Conversion of Coal Wastes and Municipal Solids Mixtures by Pyrolysis Torrefaction and Entrained Flow Gasification

2020 Gasification Project Review Meeting
September 2nd, 2020

Nicholas Schwartz
Mainstream Engineering Corporation
200 Yellow Place
Rockledge, FL 32955
www.mainstream-engr.com

Non-Proprietary
Funding Agreement No.: DE-SC0018580
Award Date: May 28, 2019
Agenda

- Project Description and Objectives
- Accomplishments
- Program Results
- Challenges and Next Steps
- Technology-to-Market
- Conclusions
Project Objectives

- Use coal wastes plus municipal solid wastes (CWPMs) to produce electricity and/or liquid fuels cleanly
- Develop technology for a modular system at mine-mouth, coal preparation locations, or military installations

Mainstream’s Approach

- Create coal-like feedstock of MSW using pyrolysis torrefaction (PT) for co-firing in entrained flow gasifiers (EFGs)
- Demonstrate pilot-scale thermal conversion of pulverized waste coal and torrefied MSW in an EFG
- Develop a process model and assess technoeconomic feasibility
Pyrolysis Torrefaction – Entrained Flow Gasifier (PT-EFG)

Process flow diagram of the PT-EFG process and reaction pathway
Target Goals

- Design and commission pilot-scale MSW torrefier
  - Target 10 lb/h capacity
- Demonstrate semi-continuous, 10 lb/h PT-EFG with >28% H₂ syngas concentration
- Demonstrate syngas upgrading for H₂:CO ratio of 2:1
- Quantify emissions of PT-EFG based on EPA other solid waste incinerator (OSWI) regulations
  - Demonstrate non-leaching vitrified slag
- Design >200 lb/h modular PT-EFG demonstrator-scale system
- Determine the most cost-effective PT-EFG size for delivering LCOE of <$100/MWh
Current Status of Project

- Finalized design of pilot-scale MSW torrefaction reactor
  - Fabrication and commissioning ongoing
- Torrefied high-value MSW material and blended with waste bituminous and anthracite
  - Completed feedstock characterization
- 10 lb/h pilot-scale EFG testing completed at Energy and Environmental Research Center (EERC)
  - Working on emissions and slag analysis
- Initial stages of designing a 200 lb/h PT-EFG demonstrator
  - Scale for demonstrating large-scale capacity
  - Process model and TEA to be completed with design
Pilot-scale MSW Torrefier

- Torrefaction reactor angle can be adjusted to accommodate different feedstocks and operating conditions
- Self-sustaining process with supplemental burners
Recent Commercialization of Small-Scale Reactor Systems

- 1 kg/h throughput
- Biomass and MSW feedstock
- Digital control
- Commercialized small-scale reactor
- Current sales orders
- Establish similar commercialization pathway for MSW torrefier

Mainstream’s Continuous Bench-scale Pyrolysis Unit
Torrefied MSW for EFG Testing

- Procured high-value MSW and completed torrefaction with commercial partner

### Torrefaction Reactor Conditions

<table>
<thead>
<tr>
<th>Temperature (°C)</th>
<th>Residence Time (min)</th>
<th>HHV (MJ/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>315</td>
<td>15</td>
<td>21.92</td>
</tr>
<tr>
<td>343</td>
<td>15</td>
<td>27.56</td>
</tr>
<tr>
<td>370</td>
<td>15</td>
<td>22.83</td>
</tr>
</tbody>
</table>

- Shredded MSW
- Torrefied MSW
- Pulverized Feed
Analysis of Torrefied MSW and Coal Waste Materials

- Higher ash content in MSW feedstock
- Sourced MSW had less plastics

### Proximate Analysis

<table>
<thead>
<tr>
<th></th>
<th>Preprocessed MSW</th>
<th>Torrefied MSW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>As Recd. Dry</td>
<td>As Recd. Dry</td>
</tr>
<tr>
<td><strong>Proximate Analysis</strong></td>
<td>(%) (%)</td>
<td>(%) (%)</td>
</tr>
<tr>
<td>Moisture</td>
<td>9.96 N/A</td>
<td>4.40 N/A</td>
</tr>
<tr>
<td>Ash</td>
<td>15.54 17.26</td>
<td>26.32 27.53</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.23 0.26</td>
<td>0.25 0.26</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0.44 0.49</td>
<td>0.92 0.93</td>
</tr>
<tr>
<td>Heating Value (Btu/lb)</td>
<td>8,233 9,144</td>
<td>11,849 12,394</td>
</tr>
</tbody>
</table>

