DOE Bioenergy Technologies Office (BETO) 2021 Project Peer Review

WBS 5.1.2.101 - Torrefaction of sorted MSW pellets for uniform biopower feedstock

3/12/2021

Feedstock Technologies

Jordan Klinger

Idaho National Lab

Idaho National Laboratory

Project Overview

From within DOE EERE, BETO released a competitive laboratory call for early-stage R&D.

Goal: “Develop innovations in the use of biomass, municipally-derived biosolids, and sorted municipal solid waste to improve the economic potential of biopower production and use in the United States.”

Our Project Objective: Use advanced compositional and thermophysical characterization methods (**INL**) to support the evaluation of novel production pathways (**MTU**) to biopower applications under the guidance of an industrial partner operating in the US power sector (**CE**).

Project Overview

- What are you trying to do?
  - Create a uninform feedstock from non-recyclable wastes for use in bioenergy (solid fuel for biopower) and biomaterials
- How is it done today and what are the limits?
  - Currently, the only accepted method is through incineration
- Why is it important?
  - Torrefaction and preprocessing strategies can create a uniform fuel, free of contamination (chlorine) that can be used is other combustion applications
- What are the risks?
  - Feedstock variability, leading to inconsistent product or high contamination
  - Plastic melt properties are incompatible with process equipment

1 – Management

- This project was a result of a competitive lab call solicitation
- The scope and approach has been through peer review (FY19, poster review for scope before project start) as well as annual AOP development and review
- Team (bi-weekly team meetings)
  - INL is leading this project, and is performing advanced characterization and measurement of decomposition kinetics for torrefaction
  - Michigan Technological University is a key partner, and is performing kinetic modeling and pilot scale torrefaction
  - Convergen Energy is a commercial partner, is providing relevant waste feedstock streams, industrial feedback
- Quarterly meetings with BETO management
- Working with INL Feedstock SOT (WBS 1.1.1.2) to evaluate process economics, and alongside MSW Decontamination (WBS 1.2.1.7) and Biomass Size Reduction, Drying, and Densification (WBS 1.2.1.2) for waste processing
- Dissemination of Project Impact
  - Peer reviewed publications
  - Conference meetings, presentations, and trade shows

2 – Approach

- Approach
  - Use realistic waste stream from industrial partner and apply torrefaction and densification strategies to make a uniform, homogenous solid fuel pellet
  - Develop models to describe the chemistry of the torrefaction preprocessing, and use them to target conditions that minimize chlorine contamination, and maximize heating value, throughput, and grindability
  - Demonstrate operation of novel pilot scale operation and use process-level data to inform TEA and LCA for evaluation of the process economics in partnership with WBS 1.1.1.2
- TEA and LCA is being performed alongside this work

2 – Approach

- Challenges
  - Producing a uniform product from a variable feed
    - include separations and severe degradation as needed
  - Handling and processing plastics at elevated temperatures (plastic softening)
    - investigate several systems, including current plastics handling extruders
  - Ensuring fuel purity and properties match what is needed by the industrial boiler
    - industry partnerships and materials characterization
- Go/No-go
  - Determine if our approach can meet homogeneity and quality metrics (heating value, chlorine content) for solid fuel pellet. Pivot to investigation of one method of densification (ring die or extrusion) to best meet these goals.

