Making the Most of Manure: Emerging Waste-to-Energy Treatments

Keri B. Cantrell, Kyoung S. Ro, Patrick G. Hunt
USDA-ARS
Coastal Plains Soil, Water, and Plant Research Center
Florence, SC 29501

Isabel M. Lima
USDA-ARS
Southern Regional Research Center
New Orleans, LA 70124

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- Thermochemical Technology Advantages
- Thermochemical Technologies
  - Pyrolysis
  - Direct Liquefaction
  - Gasification
  - Wet Gasification
- Proposed System Designs

CAFOs

- Decrease in number of farms with increase in size
- Limited Land Availability via Traditional Manure Management Practice
- Storage
- Land Application
- Relatively low capital and O&M costs

CAFOs

- Decrease in number of farms with increase in size
- Limited Land Availability via Traditional Manure Management Practice

Improvements Needed

- Surplus Manure from CAFOs – greater than crop nutrient demand
  - Transporting manure to remote crop fields
- Lagoon sludge
- Potential environmental risk
  - H2S, NH3, and CH4 from storages
  - Odors
  - Potential contamination of ground and surface waters
- Energy not utilized

Manure Characteristics

<table>
<thead>
<tr>
<th></th>
<th>Dry Manures</th>
<th>Wet Manures</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Poultry Litter(^{(i)})</td>
<td>Soil-Surfaced Feedlot(^{(i)})</td>
</tr>
<tr>
<td>TS (%)</td>
<td>82.9</td>
<td>80.2</td>
</tr>
<tr>
<td>VS (% of TS)</td>
<td>61.1</td>
<td>33.8</td>
</tr>
<tr>
<td>Ash (% of TS)</td>
<td>22.3</td>
<td>58.7</td>
</tr>
<tr>
<td>Fixed Carbon (%TS)</td>
<td>16.6</td>
<td>7.5</td>
</tr>
<tr>
<td>Carbon Content (%db)</td>
<td>38.9</td>
<td>21.7</td>
</tr>
</tbody>
</table>

**Manure Heating Values**

![Manure Heating Values Graph]

**Manure Management Practice**
- Reduce CAFO environmental impact
- Remove large amounts of organic waste
- Harness inherent energy to produce energy-dense, alternative fuels

**Research Focus**
- Identify viable TCC technologies for treatment of animal waste
- Adapt this technology to be used on-farm
- Lead to providing a source of additional energy and value-added products

**Biomass Energy Conversion Pathways**

**Thermochemical Conversion (TCC) Technology**
- High temperature chemical reforming
  - Organic bonds broken
  - Intermediates reformed into synthesis gas and hydrocarbon fuels
  - Minor residual of minerals and fixed carbon

**TCC Technology Advantages**
- Requires Smaller Footprint
  - Compact design with shorter processing time
TCC Technology Advantages

- Requires Smaller Footprint
- Reduces Disposal Requirements
  - Mass consumer of feedstock
  - More animals per land unit
- Multiplicity of End Products & Applications
  - Heat & power generation
  - Chemical feedstocks
  - Transportation fuels
  - Industrial applications
  - Future carbon trading

TCC Technology Advantages

- Requires Smaller Footprint
- Reduces Disposal Requirements
- Multiplicity of End Products and Applications Including Energy
- Provides Socio-Environmental Benefits
  - Fresh/clean air
  - Potable water
  - Pathogen, pharmaceutical, and nuisance gas elimination

Pyrolysis

- Conversion of organic material with no oxygen

<table>
<thead>
<tr>
<th>Pyrolysis</th>
<th>Syngas</th>
<th>Bio-oil</th>
<th>Char (Biochar), Ash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass: Manure Waste Residues</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

TCC Technologies

- Pyrolysis
- Direct Liquefaction
- Gasification
  - Wet Gasification

Pyrolysis: End Products

<table>
<thead>
<tr>
<th>Pyrolysis</th>
<th>Bio-oil</th>
<th>Syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biomass: Manure Waste Residues</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Char. (Charcoal) (Biochar)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Chemical Feedstocks
- Liquid Fuels
- Bioenergy Feedstock
- Soil Amendment
- Combined Heat & Power
Pyrolysis

<table>
<thead>
<tr>
<th>Mode</th>
<th>Conditions</th>
<th>Liquid (Bio-oil)</th>
<th>Char</th>
<th>Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fast</td>
<td>~500°C, vapor residence time ~1 sec</td>
<td>75</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Intermediate</td>
<td>~500°C, vapor residence time ~10-20 sec</td>
<td>50</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td>Slow</td>
<td>~400°C, vapor residence time ~hrs</td>
<td>30</td>
<td>35</td>
<td>35</td>
</tr>
</tbody>
</table>