### MSW/Bituminous Coal Blends

<table>
<thead>
<tr>
<th></th>
<th>100% MSW</th>
<th>75% MSW</th>
<th>50% MSW</th>
<th>25% MSW</th>
<th>0% MSW</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proximate Analysis</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture (wt%)</td>
<td>4.40</td>
<td>3.64</td>
<td>2.89</td>
<td>2.13</td>
<td>1.38</td>
</tr>
<tr>
<td>Ash (wt%)</td>
<td>26.32</td>
<td>31.73</td>
<td>37.14</td>
<td>42.55</td>
<td>47.96</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.25</td>
<td>0.78</td>
<td>1.32</td>
<td>1.86</td>
<td>2.40</td>
</tr>
<tr>
<td>Heating Value (Btu/lb)</td>
<td>11,849</td>
<td>11,192</td>
<td>10,536</td>
<td>9,880</td>
<td>9,223</td>
</tr>
</tbody>
</table>
EFG Testing of MSW/Waste Coal

- Measured steady-state syngas composition of MSW/waste coal blends
- Syngas composition dependent on feedstock properties
  - Lower H-content with bulk MSW feedstock

<table>
<thead>
<tr>
<th>Conditions</th>
<th>100% MSW</th>
<th>75% MSW/25% Bituminous</th>
<th>50% MSW/50% Bituminous</th>
<th>25% MSW/75% Bituminous</th>
<th>100% Bituminous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Feed (lb/h)</td>
<td>8.23</td>
<td>5.74</td>
<td>5.20</td>
<td>6.54</td>
<td>6.23</td>
</tr>
<tr>
<td>EFG Pressure (psig)</td>
<td>130.0</td>
<td>129.7</td>
<td>131.0</td>
<td>130.0</td>
<td>130.0</td>
</tr>
<tr>
<td>Avg. Temperature (°F)</td>
<td>2,689</td>
<td>2,682</td>
<td>2,682</td>
<td>2,671</td>
<td>2,685</td>
</tr>
<tr>
<td>Syngas (ft³/h)</td>
<td>212</td>
<td>239</td>
<td>217</td>
<td>239</td>
<td>234</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Syngas Composition</th>
<th>H₂ (mol%)</th>
<th>O₂ (mol%)</th>
<th>N₂ (mol%)</th>
<th>CH₄ (mol%)</th>
<th>CO (mol%)</th>
<th>CO₂ (mol%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% MSW</td>
<td>17.1</td>
<td>0.3</td>
<td>44.9</td>
<td>0.2</td>
<td>15.4</td>
<td>21.7</td>
</tr>
<tr>
<td>75% MSW/25% Bituminous</td>
<td>18.4</td>
<td>0.1</td>
<td>45.5</td>
<td>0.1</td>
<td>12.8</td>
<td>19.3</td>
</tr>
<tr>
<td>50% MSW/50% Bituminous</td>
<td>12.5</td>
<td>0.1</td>
<td>52.8</td>
<td>0.1</td>
<td>8.6</td>
<td>20.5</td>
</tr>
<tr>
<td>25% MSW/75% Bituminous</td>
<td>16.2</td>
<td>0.1</td>
<td>46.1</td>
<td>0.1</td>
<td>13.1</td>
<td>19.8</td>
</tr>
<tr>
<td>100% Bituminous</td>
<td>12.4</td>
<td>0.1</td>
<td>50.2</td>
<td>0.1</td>
<td>11.8</td>
<td>20.3</td>
</tr>
</tbody>
</table>
Slag Viscosity Measurements

- Higher temperatures required for high ash material to slag
- Target < 250 Pa\cdot s viscosity
Overview of Pilot-scale EFG Results

- High ash caused slag to plug the bottom of the reactor
  - Limestone added to feed to alleviate high slag viscosity
- 98% of the ash was recovered as slag
- EFG slag is non-leachable
  - Quench water had very little organics and trace metals
  - RDF reduced the H$_2$S in the syngas significantly
- Carbon conversion was calculated to be over 98%
- More water-gas shifting than predicted was observed
  - Actual H$_2$/CO ratio was ~1.2
  - Further water-gas shifting downstream would bring the H$_2$/CO ratio to >2, suitable for FT and liquid fuel production
Market Analysis and Industry Partners

- Conducting a market analysis
  - Determine demand and regions to commercialize PT-EFG
  - Market assessment for pilot-scale MSW/biomass torrefier
- Developing commercial partnerships with end-users
  - Gauge interest for PT-EFG in coal dominant regions
  - Determine interest in pilot-scale MSW/biomass torrefier from research labs, universities, and power producers
- Technology transfer and licensing
  - Working to transition the technology to market through licensing agreements
Technology-to-Market

- Commercialize MSW torrefier technology
- Build demonstrator-scale PT-EFG system for power generation
  - Partner with AC Power using waste coal
- Large waste coal market: 9 million tons/year, with stockpiles of 2 billion cubic yards in PA alone
- Localized in PA and WV (open to remote locations e.g. Alaska)

Fire control at Simpson Northeast coal refuse

Nemacolin Gob Pile in Greene County, PA
Commercialization Strategy

- Mainstream will manufacture the PT-EFG for power producers

Our PT-EFG system targets coal waste fired power plants to provide torrefied biomass feedstock or complete PT-EFG systems.

