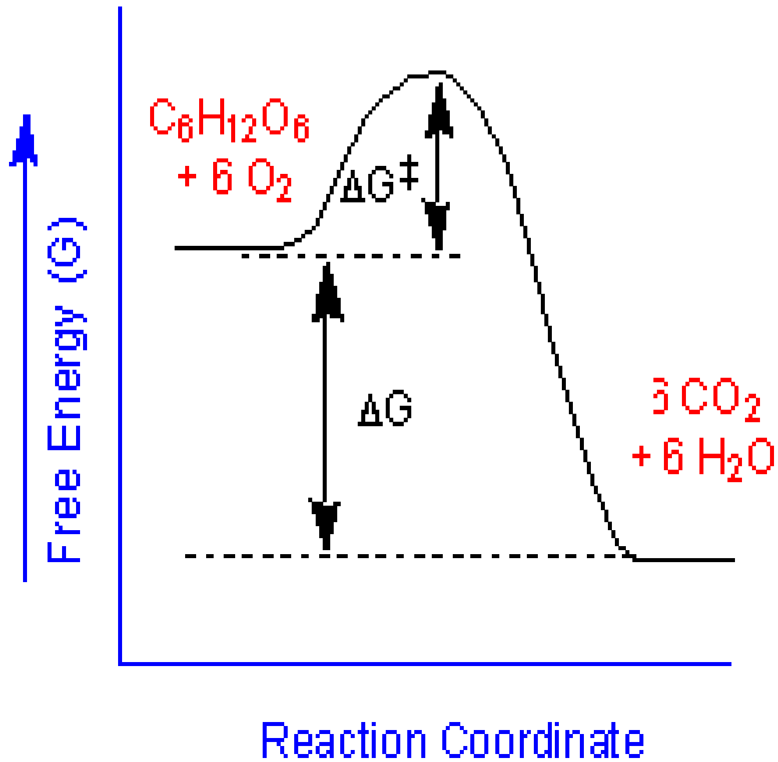
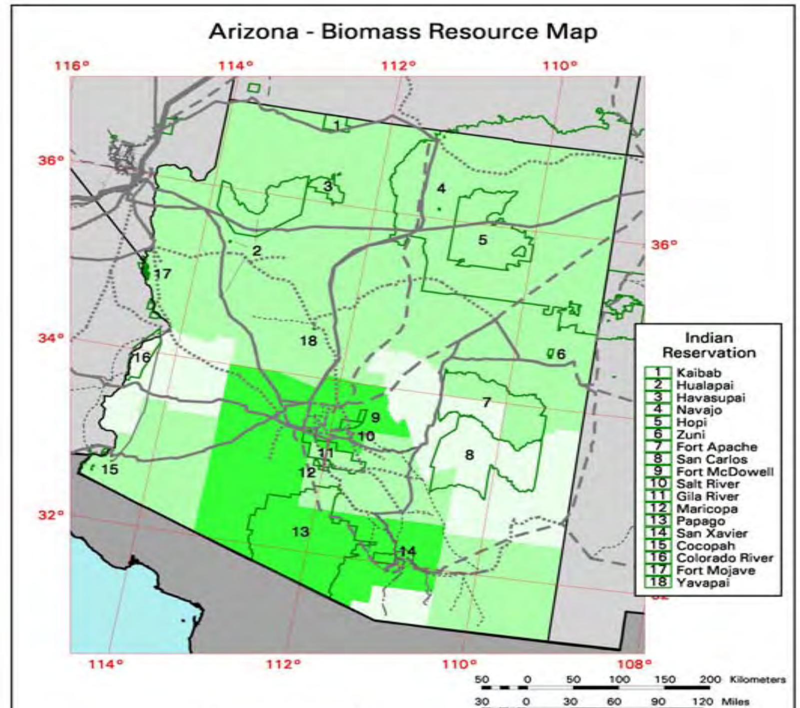


Image credit: www.ilpi.com/genchem/demo/co2mg/energydiagram.gif

The Cash Metaphor

- Wealth of energy from the sun
- Lots of energy left in ag. waste, but how do we "make change"?
- Bacteria: nature's penny-pinchers



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Biological Pathway: Methane Digestion

