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

2021 Gasification Project Review Meeting
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Non-Proprietary

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Agenda

- Program Objectives
- Combined Torrefaction-Gasification Process
- Accomplishments
- Program Results
- Technology-to-Market
- Conclusions

Program 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

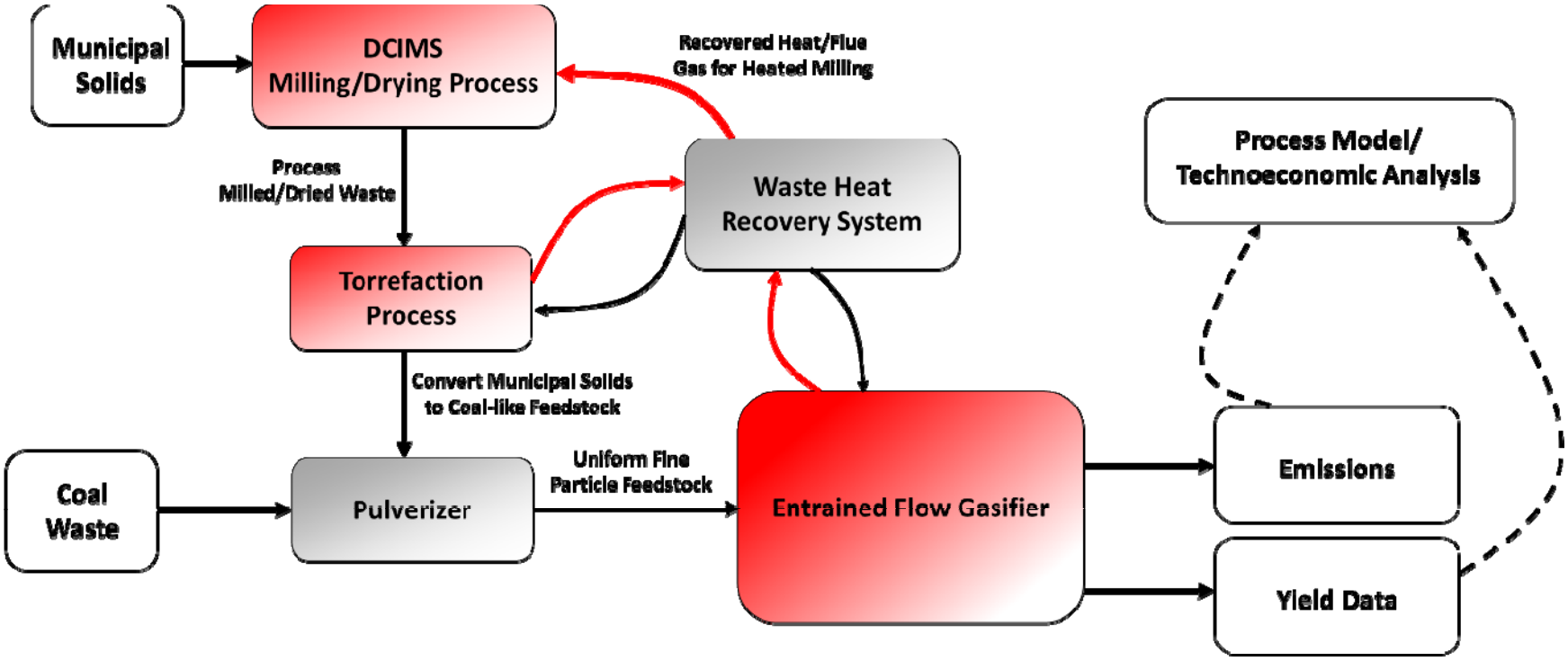
Mainstream's Approach

- 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

Significance of the Problem

- **Reclamation and processing of high-ash, low energy density waste coal**
  - Hundreds of million tons of waste coal in U.S.
- **Recover heat and energy from MSW and reduce landfill waste**
  - Many landfills are reaching capacity with limited options for waste management

Pyrolysis Torrefaction – Entrained Flow Gasifier (PT–EFG)



