BIOMASS PYROLYSIS

by

Fred L. Jones
Cogen Designs, Inc.
Waste Disposal Options

- Landfilling
- Incineration
  - Mass Burn
  - Refuse Derived Fuel (RDF)
- Gasification
- Pyrolysis
  - High Temperature
  - Low Temperature
Pyrolysis

\[ C_6H_{12}O_6 \xrightarrow{\text{Heat}} 6 \text{C} \ + \ 6 \ H_2O \]

(Oils)

(Coal)
LTMP Renewable Fuels Process

MSW → Physical Separation → RDF → Chemical Upgrading → BDF

- Ferrous Metals
- Glass
- Non-Ferrous Metals
- Bulky Plastic, Paper, Textiles
- Ceramics
- Bio-oils
Fuel Upgrading

- MSW: 5,555 Btu/lb
- RDF: 6,798 Btu/lb
- BDF: 10,483 Btu/lb

Quantities (in tons/day):
- MSW: 1500
- RDF: 1000
- BDF: 500

Legend:
- H2O
- Ash
- Sulfur
- Nitrogen
- Oxygen
- Hydrogen
- Carbon
Waste to BDF

Shredded Waste

Biomass-Derived Fuel
Why Displace Coal?

Electric Utility Fuel Use

- Coal (59.41%) 1.1 billion tons/year
- Nuclear (17.04%)
- Gas (12.51%)
- Oil (1.62%)
- Hydro (9.04%)
- Renewable (0.36%)
- Other (0.02%)

Source: US EIA
Burning Biomass-Derived Fuel

- Energy Content greater than Low S Western Coal
- Sulfur Content lower than natural coals

Easy ignition
Stable combustion
High carbon conversion
LTMP Pyrolysis Process

- Based on low temperature twin screw extruder/mixer technology
  - Forty years of experience in similar applications, over 1,200 commercial extruder/mixer units in service.
- Mixer produces highly consistent product quality
- Process can operate on a wide variety of organic waste materials
Feedstock Range
Pyrolysis Reactor

8 Tons/hr Capacity

Drive

Gearbox

Feed Hopper

Vents

Coal Discharge Chute
Internal Augers

~25 Tons/hr Capacity
BDF Production Process

Gases & Oils → Gases & Oils → H₂O → Shredded Solids

Reactor

Cooling Screw

BDF → Drive Motor
Pyrolysis at Work
Large Capacity Machines

Similar Unit --
Designed for cellulose
Vertical vs horizontal
35” Diameter Augers
100 tph vs 8 tph

Similar Unit --
Designed for Kevlar
Horizontal Configuration
31” Diameter Augers
75 tph vs 8 tph
Unique Reactor Properties

- No incineration, combustion or burning
- No air or oxygen added
- No flame
- No external heat addition
- No circulating solids
- 550°F max. operating temperature
- Single step to end product - no refining needed
Dioxin Formation

Sources: USEPA, Addnik, et. al (1991)
Incineration vs. LTMP

200 Tpd Incinerator

200 Tpd LTMP Reactor
Incineration vs Pyrolysis

Detroit Incinerator, Michigan

- Waste Quantity: 3,200 UST/d*
- Waste Moisture: 18%
- Net Power Generation: 65 MW
- Generating Efficiency: 16.9%

LTMP Pyrolysis, Illinois

- Waste Quantity: 1,232 UST/d*
- Waste Moisture: 24%
- Power from Syncoal: 35 MW
- Generating Efficiency: 19.2%

*7 day/wk average
RDF Preparation

- Shredders
- Trommel Screen
- Air Classifiers
- Baghouse
- Disk Screens
- Eddy Current Separators
- Magnetic Separators
Pyrolysis Area

Reducer

Steam Generation

Oxidizer

Dry Scrubbers

Pyrolysis Reactors

BDF Coolers

BDF to Loadout

Boiler Feedwater Treatment

Baghouses
Pyrolysis Area - High Moisture
Incineration vs Pyrolysis

Kajang Incinerator, Malaysia*

- Waste Quantity: 1,100 UST/d
- Waste Moisture: 56%
- Net Power Generation: 5 MW
- Generating Efficiency: 6.4%