- Manure contains:
  - Decomposed feed, waste feed, water
- Bacteria need:
  - Optimal pH range: 6.8-7.4
  - Temperature: 95-105 F (mesophilic bacteria)
- Groups of bacteria break down manure
  - Simplified reaction:
    - $C_6H_{12}O_6 \rightarrow 3\ CO_2 + 3\ CH_4 + \text{trace } H_2S$
    - Energy Content ~ 600 BTU per cubic foot

Image credit from www.wurdco.com/images/lecow.jpg

Know Your "Stuff": Important Terms

- How Much?
  - Total Solids Content: The percentage of manure that is dry matter, by weight, determines the type of digester
    - Volatile Solid Content: How much of that solid can bacteria convert? Methane production is often based on the volatile solids portion of the manure.
- How Long?
  - Hydraulic Retention Time (HRT): The amount of time the manure spends in the digester. Reported as the ratio of digester volume to the amount of manure added per day.

Anaerobic Digestion Values

Biogas Production Potential
Based on Typical Nutrition and 100% Manure Collection

	kWh/ head/day	Biogas Production ft3/head/day
Dairy Cow	2.5-3.7	65-80
Sows	0.2 - 0.3	5-7.5
Nursery Pigs	0.06 - .09	1.4–2.1
Finisher Pigs	0.15 – 0.22	3.5-5.5
Beef/Feeder	1.8 – 2.2	45-55
Laying Hen	.01	0.25

<u>Energy Production per 1,000 lbs live weight (Animal Unit)</u>

Species	VS lb/day	Biogas ft3/day	Energy BTU/day
Dairy	10.0	39	23,400
Swine	8.5	28	16,800
Layer Hen	12.0	37	22,000

Reproduced from Ak-Chin Biomass Feasibility Study, December 2005;

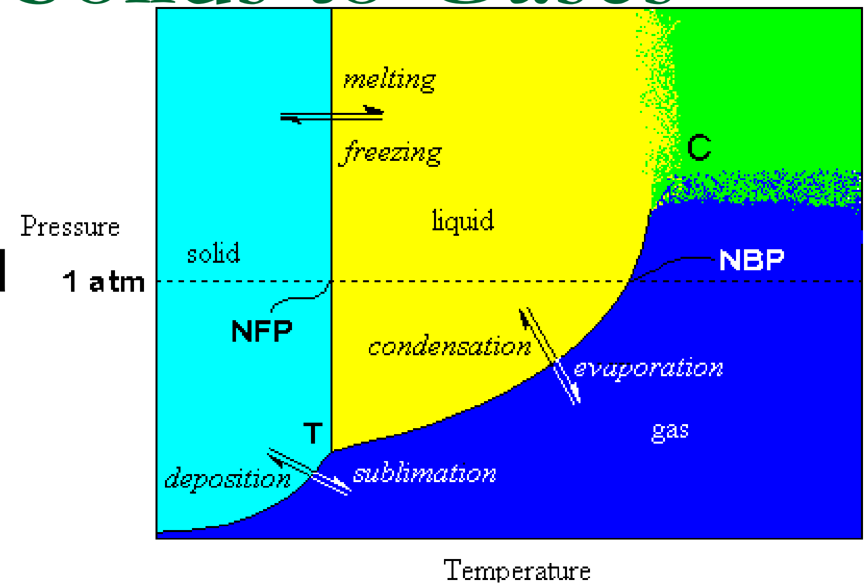
Excerpted from David Schmidt, University of Minnesota, “Anaerobic Digestion 101”

Biomass Gasification

- Hydrocarbons + excess Oxygen = Fire
- Hydrocarbons + minimal Oxygen= Syngas
  - CO + H2 + ash & tar
- Why not burn directly?
  - Burning gas is cleaner and more efficient, because gases can mix in more places
- Energy Value of about 250 BTU/cf

Gasifiers Convert Solids to Gases

- As temperature and pressure increase, the solid biomass changes phase. Four different stages:
  - Drying: remove moisture
  - Pyrolysis: tars volatized
  - Combustion: partial burning
  - Reduction: gas formation
- Tar and ash drop off, leaving a gas that can be burned in boilers or processed and used in turbines