- **COAL FEEDSTOCK**
  - Peabody Energy Corp
  - Arch Coal
  - Reading Anthracite

- **ELECTRICAL DISTRIBUTION**
  - FPL
  - PacifiCorp
  - Duke Energy

- **COAL-WASTE-FIRED POWER PLANTS**
  - Colver Power Project
  - Gilberton Power Company
  - Edensburg Power Company
  - Mt. Carmel Cogen, Inc.
  - Wheelabrator Energy Co.

- **EMISSIONS CONTROL SYSTEM MANUFACTURERS**
  - United Conveyor
  - Cabot
  - Dustex
  - ADA-ES
Concluding Remarks

- MSW torrefier system will demonstrate feasibility of scalable, continuous processing of MSW
- PT-EFG is feasible for processing torrefied MSW and waste coal materials
  - High quality syngas with potential for upgrading and production of fuels
- Favorable emissions and generates non-leaching ash and slag
- Design of modular, 200 lb/h PT-EFG system will determine economic feasibility
  - Determine capital costs, operating expenses, and LCOE
Mainstream Engineering Corporation

- Small business incorporated in 1986
- 100+ employees
- Mechanical, chemical, electrical, materials and aerospace engineers
- 100,000 ft\(^2\) facility in Rockledge, FL
- Laboratories: electric power, electronics, materials, nanotube, physical and analytical chemistry, thermal, fuels, internal combustion engine
- Manufacturing: 3- and 5- axis CNC and manual mills, CNC and manual lathes, grinders, sheet metal, plastic injection molding, welding and painting

Capabilities
- Basic Research, Applied Research & Product Development
- Transition from Research to Production (Systems Solution)
- Manufacture Advanced Products

Mission Statement
To research and develop emerging technologies. To engineer these technologies into superior quality, military and private sector products that provide a technological advantage.
Mainstream’s Focus Areas

**THERMAL CONTROL**
- High Heat Flux Cooling
- Thermal Energy Storage
- Directed Energy Weapons
- Rugged Military Systems

**TURBOMACHINERY**
- Compressors
- Turbines
- Bearings/Seals
- Airborne Power Systems

**POWER ELECTRONICS**
- High Speed Motor Drives
- Hybrid Power Systems
- Solar/Wind Electronics
- Pulse Power Supplies
- Battery Chargers

**ENERGY CONVERSION**
- Combustion
- Diesel/JP-8 Engines
- Biomass Conversion
- Alternative Fuels
- Fuel Cells

**MATERIALS SCIENCE**
- Thermoelectrics
- Batteries/Ultracapacitors
- Hydrogen Storage
- E-Beam Processing
- Nanostructured Materials

**CHEMICAL TECHNOLOGIES**
- Heat Transfer Fluids
- Catalysis
- Chemical Replacements
- Water Purification
- Chemical Sensors
SBIR Successes and Awards

- 95% DOD Commercialization Index
- SBIR spinoffs – QwikProduct Line
- SBIR spinoffs – Military Product Line
- Honors
  - 2014 DOE’s SBIR/STTR Small Business of the Year
  - 2013 Florida Excellence Award by the Small Business Institute for Excellence in Commerce
  - Winner Florida Companies to Watch
  - Blue Chip Enterprise Initiative Awards
  - Job Creation Awards
  - Two SBA’s Tibbetts Awards for Commercialization
  - State of Florida Governor’s New Product Award
  - SBA’s Small Business Prime Contractor of the Year for the Southeastern U.S.
  - SBA’s Administrator’s Award for Excellence
Source MSW and Waste Coal Materials

- MSW material sourced from BioHiTech in Harrisburg, PA
- Waste anthracite sourced from Reading Anthracite with the Gilberton Power Company (Pottsville, PA)
  - Waste coal used at Gilberton power plant
- Waste bituminous sourced from AC Power (Colver, PA)
  - Waste coal used at AC Power Operations power plant
- Procured >1,000 lb of each waste coal material
Biomass and MSW Preprocessing

- Demonstrated integrated milling-drying preprocessor for biomass and MSW
- Final moisture <10%, <3 mm particles (30%, 20-30 mm Feed)
- Process intensification reduces costs

Integrated Drying, Conveying, Inerting, Milling, Sharpening (DCIMS) System
Modular Reactor and System Design

- Developed a 1-tpd (100 lb/h) pilot-scale, fast-pyrolysis fluidized bed reactor
- Demonstrated clean combustion of pyrolysis byproducts (bio-oil, char, and gas)