LTMP Pyrolysis, Santiago

- Waste Quantity: 1,500 UST/d
- Waste Moisture: 54%
- Power from Syncoal: 25 MW
- Generating Efficiency: 19.2%

*Renewable Project of the Year 2010 -- “Power Magazine”
Process Comparisons

**Process Temperature**
- 500°F: Torrefaction, SlurryCarb, LTMP
- 1,000°F: IES
- 1,500°F: Shaw, Gasification
- 2,000°F: Thermoselect
- 2,500-3,500°F: Plasma Arc
- 14,000°F

**Process Reaction Time**
- 1 sec: Plasma Arc, Thermoselect
- 1 min: Plasma Arc, Thermoselect
- 5 min: Shaw, SlurryCarb, Gasification
- 10 min: Shaw, SlurryCarb, Gasification
- 20 min: Shaw, SlurryCarb, Gasification
- 60 min
- 90 min: Torrefaction

CDI
Process Comparisons

Energy Requirements, kWh/ton MSW

- LTMP
- Shaw
- SlurryCarb
- Plasma Arc

Process Efficiency

- Shaw
- Plasma Arc
- IES
- Gasification
- Torrefaction
- Thermoselect
- LTMP
Process Comparisons

**Product Heating Value, Btu/lb**
- Gasification: 0 Btu/lb
- Plasma Arc: 2,000 Btu/lb
- Thermoselect: 4,000 Btu/lb
- SlurryCarb: 6,000 Btu/lb
- Torrefaction: 8,000 Btu/lb
- LTMP: 10,000 Btu/lb

**Capital Cost, $/daily ton MSW**
- LTMP: $0
- Plasma Arc: $50,000
- SlurryCarb: $100,000
- IES: $150,000
- Torrefaction: $200,000
- $250,000
- $300,000
- $350,000
# Net Energy Production

<table>
<thead>
<tr>
<th>Process</th>
<th>Net Electric/ Fuel Output</th>
<th>1,000 TPD 100% Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Thermal</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gasification</td>
<td>400 kWh/ton</td>
<td>16 MWe</td>
</tr>
<tr>
<td>Pyrolysis</td>
<td>450 kWh/ton</td>
<td>19 MWe</td>
</tr>
<tr>
<td>Plasma Arc</td>
<td>400 kWh/ton</td>
<td>16 MWe</td>
</tr>
<tr>
<td><strong>Anaerobic Digestion</strong></td>
<td>125 kWh/ton</td>
<td>5 MWe</td>
</tr>
<tr>
<td><strong>Acid Hydrolysis</strong></td>
<td>31 gal EtOH/ton</td>
<td>11 mm gal/yr</td>
</tr>
<tr>
<td></td>
<td>(260 kWh/ton)</td>
<td>(11 MWe)</td>
</tr>
<tr>
<td><strong>LTMP Carbonization</strong></td>
<td>0.38 ton BDF/ton</td>
<td>137,000 tpy BDF</td>
</tr>
<tr>
<td></td>
<td>(785 kWh/ton)</td>
<td>(33 MWe)</td>
</tr>
</tbody>
</table>
Comparative Emissions

<table>
<thead>
<tr>
<th>Source</th>
<th>Emissions, Tons/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility</td>
<td>37,000</td>
</tr>
<tr>
<td>Refinery</td>
<td>5,000</td>
</tr>
<tr>
<td>Incinerator</td>
<td>2,400</td>
</tr>
<tr>
<td>Large Hospital</td>
<td>370</td>
</tr>
<tr>
<td>BDF Production</td>
<td>234*</td>
</tr>
</tbody>
</table>

*minor source
Sources of Greenhouse Gases

US EPA Data

- Landfills (20.98%) 9.0 billion tons/yr*
- Livestock (17.82%) 7.7 billion tons/yr*
- Nat. Gas Systems (17.73%) 7.6 billion tons/yr*
- Fossil Fuel Combustion (14.74%) 6.3 billion tons/yr*
- Coal Mining (8.33%) 3.6 billion tons/yr*
- Manure Management (6.56%) 2.8 billion tons/yr*
- Petroleum Systems (4.53%)
- Wastewater Treatment (4.04%)
- Forest Land (1.84%)
- Rice Cultivation (1.10%)
- Abandoned Coal Mines (0.87%)
- Petrochem Production (0.18%)
- All Other (1.27%)