3 – Impact

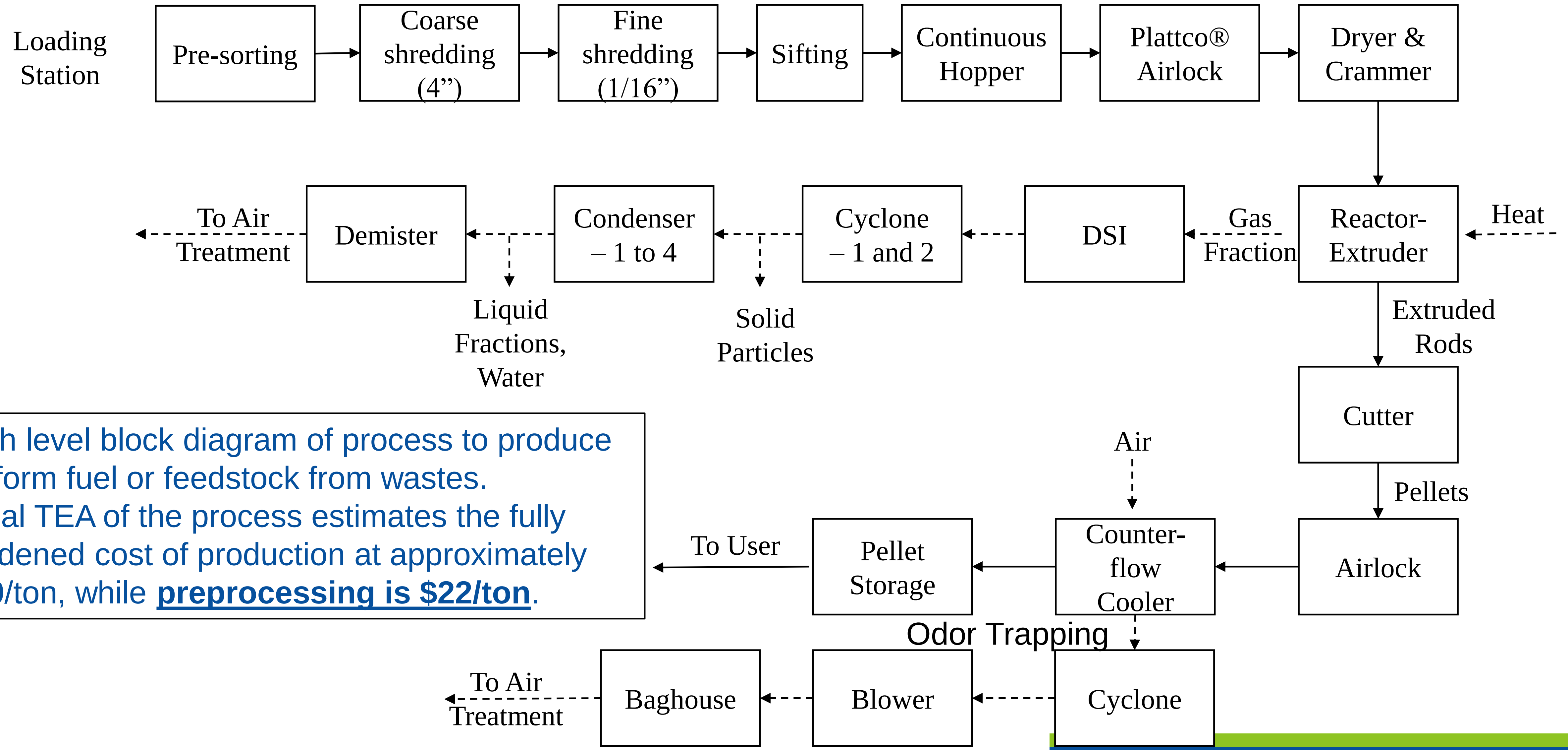
- The program outcomes are applicable to fuel suppliers and waste collectors and opens new markets for end-of-life solution to non-recyclable waste materials
- State of technology
  - Processing of MSW and wastes to alternative fuels and products is scarce outside incineration
  - Combine developing torrefaction technologies with existing compounding/extrusion techniques to develop a novel pathway for utilization of raw national resources
- Industrial Partner, Convergen Energy
  - Investigating torrefaction as a method to make a more uniform and consistent product that be compatible with a wide range of fuel boilers
- Successful dissemination will include presentations (3 workshop talks) to a broader industrial/academic audience as well as publications (2 accepted, 1 under review, 1 in preparation) in peer reviewed journals and workshops

4 – Progress and Outcomes

- The high-level goal was to develop a more uniform feedstock from wastes for bioenergy through torrefaction development
- The progress will show the scientific development that enables industrial and economic preparation of these materials