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

Current Status of Project

- **Constructed pilot-scale torrefier for MSW and other mixed wastes**
  - Finalizing automation and controls
- **Torrefied high-value MSW material and blended with waste bituminous and anthracite**
  - Completed feedstock characterization
- **Completed pilot-scale gasification of waste coal and torrefied mixed waste with EFG**
  - Characterized emissions and completed slag analysis
- **Designing demonstrator-scale PT–EFG (200 lb/h)**
  - Scale for demonstrating large-scale capacity
  - Initial process model and TEA

Mainstream's Pilot-scale MSW Torrefier

- **Torrefaction reactor designed to accommodate different feedstocks, mixtures, and blended waste streams**
- **Self-sustaining process with supplemental burners**

Mainstream's MSW Torrefier System

- Fully automated, touchscreen controls
- Biomass, MSW, mixed waste feedstocks
- 10 lb/h throughput
- Commercialization pathway based on Mainstream's small-scale reactors

Commercialize Small-Scale Reactor Systems

- Established commercialization pathway for MSW torrefier
- Expanded testing capabilities for collaborators and potential commercial partners
- Rapid testing and optimization for process scale-up

Mainstream's Commercially-available Continuous Bench-scale Pyrolysis Unit

Torrefied MSW for EFG Testing

- Procured and completed torrefaction of solid recovered fuel (SRF) with commercial partners

Shredded MSW

Torrefied MSW

Pulverized Feed

- Highly scalable torrefaction process
- Multiple industrial and commercial torrefaction systems in operation across the U.S.

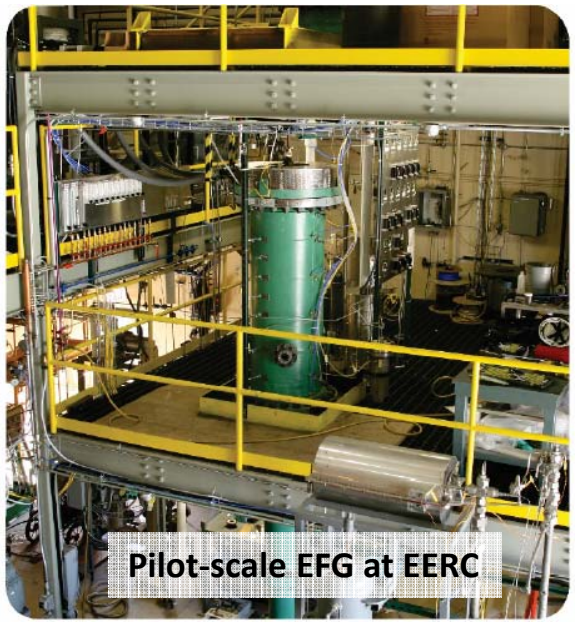
Analysis of Torrefied MSW and Coal Waste Materials

- **Blend coal waste with low-ash torrefied MSW with higher carbon and hydrogen content**

	MSW	MSW/Bituminous				MSW/Anthracite			
MSW in Blend (wt%)	**100**	**75**	**50**	**25**	**0**	**75**	**50**	**25**	**0**
Proximate Analysis (wt%)									
Moisture	4.4	3.6	2.9	2.1	1.4	6.0	7.7	9.3	10.9
Volatile Matter	43.7	36.7	29.7	22.7	15.7	33.4	23.1	12.7	2.4
Fixed Carbon	25.6	28.0	30.3	32.6	35.0	28.3	31.0	33.7	36.4
Ash	26.3	31.7	37.1	42.6	48.0	32.3	38.3	44.3	50.3
Ultimate Analysis (wt%)									
Hydrogen	4.9	4.3	3.7	3.1	2.4	4.1	3.3	2.5	1.7
Carbon	52.9	49.8	46.6	43.5	40.3	48.1	43.3	38.5	33.7
Nitrogen	1.0	0.9	0.9	0.8	0.8	0.9	0.8	0.8	0.7
Sulfur	0.3	0.8	1.3	1.9	2.4	0.3	0.3	0.3	0.3
Oxygen	14.6	12.5	10.4	8.3	6.2	14.0	13.5	12.9	12.4
Ash	26.3	31.7	37.1	42.6	48.0	32.3	38.3	44.3	50.3
Heating Value (Btu/lb)	11,800	11,200	10,500	9,880	9,220	10,058	8,317	6,575	4,833
Component (wt%)									
SiO_2	41.5	45.6	49.7	53.8	57.8	46.5	51.5	56.5	61.5
Al_2O_3	14.7	17.1	19.6	22.0	24.4	17.5	20.2	23.0	25.8
Fe_2O_3	3.6	5.1	6.7	8.2	9.8	4.0	4.4	4.9	5.3
CaO	25.2	19.2	13.1	7.0	0.9	19.0	12.8	6.6	0.4