*CO₂ Equivalent
Greenhouse Gas Reduction

LTMP Plant vs Forest Land

200 Square Miles

1 LTMP Plant = 1 Acre Forest Land

Capacity
1,600 Tons/day MSW
450,000 Tons/yr MSW

CO₂ Reduced*
1.5 million Tons/yr
12 Tons/yr

*All Greenhouse gases, as CO₂

Source: MI United Conservation Club
Dioxin Emission Factors

USEPA Dioxin Reassessment

Emission Source

- Incinerators
- Smelters
- Utility Boilers
- Kilns

Emission factor, ng TEQ/kg

- Med Waste
- Haz. Waste
- MSW WWTP Sludge
- Wood
- Oil
- Aluminum
- Lead
- Iron
- Copper
- Cement Kiln
Environmental Impact

LTMP Carbonization vs Incineration*

*Includes impact of BDF Use

Source: Technical University of Denmark, Nov. 2007
Recycling Performance

81.6% Recovery

- RDF (75.83%)
- Paper, Textiles (4.00%)
- Bulky Plastic (4.00%)
- Residue (14.40%)
- Fe (4.80%)
- Non-Fe (0.97%)
Recycling Goals

Comparison with LTMP Process
Feed Coal Samples

PRB Coal  BDF (Syncoal)  Bit. Coal Mix
## Coal Analyses

<table>
<thead>
<tr>
<th></th>
<th>BDF</th>
<th>PRB Coal</th>
<th>Bit Blend</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VM, %</td>
<td>53.14%</td>
<td>30.04%</td>
<td>29.46%</td>
</tr>
<tr>
<td>H₂O, %</td>
<td>1.82%</td>
<td>30.47%</td>
<td>11.49%</td>
</tr>
<tr>
<td><strong>Ultimate</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C, %</td>
<td>57.49%</td>
<td>49.52%</td>
<td>67.88%</td>
</tr>
<tr>
<td>H, %</td>
<td>5.67%</td>
<td>3.39%</td>
<td>4.26%</td>
</tr>
<tr>
<td>O, %</td>
<td>11.41%</td>
<td>11.31%</td>
<td>6.27%</td>
</tr>
<tr>
<td>N, %</td>
<td>1.06%</td>
<td>0.71%</td>
<td>1.29%</td>
</tr>
<tr>
<td>S, %</td>
<td>0.29%</td>
<td>0.23%</td>
<td>1.75%</td>
</tr>
<tr>
<td>HHV, Btu/lb</td>
<td>10,236</td>
<td>8,264</td>
<td>11,628</td>
</tr>
<tr>
<td>Hg, ug/g</td>
<td>0.04</td>
<td>0.07</td>
<td>0.134</td>
</tr>
<tr>
<td>Lb CO₂/MMBtu</td>
<td>205.8</td>
<td>219.6</td>
<td>213.9</td>
</tr>
<tr>
<td>Stack Losses, %*</td>
<td>12.8%</td>
<td>14.7%</td>
<td>11.3%</td>
</tr>
<tr>
<td>Comb. Eff’y, %*</td>
<td>87.2%</td>
<td>85.3%</td>
<td>88.7%</td>
</tr>
</tbody>
</table>

*15% XS Air, 350°F Stack Temperature
Coal Mercury Content

Mercury Content, µg/g

Coal Producing State

AL  AK  AZ  CO  IN  KS  KY  MO  MT  ND  OK  TN  UT  VA  WV  BDF
Thermogravimetric Analysis

Air Burnout of 200x400 Mesh Fuels

% Burnoff

Temperature, °F

BDF1
BDF2
PRB Sb
Ill #6 Hvc
Pitt. #8 Hvb
MD mvb
Furnace Views

PRB Coal

BDF (Syncoal)

TES Coal Mix
Carbon Burnout

BDF Ash

Bit. Coal Ash
Emission Reductions

- Hg: 67%
- SO2: 54%
- NOx: 92%
- NH3: Unmeasurable
- CH4: 15%
- CO2: 9.4%

[Graph showing normalized emission rates for different pollutants: Hg, SO2, NOx, NH3, CH4, and CO2.]

