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

2020 Gasification Project Review Meeting
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Agenda

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

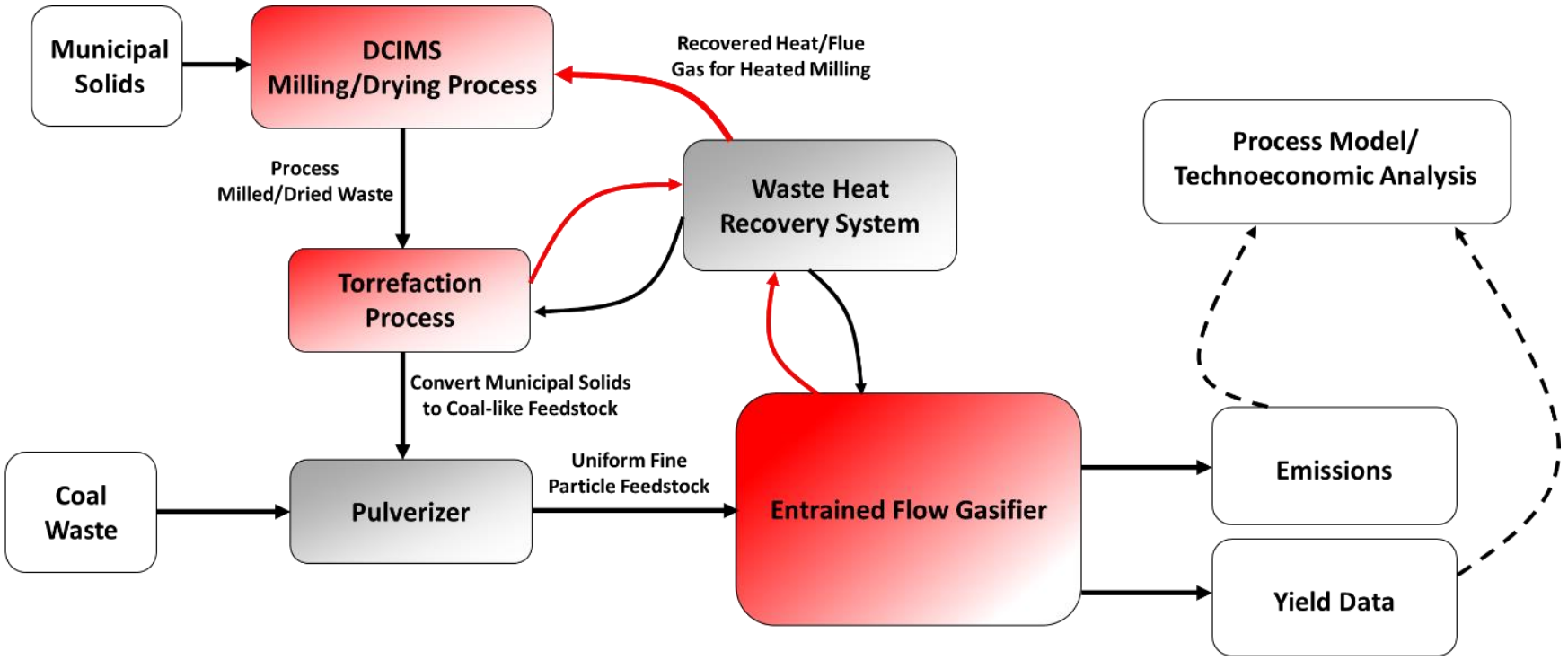
Project Objectives

- 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

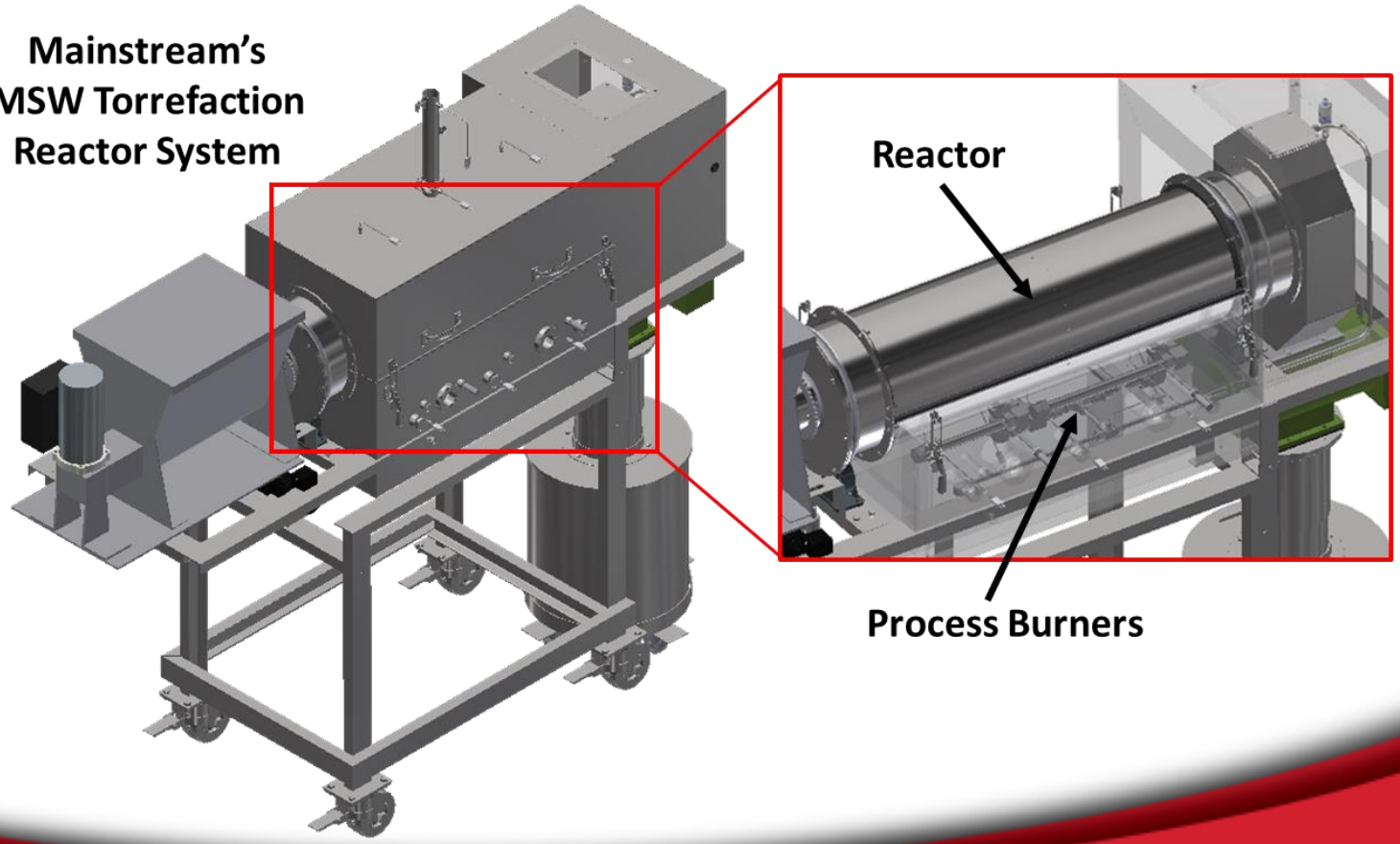
- **Design and commission pilot-scale MSW torrefier**
  - Target 10 lb/h capacity
- **Demonstrate semi-continuous, 10 lb/h PT-EFG with >28% H_2 syngas concentration**
- **Demonstrate syngas upgrading for H_2:CO ratio of 2:1**
- **Quantify emissions of PT-EFG based on EPA other solid waste incinerator (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

Temperature (°C)	Residence Time (min)	HHV (MJ/kg)
315	15	21.92
343	15	27.56
370	15	22.83

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**

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

	Anthracite Coal Waste		Bituminous Coal Waste	
	As Recd.	Dry	As Recd.	Dry
Proximate Analysis	(%)	(%)	(%)	(%)
Moisture	1.99	N/A	1.38	N/A
Ash	47.07	48.03	47.96	48.63
Sulfur	0.45	0.46	2.40	2.43
Heating Value (Btu/lb)	9,177	9,364	9,223	9,352

	MSW/Bituminous Coal Blends				
Proximate Analysis	100% MSW	75% MSW	50% MSW	25% MSW	0% MSW
Moisture (wt%)	4.40	3.64	2.89	2.13	1.38
Ash (wt%)	26.32	31.73	37.14	42.55	47.96
Sulfur	0.25	0.78	1.32	1.86	2.40
Heating Value (Btu/lb)	11,849	11,192	10,536	9,880	9,223