Bridgewater, 2007

Slow Pyrolysis

Biomass: Manure Waste Residues → Slow Pyrolysis → Char, (Charcoal) (Biochar) → Activated Carbon

Char and Activated Carbon Making

Dried poultry manure → Pellet Mill → Charcoal Making

Activated Carbon: Physical Properties

<table>
<thead>
<tr>
<th></th>
<th>Yield %</th>
<th>Surface Area m²/g</th>
<th>Attrition %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broiler Litter</td>
<td>22.7</td>
<td>441</td>
<td>17.9</td>
</tr>
<tr>
<td>Broiler Cake</td>
<td>11.0</td>
<td>395</td>
<td>24.0</td>
</tr>
<tr>
<td>Turkey Litter</td>
<td>21.1</td>
<td>414</td>
<td>20.0</td>
</tr>
<tr>
<td>Turkey Cake</td>
<td>16.4</td>
<td>394</td>
<td>25.8</td>
</tr>
<tr>
<td>Duck Manure</td>
<td>18.9</td>
<td>902</td>
<td>14.7</td>
</tr>
<tr>
<td>PUR RF</td>
<td></td>
<td>474</td>
<td>32.0</td>
</tr>
<tr>
<td>Coal</td>
<td>70.0</td>
<td>0</td>
<td>13.8</td>
</tr>
<tr>
<td>Coconut Shell</td>
<td>22.7</td>
<td>843</td>
<td>22.3</td>
</tr>
<tr>
<td>Wood</td>
<td>17.9</td>
<td>849</td>
<td>15.6</td>
</tr>
</tbody>
</table>

Activated Carbon: Metal Ion Adsorption

<table>
<thead>
<tr>
<th>mg-metal/g-carbon</th>
<th>Cu²⁺</th>
<th>Cd²⁺</th>
<th>Zn²⁺</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broiler Litter</td>
<td>76.3</td>
<td>122.5</td>
<td>87.0</td>
</tr>
<tr>
<td>Broiler Cake</td>
<td>120.7</td>
<td>149.0</td>
<td>126.9</td>
</tr>
<tr>
<td>Turkey Litter</td>
<td>104.9</td>
<td>161.9</td>
<td>113.2</td>
</tr>
<tr>
<td>Turkey Cake</td>
<td>90.2</td>
<td>166.4</td>
<td>109.2</td>
</tr>
</tbody>
</table>

Minimal adsorption for activated carbon from coal, wood, or coconut shells

Lima and Marshall, 2005
**Activated Carbon: NH₃ Adsorption**

Linear relationship between Bed Depth and NH₃ Breakthrough Time

**Slow Pyrolysis**

Biomass: Manure Waste Residues → Slow Pyrolysis → Charcoal (Biochar)

- Activated Carbon
- Bioenergy Feedstock
- Soil Amendment
- Carbon Sequestration

**Biochar Production**

- Bench-scale production
- Separated swine solids
- Pyrolyzed under N₂ at 500°C; no activator
- Stable product
- Little to no volatile material remaining
- Energy content increase 30-50%

**Biochar Application**

- Soil amendment
  - Bio-charcoal and poultry litter
- Test potential to:
  - Increase carbon content
  - Build aggregation

Charcoal added to soil for lab incubation study. Source: J.M. Novak, USDA-ARS

**Energy Balance for Carbonizing Cellulose**

- Biochar HHV
- Gas HHV
- Expansion of Gas
- Sensible Heat
- Heat of Reaction

Can we carbonize wet livestock wastes with positive energy budget?

**Drying Energy**

- Wet manure like dairy and swine require energy input to dry
- Decreases available energy of biochar for alternative uses

![Drying Energy Graph](image1)

**Direct Liquefaction**

- **Pyrolysis**
- **Direct Liquefaction**
  - Aqueous feedstock
  - Oxygen-limited atmosphere
  - Pressurized environment
    - 5 to 20 MPa
  - Bio-oil desired product
    - ~70%
- **Gasification**
  - Wet Gasification

![Direct Liquefaction Graph](image2)

**Gasification**

- **Pyrolysis**
- **Direct Liquefaction**
- **Gasification**
  - Dry (air-blown)
  - Wet Gasification

**Gasification Process**

- Air, water, and oxygen serve as oxidizers
- Temperature range 800-1000°C
**Gasification Process**
- **3 Main Stages**
  - Drying: 100-150°C
  - Volatilization: 250-550°C
  - Gasification: 700-1300°C