Legend:
- BDF
- PRB
- Bit
Stack H$_2$O Content

2% Combustion Efficiency Gain

% H$_2$O, as measured

BDF | PRB | BIT
Boiler Efficiency

![Graph showing the relationship between moisture content and boiler efficiency for various materials like Syncoal, PRB Coal, Corn Stover, Urban Wood Waste, Poplar, Douglas Fir, Hemlock, Pine Needles Bagasse, Douglas Fir Bark, Red Canary Grass, and Sudan Grass. The graph indicates a decrease in boiler efficiency as moisture content increases.](image)
Power Generation

Basis: 1 million tpy Fuel Rate

- Syncoal
- Ill #6 Coal
- Switchgrass
- PRB Coal
- Rice Hulls
- Red Oak
- Pine
- Douglas Fir Bark
- Bagasse
- Red Canary Grass
- Sudan Grass

Power Output, MW vs. % Moisture.
CO₂ Emissions

10,000 Btu/kWh Heat Rate

14.3% Reduction
Grindability

80/20 Coal/BDF blend
Grindability comparable to Western coals
Pulverizer stays clean
No sample compaction
Moisture Pickup

- Heavy Rains
- Rain
<table>
<thead>
<tr>
<th><strong>BDF/Biomass Comparison</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rail Transportation</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Fuel Unloading</strong></td>
</tr>
<tr>
<td><strong>Fuel Storage</strong></td>
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<tr>
<td><strong>Moisture Pickup</strong></td>
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<tr>
<td><strong>Dust Generation</strong></td>
</tr>
<tr>
<td><strong>Grindability</strong></td>
</tr>
<tr>
<td><strong>Mill Clearing Cycle</strong></td>
</tr>
<tr>
<td><strong>Primary Air Flow</strong></td>
</tr>
</tbody>
</table>
## BDF/Biomass Comparison

<table>
<thead>
<tr>
<th></th>
<th>Wood Pellets</th>
<th>BDF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam conditions</td>
<td>Decreased superheat, reheat temperatures</td>
<td>Same as coal</td>
</tr>
<tr>
<td>Cl Corrosion</td>
<td>Serious - may require doping with sulfur</td>
<td>Same as coal</td>
</tr>
<tr>
<td>Plant Capacity</td>
<td>17% Derating</td>
<td>Same as coal</td>
</tr>
<tr>
<td>Plant Heat Rate</td>
<td>4% Efficiency Loss</td>
<td>2% Efficiency Gain</td>
</tr>
<tr>
<td>CO₂ Emissions</td>
<td>8% Increase</td>
<td>15% Reduction</td>
</tr>
<tr>
<td>SO₂ Emissions</td>
<td>Reduction</td>
<td>50-93% Reduction</td>
</tr>
<tr>
<td>Hg Emissions</td>
<td>50% Reduction</td>
<td>55-70% Reduction</td>
</tr>
<tr>
<td>Heat Value</td>
<td>8,297 Btu/lb</td>
<td>10,400 Btu/lb</td>
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</table>
# BDF Ash Analyses

<table>
<thead>
<tr>
<th>Ash Minerals</th>
<th>Trace Elements (TCLP)</th>
<th>Sample</th>
<th>QL</th>
<th>Reg. Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>As, mg/L</td>
<td>BQL*</td>
<td>0.20</td>
<td>5.0</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>Ba</td>
<td>BQL</td>
<td>5.00</td>
<td>100.0</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>Cd</td>
<td>BQL</td>
<td>0.10</td>
<td>1.0</td>
</tr>
<tr>
<td>CaO</td>
<td>Cr</td>
<td>BQL</td>
<td>0.10</td>
<td>5.0</td>
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<tr>
<td>MgO</td>
<td>Pb</td>
<td>0.47</td>
<td>0.10</td>
<td>5.0</td>
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<tr>
<td>TiO₂</td>
<td>Hg</td>
<td>BQL</td>
<td>0.00057</td>
<td>0.2</td>
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<tr>
<td>K₂O</td>
<td>Se</td>
<td>BQL</td>
<td>0.20</td>
<td>1.0</td>
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<tr>
<td>Na₂O</td>
<td>Ag</td>
<td>BQL</td>
<td>0.10</td>
<td>5.0</td>
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<tr>
<td>SO₃</td>
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<td></td>
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<tr>
<td>MnO₂</td>
<td></td>
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</tr>
<tr>
<td>P₂O₅</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SrO</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BaO</td>
<td></td>
<td></td>
<td></td>
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</tbody>
</table>