EFG Testing of MSW/Waste Coal

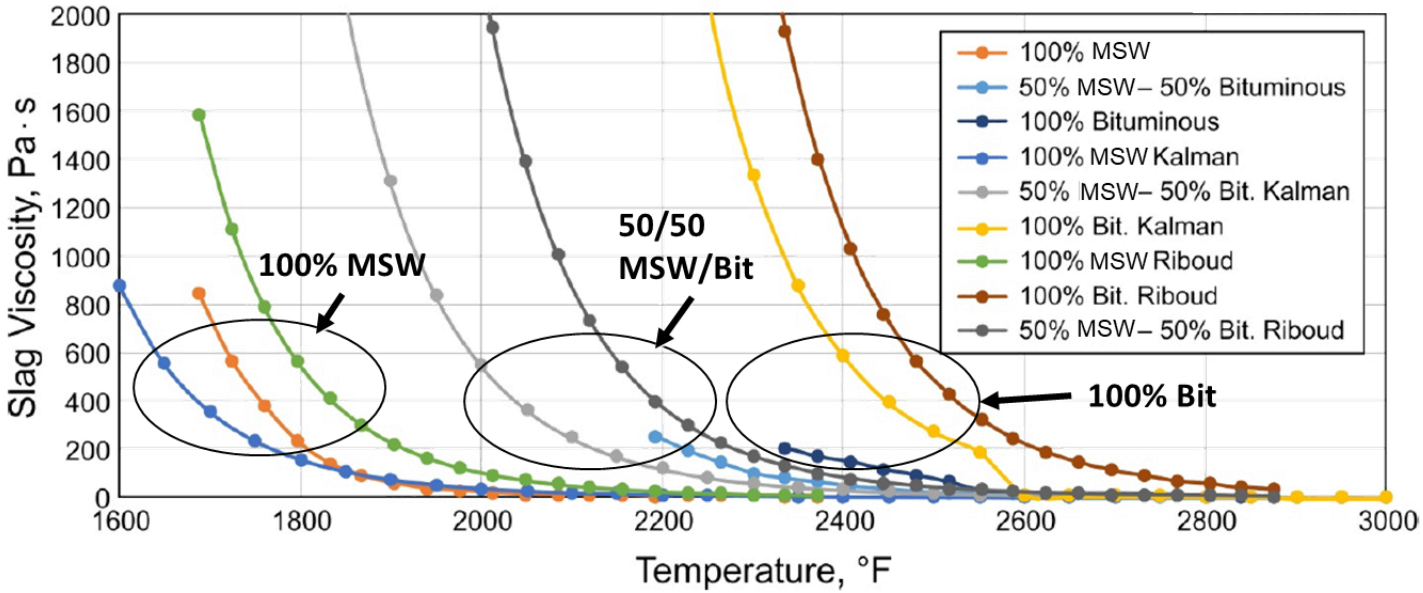
- **Measured steady-state syngas composition of MSW/waste coal blends**
- **Syngas composition dependent on feedstock properties**
  - Lower H-content with bulk MSW feedstock

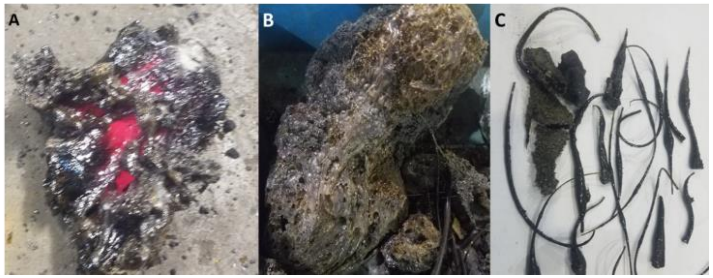
Pilot-scale EFG at EERC

Conditions	100% MSW	75% MSW/ 25% Bituminous	50% MSW/ 50% Bituminous	25% MSW/ 75% Bituminous	100% Bituminous
Fuel Feed (lb/h)	8.23	5.74	5.20	6.54	6.23
EFG Pressure (psig)	130.0	129.7	131.0	130.0	130.0
Avg. Temperature (°F)	2,689	2,682	2,682	2,671	2,685
Syngas (ft^3/h)	212	239	217	239	234
Syngas Composition					
H_2 (mol%)	17.1	18.4	12.5	16.2	12.4
O_2 (mol%)	0.3	0.1	0.1	0.1	0.1
N_2 (mol%)	44.9	45.5	52.8	46.1	50.2
CH_4 (mol%)	0.2	0.1	0.1	0.1	0.1
CO (mol%)	15.4	12.8	8.6	13.1	11.8
CO_2 (mol%)	21.7	19.3	20.5	19.8	20.3

Slag Viscosity Measurements

- Higher temperatures required for high ash material to slag
- Target < 250 Pa·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_2S 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