Biomass Gasification via Partial Oxidation (Auto Thermal)

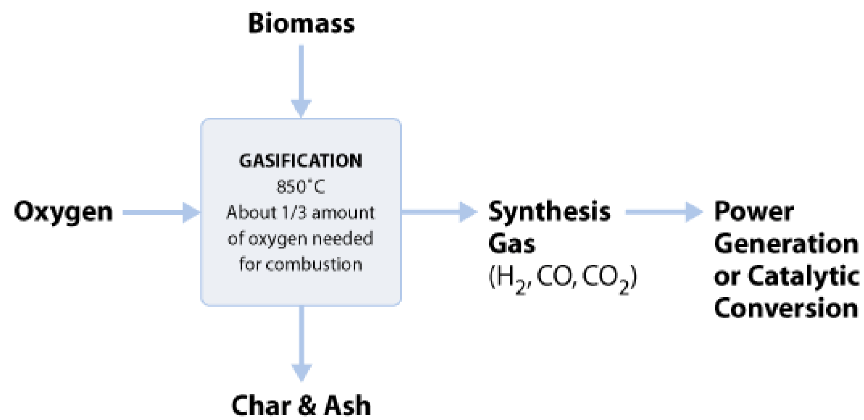


Image credits: Queen's University Chemistry Department,

NREL Biomass Program: Thermochemical Platform

To Remember:

Anaerobic Digestion

- Better for wet residues
- Must be sized correctly
- Living system, needs proper attention and upkeep
- Faster digestion at higher temperatures

"Low and Slow"

Gasification

- Best suited for dry residues
- Applicable for almost any biomass product
- Feedstock attributes vary widely
- Need to add energy to get energy

"Fast and Furious"

Technology Overview

Introductory Notes

- Similarities in desired end product
- How do we get it?
  - Reactions in a vessel:
    - Low & slow
    - Fast & furious
- Feedstock + energy → Fuel source

Methane Digesters

- System Components:
  - Manure Collection
  - Pretreatment
  - Digester Vessel
  - Biogas Recovery System
  - Biogas Clean-up
  - Biogas Handling & Use Equipment

Types of Digesters

- Covered Lagoon
- Complete Mix
- Plug-Flow

Covered Lagoon:

- Fabric covers the manure lagoon and traps biogas, extracted through a suction pipe.
- Least controlled system
- Lower capital, lower yield
- Hydraulic Retention Time of 40-60 days
- Works best with waste from 0.5-3% solids.

Image from
http://www.age.uiuc.edu/bee/RESEARCH/cover/coverpaper1.html

Complete Mix Digester:

- Vessel where heated manure is continuously kept in suspension by a mechanical or gas mixer.
- Manure processing takes about 20 days.
- Works best with manure 3-10% solids.