>90% purity and uniformity are targeted

4 – Progress and Outcomes

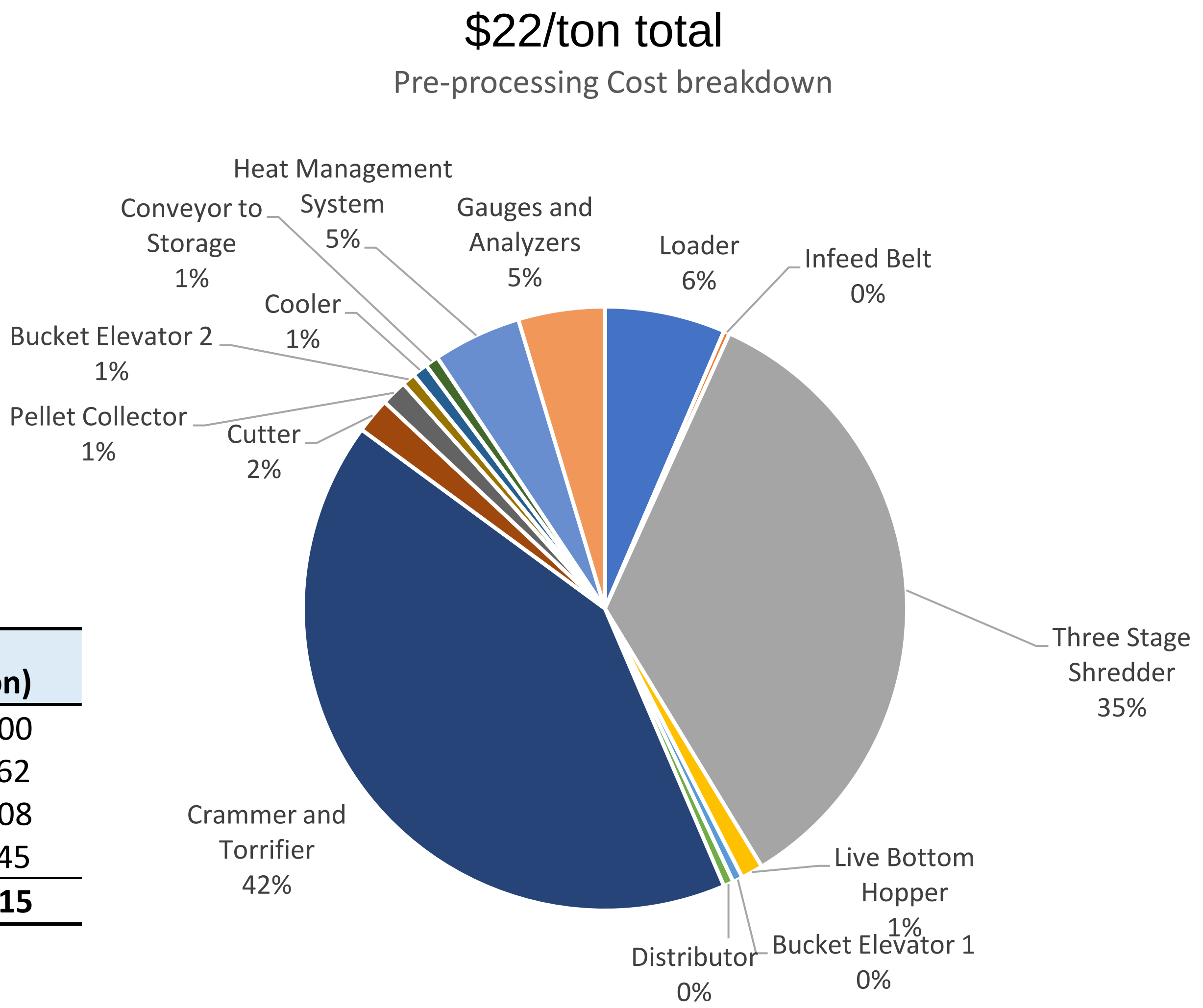


- High level block diagram of process to produce uniform fuel or feedstock from wastes.
- Initial TEA of the process estimates the fully burdened cost of production at approximately $50/ton, while **preprocessing is $22/ton**.

4 – Progress and Outcomes

- Baseline cost of preprocessing MSW is estimated at $50.15/dry ton (2020$).
- The crammer-torrefier unit accounts for $9.14/dry ton (nearly 42%) of the preprocessing costs ($22/ton).
- Sensitivity analysis shows costs range between $47 and $53/dry ton.

	Cost ($/dry ton)	
Preprocessing cost per dry ton	$	22.00
Installation cost per dry ton	$	8.62
Labor cost per dry ton	$	15.08
Maintenance cost per dry ton	$	4.45
Total cost per dry ton	**$**	**50.15**