Gasification of MSW/Waste Coal

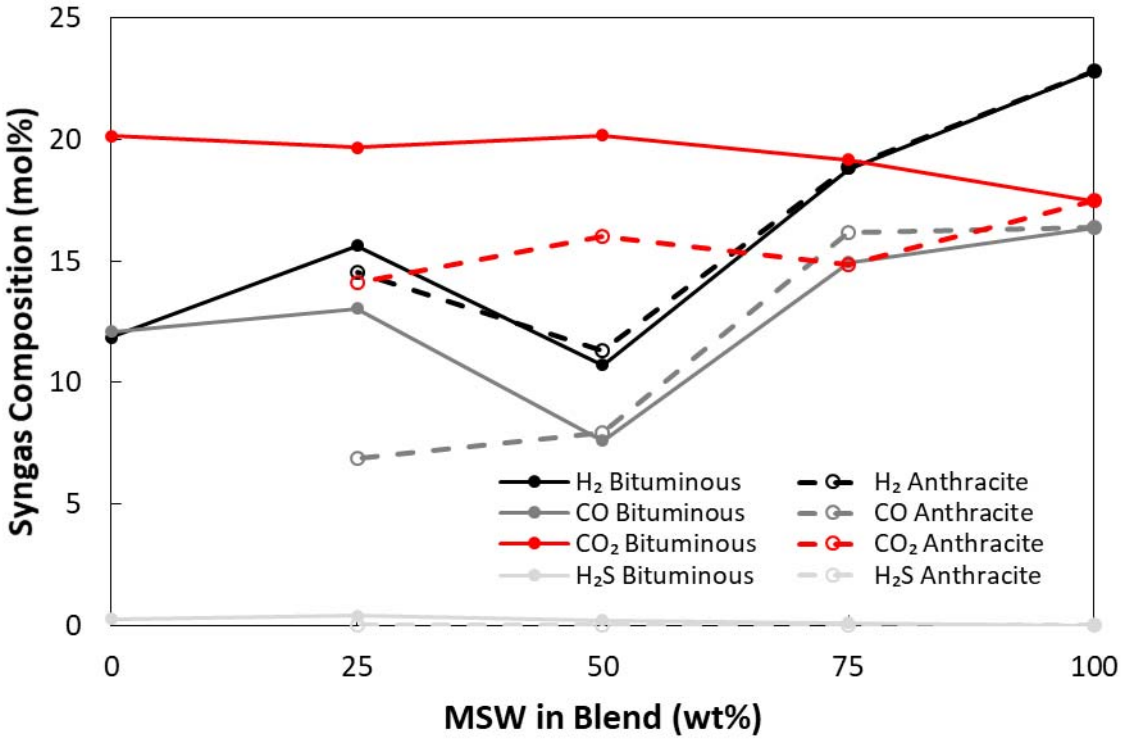
- **Measured steady-state syngas composition of MSW/waste coal blends**
- **Over 95% of ash recovered as non-leaching slag**
- **Over 97% carbon conversion for all feedstock blends**
  - High H_2 syngas with little CH_4