*Below Quantitative Limit
Bio-oil Boiler Fuel

Vents 2/3 - Bio-Oil
# Oil Characteristics

<table>
<thead>
<tr>
<th></th>
<th>MeOH</th>
<th>EtOH</th>
<th>Bio-Oil</th>
<th>Biodiesel</th>
<th>No. 2</th>
<th>No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>37.48%</td>
<td>52.14%</td>
<td>60.84%</td>
<td>76.14%</td>
<td>87.18%</td>
<td>85.60%</td>
</tr>
<tr>
<td>H</td>
<td>12.58%</td>
<td>13.13%</td>
<td>8.76%</td>
<td>11.25%</td>
<td>12.50%</td>
<td>9.70%</td>
</tr>
<tr>
<td>O</td>
<td>49.93%</td>
<td>34.73%</td>
<td>29.20%</td>
<td>12.10%</td>
<td></td>
<td>1.80%</td>
</tr>
<tr>
<td>N</td>
<td>0.58%</td>
<td>0.20%</td>
<td>0.02%</td>
<td>0.10%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>0.18%</td>
<td>0.20%</td>
<td>0.30%</td>
<td>2.30%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash</td>
<td>0.06%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.50%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>MeOH</th>
<th>EtOH</th>
<th>Bio-Oil</th>
<th>Biodiesel</th>
<th>No. 2</th>
<th>No. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Btu/lb (HHV)</td>
<td>9,750</td>
<td>12,800</td>
<td>12,026</td>
<td>16,095</td>
<td>19,430</td>
<td>18,300</td>
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<tr>
<td>Btu/gal</td>
<td>64,250</td>
<td>84,100</td>
<td>112,202</td>
<td>118,300</td>
<td>140,090</td>
<td>143,655</td>
</tr>
<tr>
<td>SpGr, lb/gal</td>
<td>6.63</td>
<td>6.61</td>
<td>9.33</td>
<td>7.35</td>
<td>7.21</td>
<td>7.85</td>
</tr>
<tr>
<td>Visc @ 60°F</td>
<td>0.59</td>
<td>1.19</td>
<td>5.09</td>
<td>7.50</td>
<td>3.30</td>
<td>450</td>
</tr>
</tbody>
</table>
Chloride Content

Source: "Chloride Issues with Biomass Co-firing in PC Boilers," Duong & Tillman
Syncoal Production Cost

Stand-Alone Plant

Feedstock Moisture, %

Syncoal Cost, $/ton

- Pine - $35/ton
- Bagasse - $20/ton
- Pine - $35/ton
- Bagasse - $35/ton
- Miscanthus - $35/ton
- Urban Wood Waste - $35/ton
- Switchgrass - $35/ton
- MSW - $22/ton
- RDF - $10/ton
- MSW - ($35)/ton
- Bit Coal - $55/ton
- PRB Coal - $35/ton
On August 18, 2009 the Massachusetts Department of Energy Resources (DOER) announced that only waste-based biofuels will qualify toward fulfilling its biofuel requirements “until further notice.” The announcement … excludes using other renewable and sustainable biomass feedstocks, such as agricultural crop residues and algae.
MSW/BDF as a Renewable Resource

- Overwhelmingly agricultural biomass
- Continuously produced - little seasonality
- No diversion of existing crop lands required
- Produced at energy use centers - low transport costs
- Collection ("harvesting"), distribution systems already in place
- BDF makes MSW/biofuels compatible with existing energy technologies
- BDF burns cleaner than the fossil fuel it displaces
- BDF process offers huge GHG benefits
Before/After
Completed Project Site