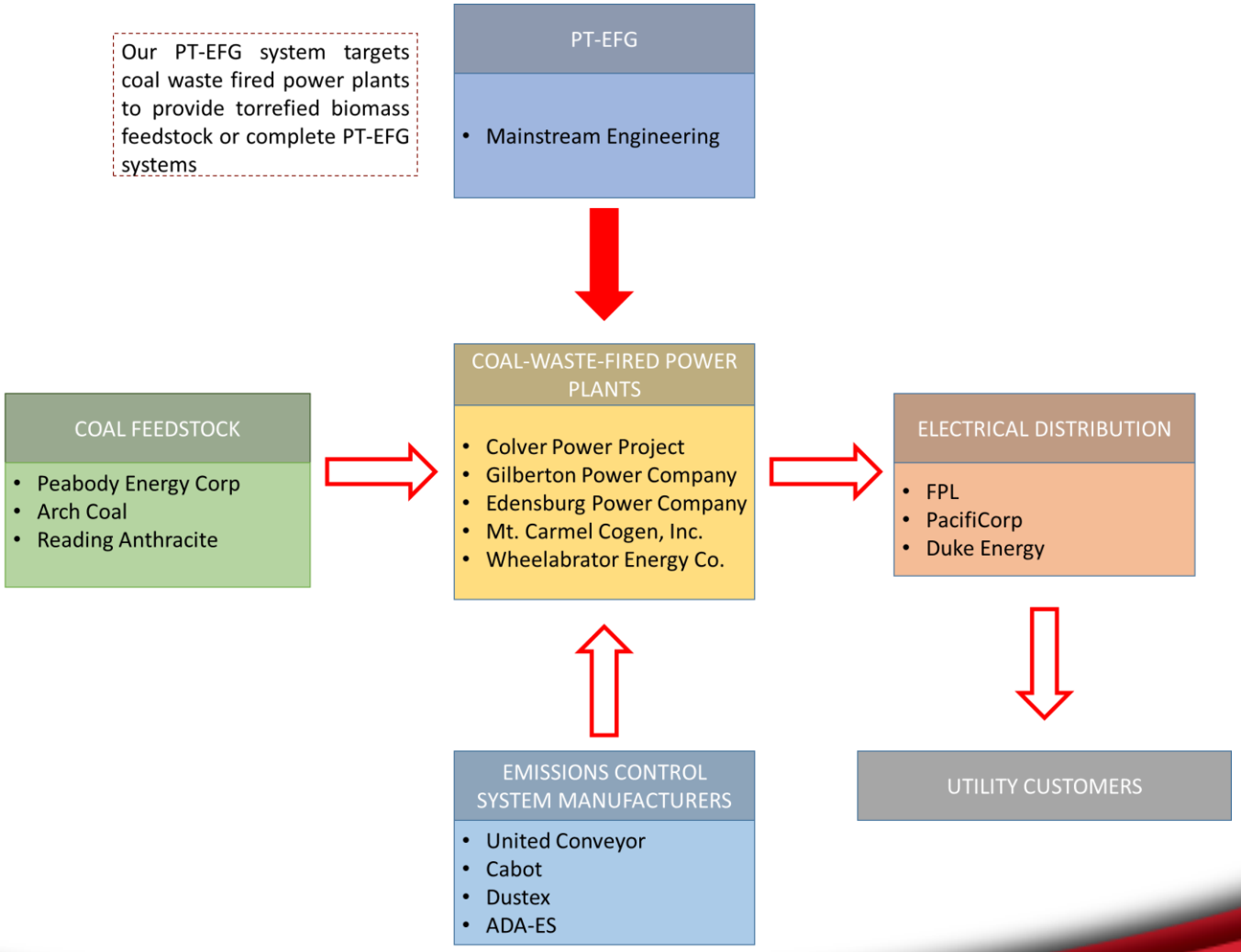
- **Commercialize MSW torrefier technology**
- **Build demonstrator-scale PT-EFG system for power generation**
  - Partner with AC Power using waste coal
- **Large waste coal market: 9 million tons/year, with stockpiles of 2 billion cubic yards in PA alone**
- **Localized in PA and WV (open to remote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



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

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

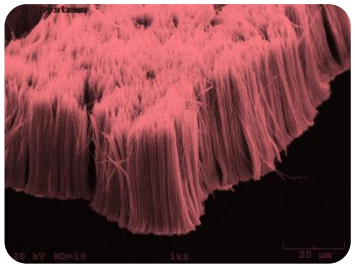
- High Heat Flux Cooling
- Thermal Energy Storage
- Directed Energy Weapons
- Rugged Military Systems

