Introduction

MATRIC has conducted significant research and development on biomass gasification technologies

- Biological gasification
- Thermal gasification

Both general technologies produce combinations of gas, liquid and solid phase components

- Gas and liquid phase separations and further reformation can yield both energy and chemical intermediate products
- Certain solid co-products are also useful in agriculture

MATRIC believes that gasification generally offers the widest variety of options for feedstock utilization and economical product development
Anaerobic Digestion Advantages

Anaerobic Digestion is a process that is used around the world to manage waste from the farm and food processing industries.

- Europe – Denmark, Great Britain and Germany
- Asia – India
- North America – United States and Canada

Most of the Anaerobic Digestion processes in the United States are used to treat municipal wastes.

Anaerobic Digestion technology is diverse and flexible

- Simple/minimally engineered systems – individual farms
- Complex systems – centralized/regional anaerobic digestion plants
- Integrations – Waste Treatment Plants, Biorefineries, Petrochemical Plants
### Anaerobic Digestion Product Conversion

In practical terms, Anaerobic Digestion can economically convert organic wastes to valuable products and at the same time provide environmental benefits.

#### Biogas
- Contains 60 – 70 mole% methane
- Balance is essentially CO₂ – takes methane gas out of atmosphere

#### Solids
- Pathogen and essentially odor free
- Reduced solids and nutrient content (watershed area benefit)
- May still be fairly rich in carbon (10 – 50 % of influent)

#### Liquid
- Concentrate nutrients for sale as fertilizer
- Limit nutrient pollution from watershed areas (particularly N and P)
AD Value Proposition

Biogas Cycle

Biofuel production

Agricultural Waste
Ethanol Stillage
Biodiesel Glycerin

Organic wastes

Photosynthesis

Energy crops

Biofertilizer

Anaerobic digestion

Biogas

Solar energy

H₂O

CO₂

CO₂

Electrical and/or thermal energy

Natural gas pipeline

Courtesy of Dr. A.C. Wilkie, U. Florida
Main focus has been on treatment, although WVSU has also conducted crop trials with the effluent – several papers published and website for BIOPLEX (http://bioplexproject.wvstateu.edu/index.html). This digester is thermophilic – see reference # 4

Collection, storage and product handling/utilization are the big expenses, both in capital and operating/maintenance cost.

Using process engineering principles to understand these systems better.

- Value Engineering
- Design for Six Sigma (DFSS)
- NPV Analysis

Extensively using work of Dr. Martin (2007) – see reference # 10

MATRIC leverages its own innovations and proven technologies (open source discussions of Biogas Energy, Kompogas and Schmack Biogas AG systems will be discussed in this presentation) to add value to conventional Anaerobic Digestion processes.
Biomass Consumed

Traditional Feedstocks
- Agricultural Wastes
- Municipal Wastes
- Food Residuals and Processing Wastes

Feedstocks of Growing Importance
- Industrial Wastes
- Ethanol Stillage
- Biodiesel Glycerin
- Other (i.e., Landfill Leachates)
AD Conversion of Biomass to Energy

- **Complex Organic Carbon**
- **Hydrolysis**
- **Monomers & Oligomers**
- **Acidogenesis**
- **Organic Acids**
- **Acetogenesis**
- **Acetate – H₂ / CO₂**
- **Methanogenesis**
- **CH₄ + CO₂**

Courtesy of Dr. A.C. Wilkie, U. Florida
AD Conversion of Biomass to Energy

Anaerobic Digestion Relay Race
Passing the Carbon Baton

Courtesy of Brian Duff, BBI International
AD Conversion of Biomass to Energy

**Hydrolysis**
- Enzymes excreted by fermentative bacteria convert complex, heavy, un-dissolved materials (proteins, carbohydrates, fats) into less complex, lighter, materials (amino acids, sugars, alcohols...).

**Acidogenesis**
- Dissolved compounds are converted into simple compounds, (volatile fatty-acids, alcohols, lactic acid, CO2, H2, NH3, H2S ) and new cell-matter.