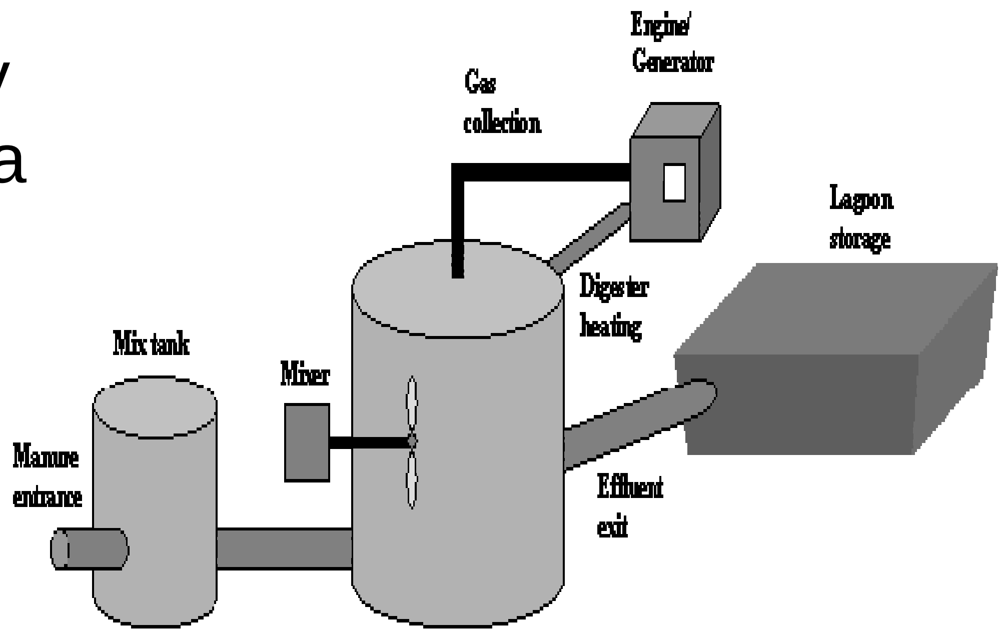


Image credit: http://www.cogeneration.net/Anaero2.gif

Plug-Flow:

- A three-part system with manure collector, mixing area, and digester.
- Feedstock moves through in “batches”
- 20-30 days HRT
- Higher capital cost.
- Works best on manure with 10-13% solids.