**Low-grade gas**
- Less than 5MJ/m³
- Natural gas: 37 MJ/m³
- Severely diluted with N₂ (~60%)
- H₂:CO vary
- Minor amounts of CH₄
- Residual solid product
  - Depends on ash content

**Gasification: Enhancements**
- **Steam Injection**
  - Improved gas quality with increased H₂
  - Decreased char formation
- **Catalyst Addition**
  - Examples: Langbeinite, Alkali Salts
  - Improve synthesis gas quality and production
  - CO₂ production cut in half
  - Increase gasification rate
  - Complete fixed carbon conversion

**Wet Gasification**
- **Catalytic Hydrothermal Processing**
  - Pacific Northwest National Laboratory (D. Elliott et al.)
  - 250 to 360 °C and up to 22 MPa (215 atm)
  - Ru catalysts
  - Tested with dairy manure
  - Elliott et al., 2004
  - 90% Heat recovery

**Wet Gasification: Products**
- CH₄: 55%
- CO₂: 45%
- Heat-Treated Water
- Oils, Tars
- Char, Ash

**Wet Gasification System**
- Wet Biomass
- Heat Exchange
- Catalytic Reactor, 350°C, 200 atm
- CH₄ & CO₂
- Electricity
- Water, NH₃, Salts
- Gas/Liquid Separation
- Pressure Letdown
- Electricity
- Wet Biomass

Ro et al., 2007
Energy Generation

- No Heat Recovery

- 90% Heat Recovery

Gas Comparison

- Wet Gasification vs. Anaerobic Digestion
- Model 5000 sow, farrow-to-wean farm
- Waste stream: 13,800 gpd
  - 3560 lb VS/d

- Modeled reactions
- Methane Concentration
  - 53% - Wet Gasification
  - 68% - Anaerobic Digestion
- VS-Carbon Conversion to Gas
  - >99% - Wet Gasification
  - 64% - Anaerobic Digestion

Proposed Wet Gasification Swine Manure Management System

- Livestock House
- Livestock Water Recycle
- Wet Gasification
- NH₃ Capture
- Combined Heating & Power
- Steam Reforming/Partial Oxidation
- Catalytic TCC
- Liquid Fuels
- CH₄ & CO₂
- Fertilizer

USDA-ARS Liquid Waste Treatment System

- Consumables
- Flush Water
- Livestock House
- Pathogen-free Water Recycle
- Solids Separation
- Nitrification/Denitrification
- Phosphorus Removal
- Compost
- Fertilizer
**Considerations**

- Many designs still in R&D stages
- Process Implementation
  - Efficient heat recovery/exchange for drying manures
  - High pressure delivery
  - Depressurization avoidance
  - Plugging
  - Robust catalyst
  - Efficient recovery of nitrogen
  - Simple, safe, and robust operation

**USDA-ARS Liquid Waste Treatment System**

- **Livestock House**
  - Flush Water
  - Pathogen-free Water Recycle
  - Solids Separation
  - Nitrification/Denitrification
  - Phosphorus Removal
  - Gasification
  - Slow Pyrolysis
  - Fertilizer

**Bio-Thermochemical Waste Treatment System**

- **Livestock House**
  - Microbial Conversion
  - Solids Separation
  - N-Removal
  - Drying Heat
  - Gas
  - CHP
  - Bio-char

- **Bioenergy Feedstock**
  - Gasification
  - Residue
  - Soil Amendment
  - Bioenergy Feedstock

- **Liquid Fuels**
  - CHP
  - Residue
  - Soil Amendment

- **'Green Coal'**
  - Slow Pyrolysis
  - Gas
  - Heat

- **Soil Amendment**
  - CHP
  - Residue
  - Soil Amendment

- **Compost/Land Application**
  - CHP
  - Compost/Land Application

- **Consumables**
  - Water Recycle
Considerations

- Feedstock Conditioning and Characterization
  - Solid Separation, Dewatering, and Drying
  - Grinding, Blending, and Pelletizing
    - Smaller, uniform particles aid efficiency and consistency
  - Sulfur and ash removal
  - Bed agglomeration
  - Silica-based sticky phase

- Solid Separation, Dewatering, and Drying

Next Generation Systems

- Effectively extract manure energy
- Eliminate ground and surface water contamination
- Nitrogen recovery potential
- Phosphorous concentrated in char/ash
- Substantial fugitive gas and odor removal
- Heat-treated recycled wastewater
- Destruction of pathogens, pharmaceuticals, and estrogens

Thank You

Dr. Keri Cantrell
USDA-ARS
Coastal Plains Soil, Water, and Plant Research Center
2611 W. Lucas St.
Florence, SC 29501
keri.cantrell@ars.usda.gov