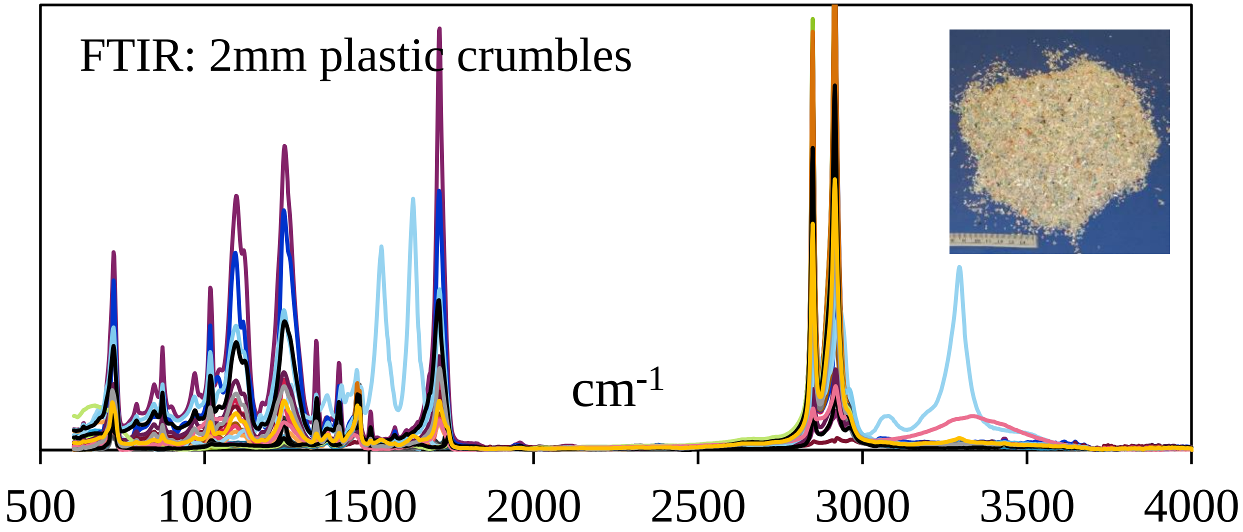
4 – Progress and Outcomes

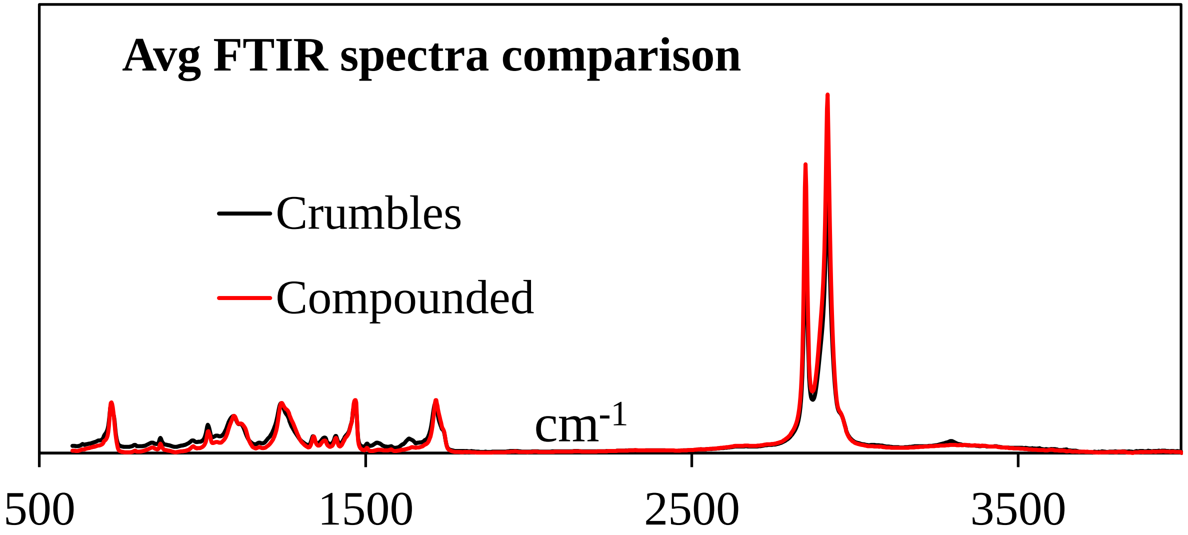
Operational pilot system testing and validating project analytical findings

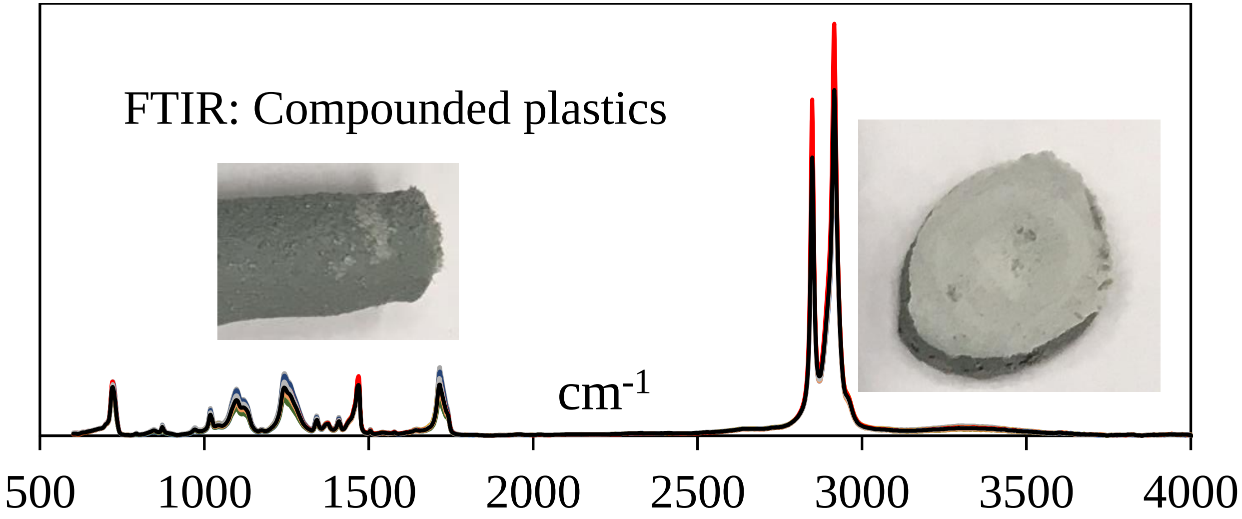
4 – Progress and Outcomes

- Analytical developments have:
  1. Shown improvements to homogeneity
  2. Demonstrated interaction between material components to accelerate conversion
  3. Developed advanced models to represent the chemical kinetics of the process to inform industrial operation