**Acetogenesis**
- Digestion products are converted into acetate, H2, CO2 and new cell-matter.

**Methanogenesis**
- Acetate, hydrogen plus carbonate, formate or methanol are converted into CH4, CO2 and new cell-matter.
Factors Controlling Conversion

1. The type of waste being digested – Lignin, non-water soluble organics, nitrogen, sulfur
2. Its solids concentration – typically 6 – 7 wt% for good digestion of most biomass
3. Its temperature – Thermophilic 130 – 136 F (Class A Biosolids), Mesophilic 95 – 100 F (Class B Biosolids)
4. The presence of toxic materials – fungicides, antibacterial agents
5. The pH and alkalinity – optimum 6.8 – 8.5 for methane production; indication of acid inhibition
6. The hydraulic retention time – optimally set to ensure maximum solids conversion to gas
7. The solids retention time – optimally set to sustain bacteria growth while converting solids to gas
8. The ratio of food to microorganisms – no food, no bacteria growth
9. The rate of digester loading – helps establishes digester size and F/M ratio
10. The rate at which toxic end products of digestion are removed
The Anaerobic Digestion Process

Cow slurry
Pig slurry
Poultry manure

Daily loading rate
Winter 18 m³
Summer 12 m³
at 9% DM* 14% DM*

Biogas production
450 m³ per day

Anaerobic digester
Capacity 335 m³
Retention time 20 days
Temperature 35°C

Daily flow rate
Winter 18 m³ 5.5% DM*
Summer 12 m³ 8.4% DM*

Daily flow rate
Winter 15 m³ 4% DM*
Summer 10 m³ 7% DM*

Separator throughput
4 m³/hr

Existing storage tank
and lagoon

Separated fibre daily output
3 tonnes

DM* = dry matter

Courtesy of CADDET Centre for Renewable Energy, Walford College Anaerobic Digester
Digester Types

High Rate Reactors
1. Packed Film Reactor
2. Upflow Anaerobic Sludge Blanket (UASB)
3. Horizontal Baffle Reactor (HBR)
4. Completely Mixed Thermophilic Reactor (WVSU Pilot Plant)
5. Contact Reactor
6. Contact Stabilization Reactors
7. Acid Phased Reactors
8. Temperature Phased Reactors

Low Rate Reactors
1. Anaerobic Covered Lagoon
2. Completely Mixed Mesophilic Digester
3. Plug Flow Digester

Hybrids
1. Contact/Fixed Film Reactor

Not So Highly Engineered
Highly Engineered
Anaerobic Digestion Engineering

![Diagram of the AD process](image)

- **Biogas Storage**
- **Biogas Treatment**
- **Pre-treatment**
- **Collection**
- **Storage**
- **Transfer**
- **Treatment**
- **Utilization**

**Overview of the AD process**

- Process heat; space heating, water heating
- Electricity
- Combined heat and power
- Transport

**Biogas Utilization**

- Engine/generator
- Vehicle engine
- Fibre composting
- Fibre (straight to land)

**Storage**

- Digestate
- Liquefied storage and distribution
- Storage and any pre-treatment (such as mixing feedstocks, screening and chopping)

**Courtesy of British Biogen**
Farm to Fuel Process Description

Schmack EUCO® Titan

Collection

Biogas Storage

Biogas Treatment

Biogas Utilization

Transfer

Storage

Phased Digestion

Utilization

Transfer
Some Process Unit Operations

1. CALIX reception pit
2. PASCO feeding system
3. At least one COCCUS® TS pit storage fermenter
4. Cogeneration unit and professional control system within the AIO (all-in-one) technical-system container
5. SULA fermentation-residue repository
Alternate AD Reactor Design