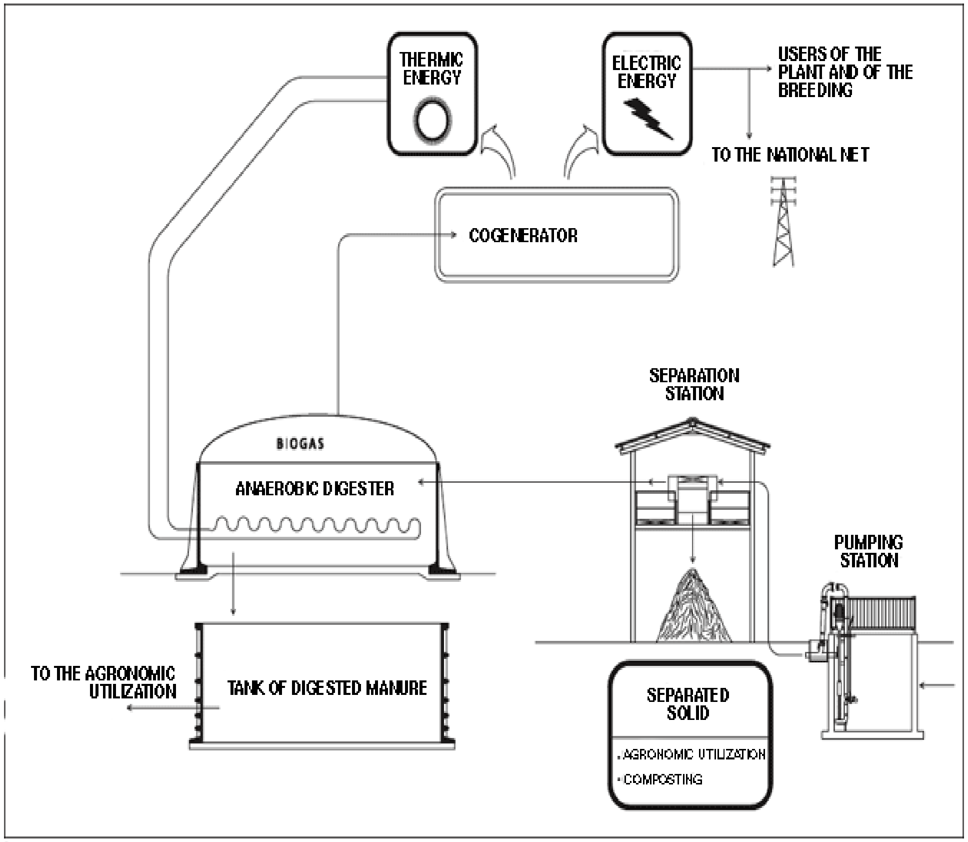


Image from http://www.rotaguido.it/immagini/biogas/schemi/eng/3.gif

Summary of Digester Types

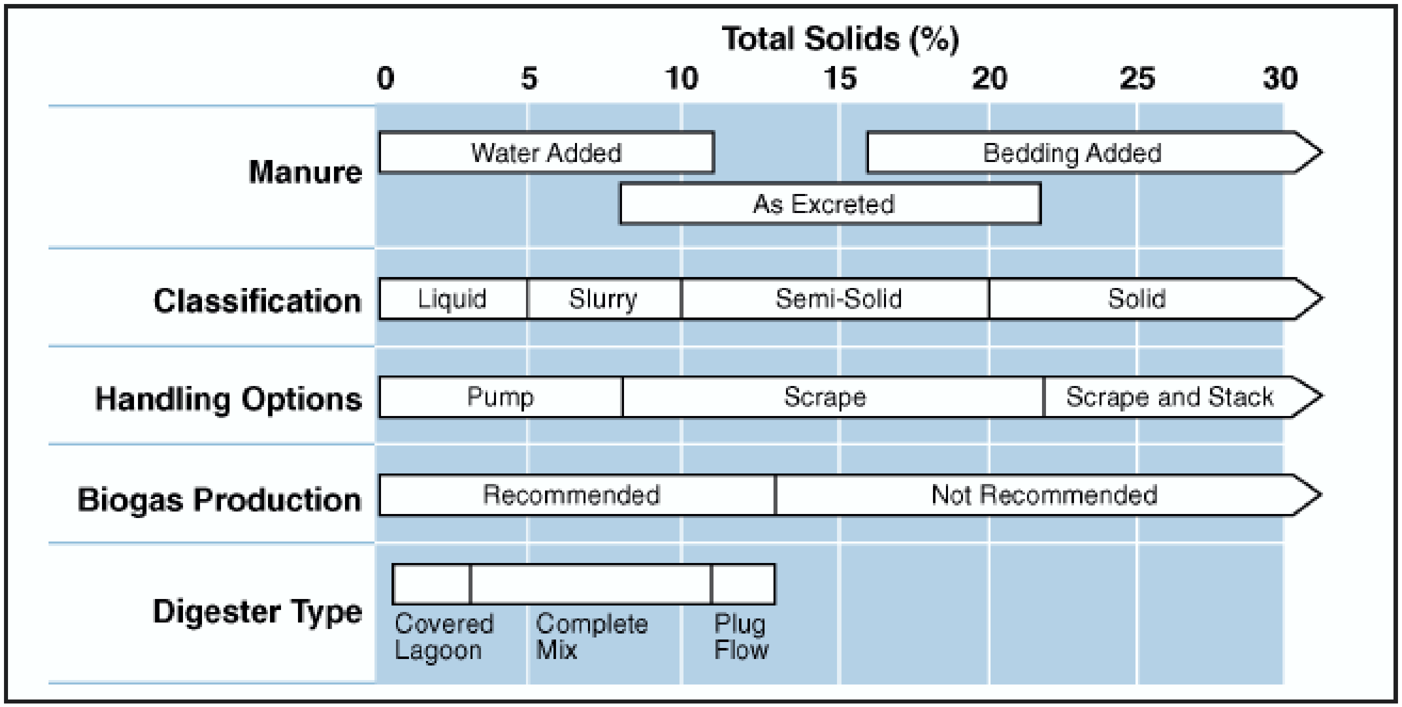
Types of Digesters and Their Characteristics

Type of Digester	Level of Technology	Influent Solids Concentration	Solids Allowable	Supplemental Heat	Hydraulic Retention Time (HRT) (days) (1)
Ambient Temperature Covered Lagoon	Low	0.1 – 2.0 %	Fine	No	40+
Complete Mix	Medium	2.0 – 10.0 %	Coarse	Yes	15+
Packed Reactor (2)	Medium	0.5 – 2.0 %	Soluble	Yes	2+
Plug Flow (3)	Low	11.0 – 13.0 %	Coarse	Yes	20+

(1) HRT = Hydraulic Retention Time = digester volume/daily influent volume
(2) Attached growth reactors
(3) Dairies only

Source: Ak-Chin Biomass Energy Feasibility Study, 13.

What's the right type of digester?