4 – Progress and Outcomes



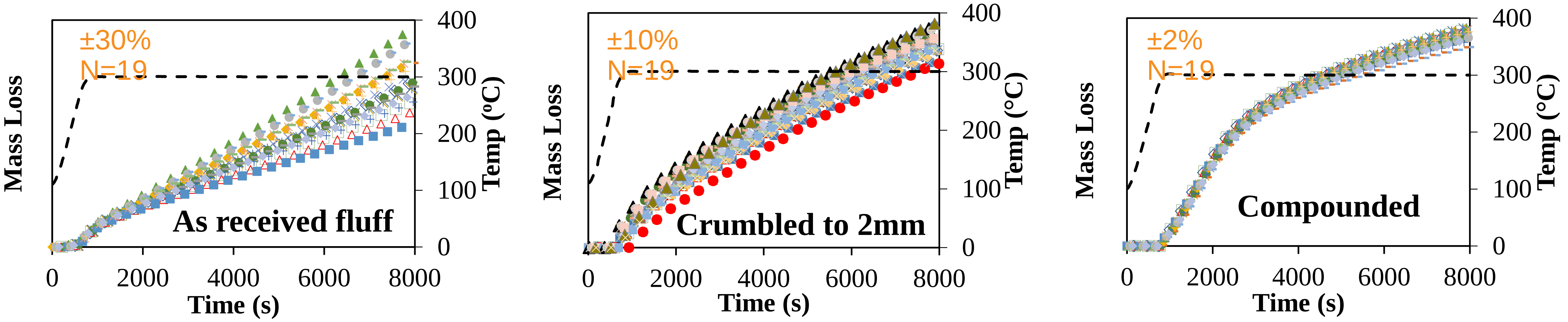




- Chemical (and physical/mechanical) signature for mixed waste is highly variable
- Combinations of size reduction and compounding can homogenize the macro- and meso-scale properties and composition of the materials

4 – Progress and Outcomes

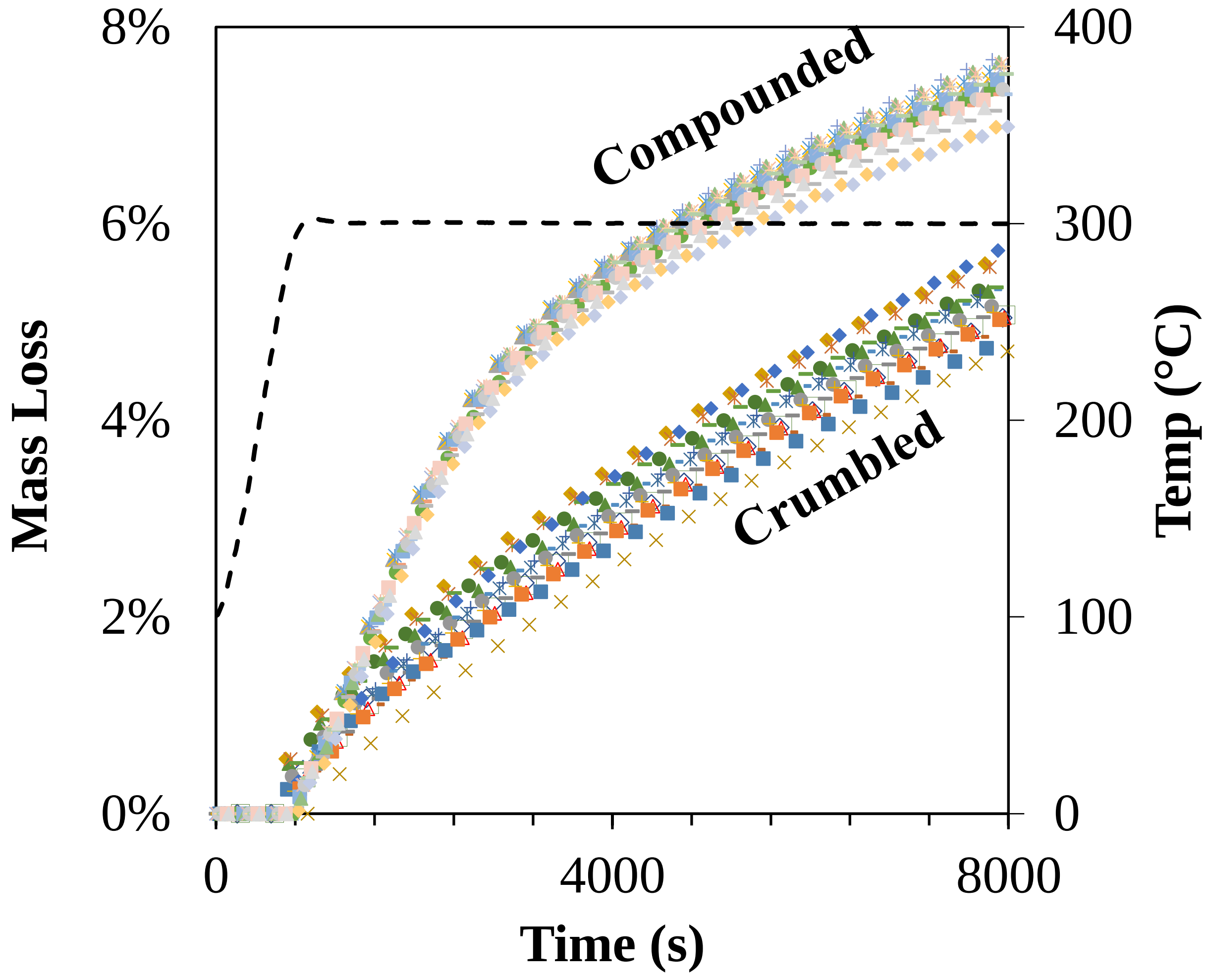
Homogenizing by Crumbling and Compounding