Pilot-scale EFG at EERC

	MSW	MSW/Bituminous				MSW/Anthracite		
MSW in Blend (wt%)	**100**	**75**	**50**	**25**	**0**	**75**	**50**	**25**
Fuel feed (lb/h)	4.8	5.7	5.2	6.5	6.2	5.1	3.3	3.1
Limestone (lb/h)	0.0	0.0	0.3	1.6	2.1	0.0	0.0	0.0
Steam feed (lb/h)	6.2	6.8	6.8	6.8	6.8	6.2	6.7	6.7
O_2 Flow (scfh)	58.6	57.5	60.0	58.1	65.0	54.7	45.9	33.4
Purge N_2 Flow (scfh)	136	176	190	180	173	158	174	179
Temperature (°F)	2,656	2,566	2,572	2,530	2,593	2,578	2,645	2,627
Syngas Flow (scfh)	235	239	217	239	236	243	199	204
Filter Ash (lb/h)	0.12	0.21	0.03	0.05	0.93	0.10	0.00	0.00
Carbon Conversion (%)	97.5	92.0	98.8	98.1	97.5	99.8	100.0	100.0

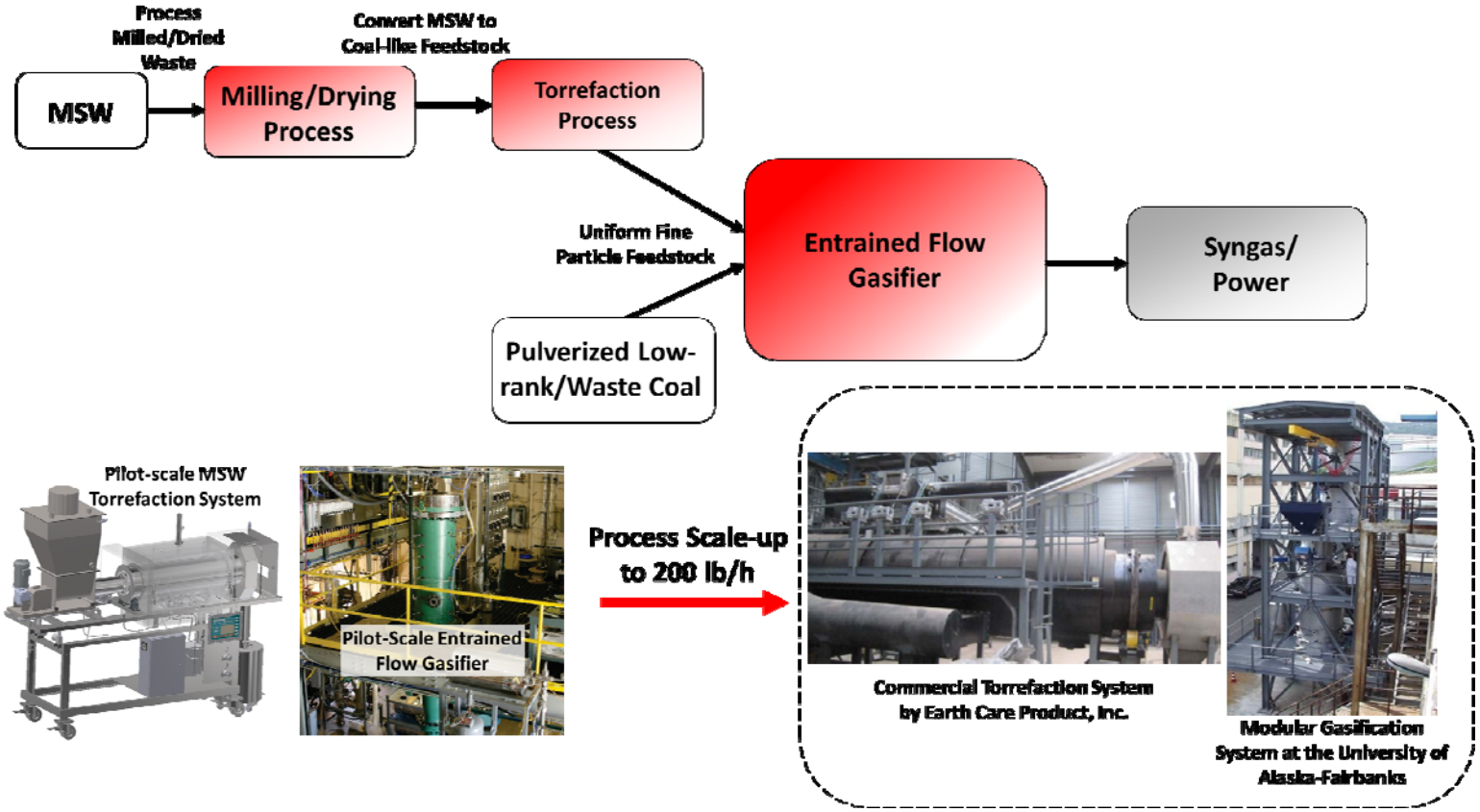
EFG Syngas Composition

- Blending torrefied MSW improves syngas quality
- Negligible amounts of CH_4 or H_2S
- Higher H_2 and CO_2 content than predictive model