ENERGY CONVERSION

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

TURBOMACHINERY

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

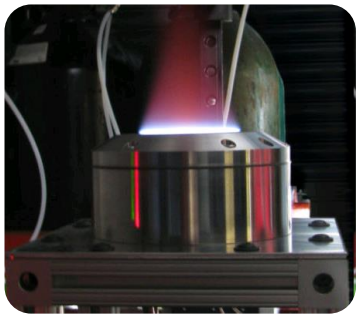


MATERIALS SCIENCE

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

POWER ELECTRONICS

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



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**

GILBERTON POWER COMPANY

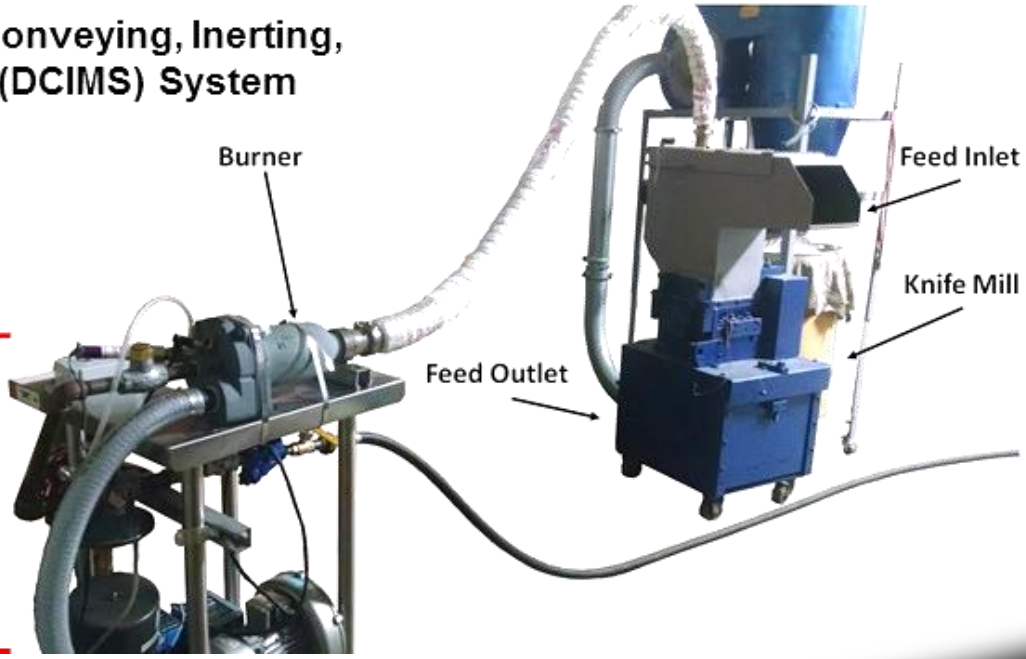
FAMOUS READING ANTHRACITE

A/C POWER COLVER OPERATIONS

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

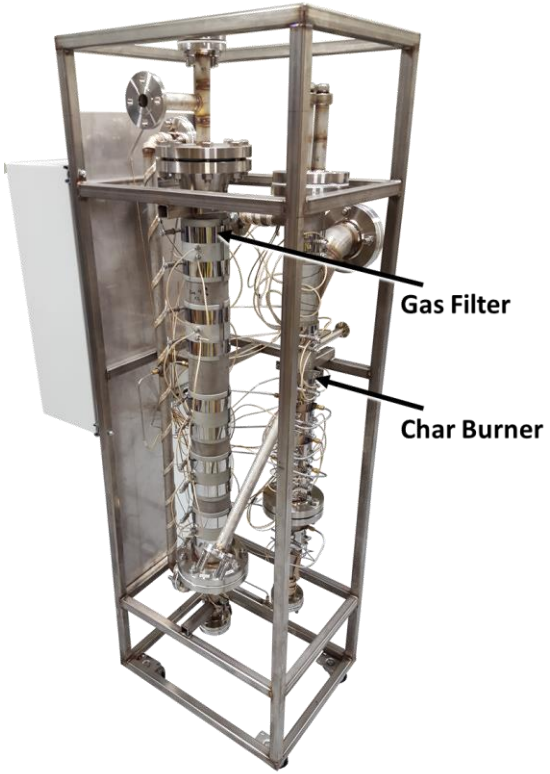
Integrated Drying, Conveying, Inerting, Milling, Sharpening (DCIMS) System



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)

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



Mainstream's pilot-scale pyrolysis char burner