- Extent of reaction (mass loss) with processing time at 300°C
- No processing (fluff) is highly variable in what product you will end up with
- Size reduction help create a more uniform degradation rate
- Compounding and size reduction create a uniformly processed product (**93% more uniform** than using no preprocessing)

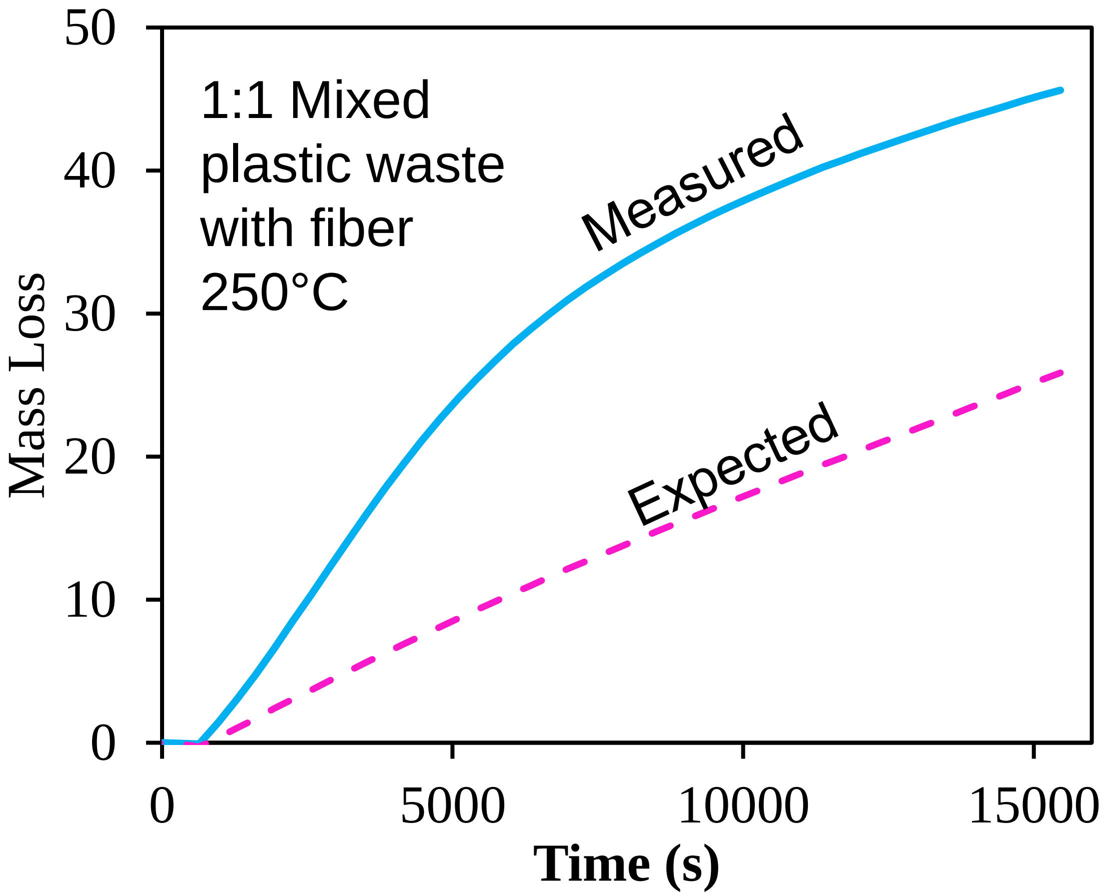
4 – Progress and Outcomes

- Size reduction alone is not enough to make a uniform material
- For the case of a torrefaction feed, compounding the material enables uniform preprocessing
- The physical and chemical intimacy of the material after preprocessing enhance degradation rate