AgStar guidance documents a great resource

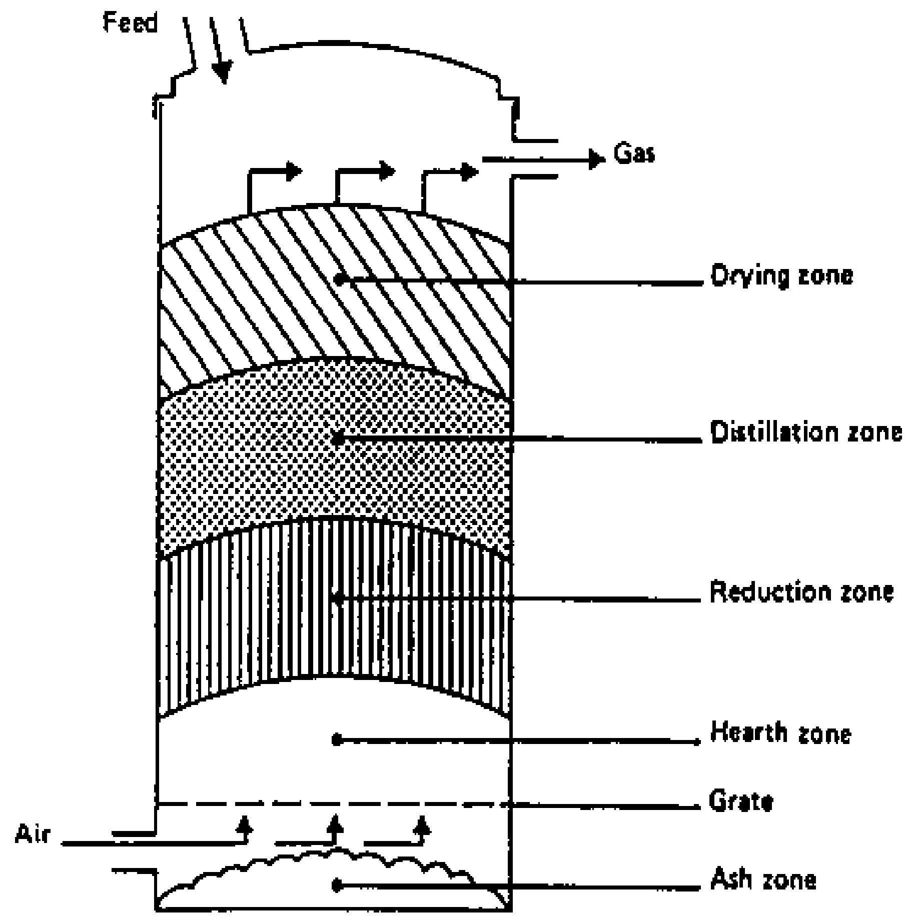
Source: EPA AgStar, *Managing Manure with Biogas Recovery Systems*

Gasifiers at a Glance

- Vary by pressure value, combustion location, and air/steam/oxygen input location
- Combined Heat and Power (thermal and electrical recovery) increases efficiency
- Biomass Integrated Combined Cycle
  - Most biomass energy uses waste wood at industrial facilities:
    - Scandinavian Countries
    - Snowflake Abitibi Plant