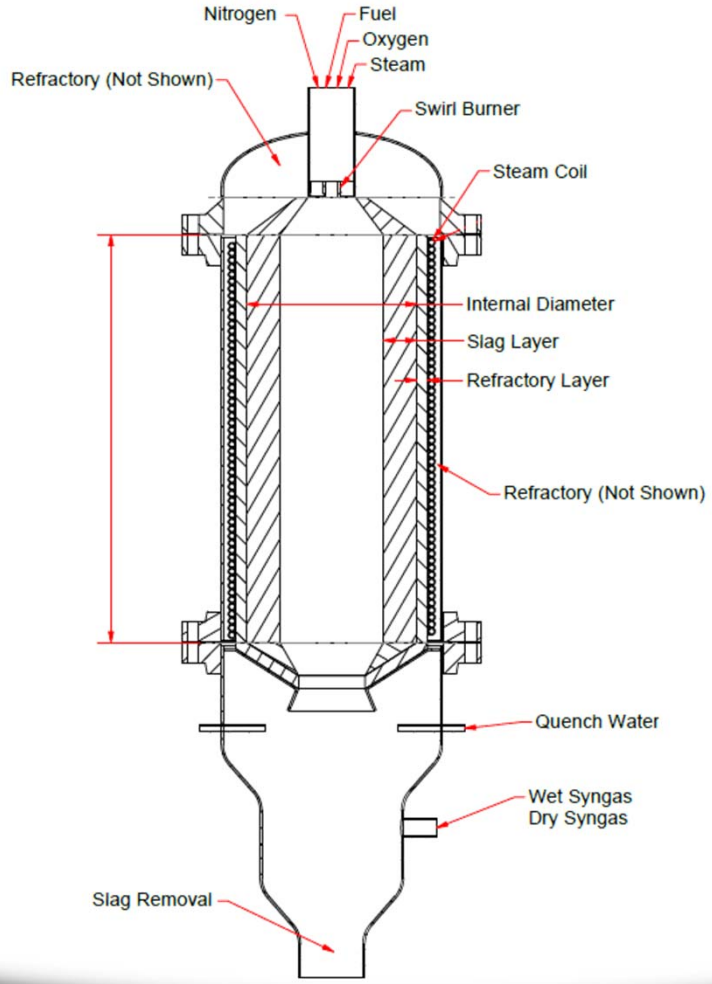
Demonstrator-scale PT–EFG to Transition to Commercial Scale

- **Mainstream partnering with energy companies to scale-up**



EFG Design for PT–EFG Process

- **Designed 200–300 lb/h (20 MW_{th}) EFG using Aspen-based process model and experimental data**



Predicted Syngas Composition

Syngas	Composition (-)
H_2O	0.262
N_2	8.628
NH_3	0.00024
H_2	28.252
CO	32.939
CO_2	29.295
COS	0.046
H_2S	0.578
H_2S + COS	0.623

Market Analysis and Industry Partners

- **Independently commercialize MSW torrefier system**
- **Build demonstrator-scale PT-EFG system for power generation**
  - Partner with energy producers, manufacturers, and end users
  - Commercial partner funding driving first build
- **Direct technology for MSW and broad waste streams**
  - Large MSW and waste coal market