4 – Progress and Outcomes

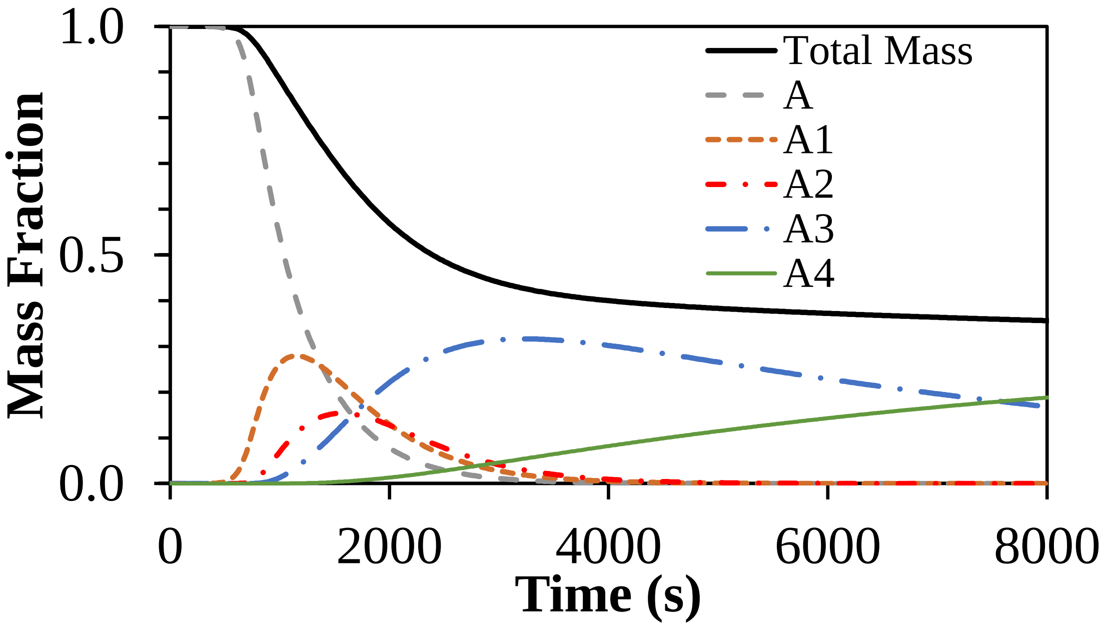
- Certain feedstock mixtures and reactor conditions exhibited decomposition synergy led to accelerated processing
- This could imply that analytically informed selection of conditions could reduce capital equipment size, increase throughput and decrease energy consumption

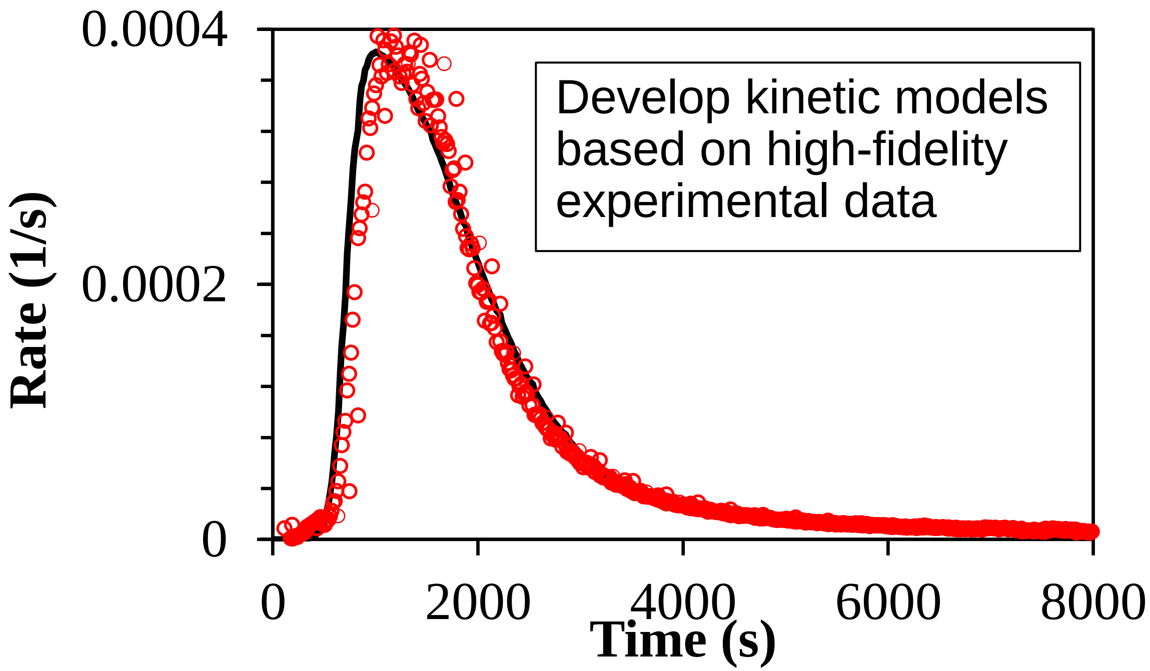


Xu, Z. et al. Bypassing Energy Barriers in Fiber-Polymer Torrefaction. Frontiers in Energy Research. Special Issue. Accepted for publication.

4 – Progress and Outcomes

- To better understand how the material attributes and processing impacts the conversion and product quality, a series mechanism was used to develop chemical kinetics