Up-Draft Reactor

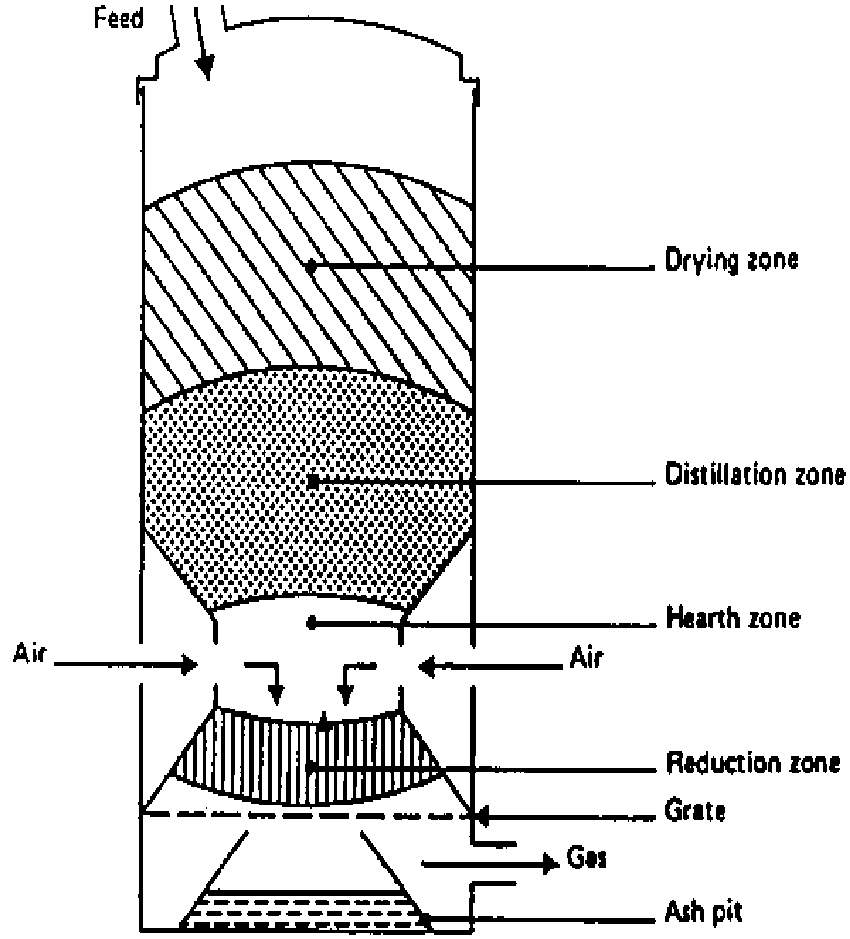
- Biomass introduced at top
- Phase changes at levels of reactor
- Lower pressure drop



Source: Food and Agriculture Organization, Wood Gas as Engine Fuel

Down-Draft Reactor

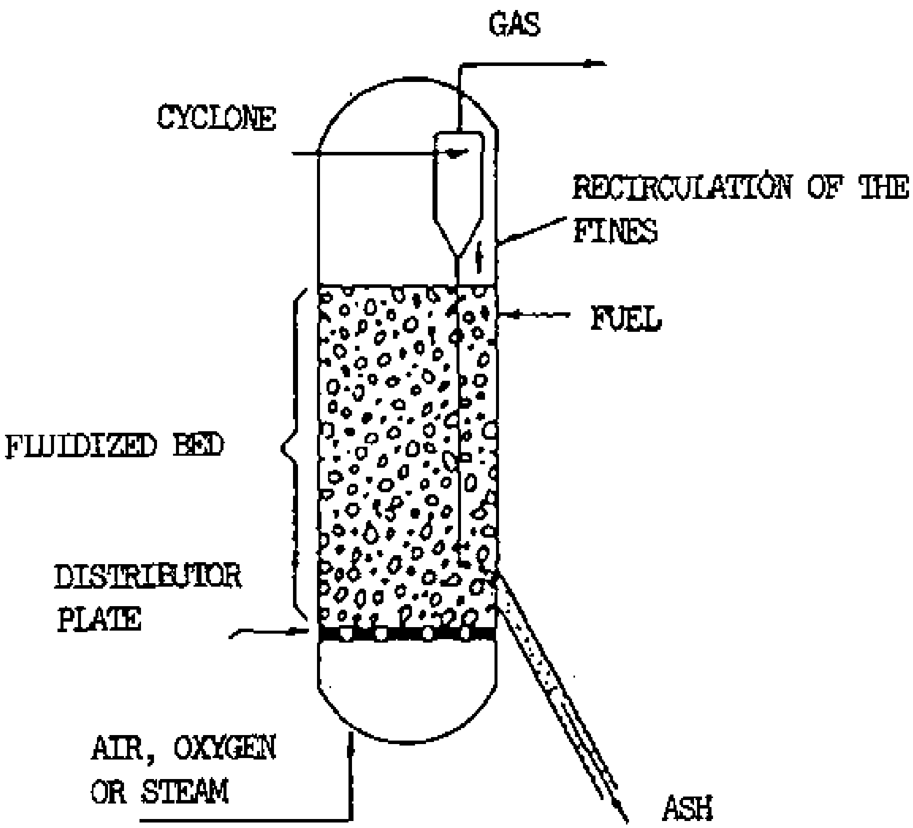
- Air current pushed from the bottom
- Low sensitivity to dust and tar content of fuel
- Infeasible for small particles
- Tall design needs