MSW sorting facility

Coal refuse fire control

Waste coal stockpile

Concluding Remarks

- **PT–EFG is feasible for processing torrefied MSW and waste coal materials**
  - High quality syngas (20%–30% H_2) with potential for upgrading and production of fuels
  - Generates non-leaching ash and slag
- **Economically favorable at large scales 10–50 MW**
  - Capital cost $937/kW (below $1,000/kW DOE target)
  - LCOE of modular 10 MW PT–EFG is 10 cents/kWh (lower than residential/commercial prices of 10.7–12.8 cents/kWh)
- **Strong commercial support for development of demonstrator-scale PT–EFG**

Supporting Slides

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

1 - ENGINEERING OFFICES
2 - RESEARCH & DEVELOPMENT
3 - RESEARCH & DEVELOPMENT
4 - PRODUCTION
5 - PRODUCT DEVELOPMENT
5a - MAINSTREAM EBEAM
6 - CONTROLLED-ATMOSPHERE BRAZING FACILITY
7 - ROTOMOLD PRODUCTION

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

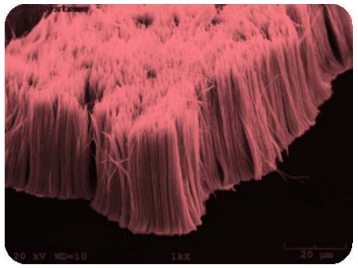
- High Heat Flux Cooling
- Refrigerant Cooling
- Thermal Energy Storage
- Heat Exchangers
- Directed Energy Weapons
- Rugged Military Systems

ENERGY AND SUSTAINABILITY

- Thermochemical Conversion
- Chemical Formulation
- Separation Processes
- Water Purification
- Smart Sensors
- Catalysis

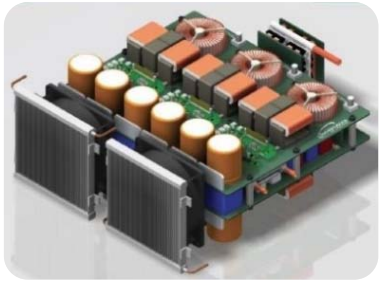
MECHANICS

- Heavy Fuel Engines/Generators
- Turbines/Compressors
- Mechanical Components and Systems
- Custom Test Hardware



MATERIALS SCIENCE

- Nanostructured Materials
- Echem & Solid State Energy
- EBEAM Materials Processing
- Vapor Phase Growth



POWER ELECTRONICS

- Military Grade Power Supplies
- Variable Speed Motor Drives
- Power Factor Correction
- Hybrid Power Systems
- Pulse Power Supplies

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**

GPC GILBERTON POWER COMPANY

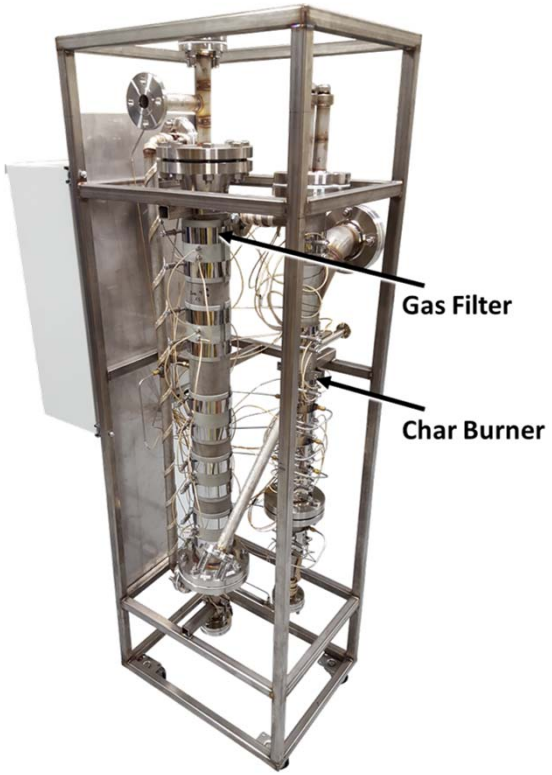
FAMOUS READING ANTHRACITE

A/C POWER COLVER OPERATIONS

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)

Mainstream's pilot-scale pyrolysis solid waste remediation system (*py*-SWRS)



Mainstream's pilot-scale pyrolysis char burner