Kompogas Thermophilic Horizontal Plug Flow Digester

Courtesy of Kompogas
MATRIC Hydrid Digestion System Design

Hybrid design that combines mesophilic and thermophilic process units

Efficiently utilizes the widest variation in feedstock

• From liquids to cellulosic biomass

Produces Class A solids ready for agricultural or other uses

Maximizes the production of methane and efficiently manages the diverse kinetics of variable feedstock
PYROLYSIS

Thermal Gasification
## Thermal Gasification of Biomass

<table>
<thead>
<tr>
<th>Process</th>
<th>Liquid</th>
<th>Char</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fast Pyrolysis</strong></td>
<td>75%</td>
<td>12%</td>
<td>13%</td>
</tr>
<tr>
<td>• Moderate temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Short residence time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Torrefaction</strong></td>
<td>30%</td>
<td>35%</td>
<td>35%</td>
</tr>
<tr>
<td>• Low temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Long residence time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Gasification</strong></td>
<td>5%</td>
<td>10%</td>
<td>85%</td>
</tr>
<tr>
<td>• High temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Long residence time</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- Ideal for fuel production; yields are about the same as oil refinery processing of heavy crude oil
- Traditional charcoal and coke production technology
- Production of the maximum quantity of biogas for further separations and reformation

Chart courtesy of Stefan Czernik, National Renewable Energy Laboratory
Pyrolysis

Thermal decomposition occurring in the absence of oxygen

Always the first step in combustion and gasification processes

Known as a technology for producing charcoal and chemicals for thousands years

Pyrolysis is a “green” process

- Low to no CO₂ emissions (no oxygen present)
- Feedstocks and thus energy produced is renewable
Fast Pyrolysis of Biomass

Fast pyrolysis is a thermal process that rapidly heats biomass to a carefully controlled temperature (~500°C), then very quickly cools the volatile products (<2 sec) formed in the reactor.

Three Products from Fast Pyrolysis

- Bio-oil—a liquid that can be stored and transported
- Bio-gas—a methane-rich gas that can be stored and transported
- Bio-char—a carbon-rich solid that is easily handled

Has been developed in many configurations to satisfy specific feedstock requirements.
Pyrolysis Process Steps

- **Drying**: <10% moisture; feed and reaction water end up in bio-oil
- **Comminution**: 2mm (bubbling bed), 6 mm (CFB)
- **Fast pyrolysis**: High heat rate, controlled T, short residence time
- **Char separation**: Efficient char separation needed
- **Liquid recovery**: By condensation and coalescence.

Chart courtesy of Stefan Czernik, National Renewable Energy Laboratory
Fast Pyrolysis End-Uses

Chart courtesy of Stefan Czernik, National Renewable Energy Laboratory
MATRIC Intermediate Pyrolysis

Intermediate Pyrolysis uses lower temperatures and longer residence times to control the ratios of oil, gas and char.

Patented reactor design allows units to be smaller which means less capital intensive and less operational costs.

Lower temperatures making it more favourable for operations.

Offers the ability to have a more customizable product offering.

Applicable to a wide range of both hardwood and softwood species.

Pyrolysis occurs in a more stable and better controlled temperature regime.
Summary

Gasification is one of the most robust technical solutions for the production of chemical and energy products from biomass

MATRIC’s unique biological and thermal gasification systems have a wide range of applications

- Feedstocks—ag waste, wood chips, energy crops, etc.
- End-products—methane, syngas, bio-oils, fertilizers, etc.

Multiple implementations have allowed for generational improvements of the systems
References

5. Roy, K., Moyers, Dr. C., Rader, J. (2008), Application of Process Engineering Principles to Anaerobic Digestion, report to West Virginia State University
7. USDA Soil Conservation Service, Agricultural Waste Management Field Handbook, Chapter 9
9. Heath, T., British Biogen, Anaerobic Digestion of Farm and Food Processing Residues: Good Practice Guidelines
10. Martin, Dr. J (2007), A Protocol for Quantifying and Reporting the Performance of Anaerobic Digestion Systems for Livestock Manure