Source: Food and Agriculture Organization, Wood Gas as Engine Fuel

Fluidized Bed Reactor

- Fluid (liquid or gas) passed through particles at high velocity
- Air blown up through the biomass bed at high velocity
- Continuous mixing of solids, act like a fluid and react efficiently
- May be difficult to control



Source: Food and Agriculture Organization, Wood Gas as Engine Fuel

Economic Feasibility

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Images: www.dkimages.com/.../previews/986/10063484.JPG

Economics

- Just because you can, doesn’t mean you should
- Feasibility depends on
  - Costs: From Manufacturers
  - Benefits:
    - Monetary:
      - Avoided cost of energy
      - Avoided GHG emissions (CCAR Livestock Protocol)
    - Non-Monetary:
      - Odor control
      - Pathogen Reduction
      - Total Oxygen Demand reduction (Water Quality Impacts)
      - Homogenous effluent

Analytical Planning Steps

- Assess the resource
  - Availability
  - Quality
  - Energy content
- Estimate benefits
  - Avoided costs of energy, compliance, alternative disposal techniques
  - Suitability of benefits for core objectives
- Technology Review
  - Technology costs
- Site Selection
- System Design
- Full Economic Assessment

Rough costs

Anaerobic Digestion

- Conventional manure treatment and storage options cost
  - $50-200 per 1000 pounds of live weight (Animal Unit, AU), depending on materials, design, local rainfall, and cost of process water.
- Anaerobic Digesters
  - $150-450 per AU.
  - System for 1,000 cows or 4,000 pigs costs about $240,000 to $285,000.
  - Economies of scale

Biomass Gasification

- Alternatives to Gasification
  - Open Burning
  - Land fill
  - Compost
- Gasifier Costs
  - $1,400-2,000/kW
  - Feedstock quality and transportation costs
  - Economies of scale

Considering Benefits

- Waste Management:
  - Pollution control need not be a pure cost item
  - Possible revenue generation opportunity
- Offset energy consumption
- Decrease Liability/regulatory burden
- External Relations & Marketing
  - Odor Reduction
  - “Going Green”

Examples: Methane Digesters

Applications include:

- Landfill Gas recovery
- Wastewater Treatment plants
  - City of Flagstaff, Wildcat Hill Waste Recovery
- Animal Agriculture
  - Examples from Midwest and California

Haubenschild Farm Methane Digester

- Dairy undergoing planned expansion in 1999
- System Layout: Plug-Flow, heated
  - 130' x 30' x 14' digester; 130 kW generator, water heating system
- System Cost: $355,000 total; $444/cow
  - $127,500 in grants; $150,000 no-interest MDA loan
- System Benefits
  - Avoided cost of heat & electricity:
  - Chicago Climate Exchange GHG credits
- Simple Payback of 5 years

Van Ommering Dairy, Lakeside, California

- 480 cow dairy
- Plug-Flow system
  - 5,000-6,000 gallons manure slurry/day
  - 35,000 cf/day biogas production ➔1,427 kWh/day
  - HRT about 20 Days
- System Cost: $832,838
- 15.7 year estimated payback period

Examples: Biomass Power Plant

- Snowflake White Mountain Power
- $53 million; 24 MW
- Fluidized bed boiler
- Will use residues from Abitibi Paper Mill
  - 250 dry tons/day of fibers
  - Burn-out from Rodeo-Chedeski fire

Biomass Gasifier: Fibrominn, LLC Benson, Minnesota

- 55 MW capacity; $200 million investment
- 2,000-2,500 tons/day consumption;
  - 500,000 tons/year of turkey litter
  - Other locally available feedstocks mixed in
- Produce fertilizer from ash
- Factors:
  - Long-term contract with area turkey farms
  - Minnesota Renewable Portfolio Standard
    - Biomass set-aside

Conclusion

- Mature technologies exist to convert waste to energy
- Good technical and economic analytic resources available from EPA, USDA, Arizona Extension, engineers and consultants
- Waste management has cash flow potential
- May make economic sense for you
- “One man’s trash….”

In Closing:

"Even if you're on the right track, you'll get run over if you just sit there…"

-Will Rogers

Waste not,
Want not

Image: whyfiles.org/.../images/wind_turbine.jpg