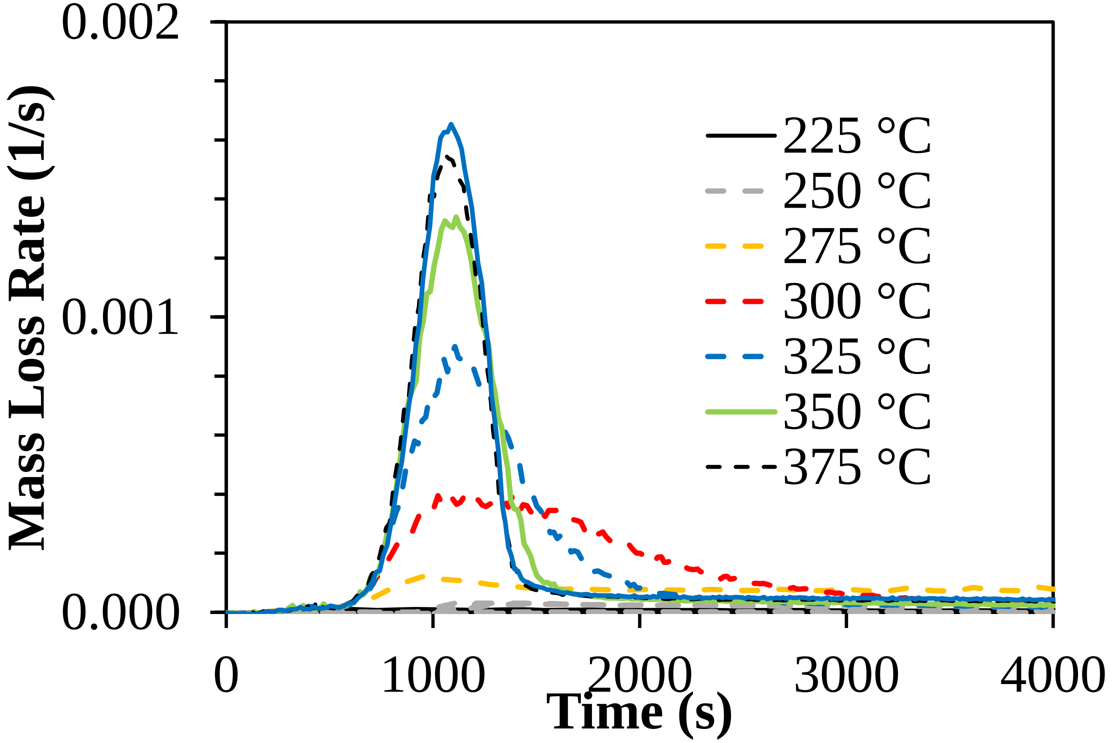


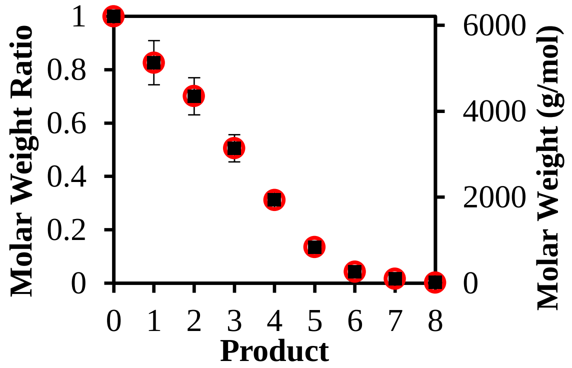


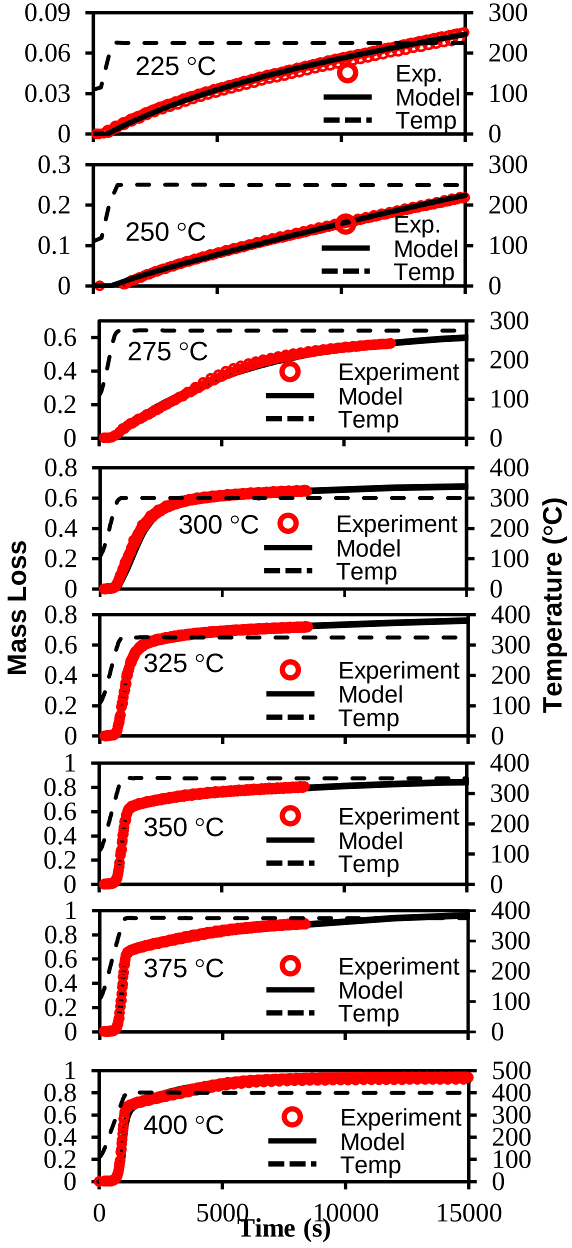
Develop kinetic models based on high-fidelity experimental data

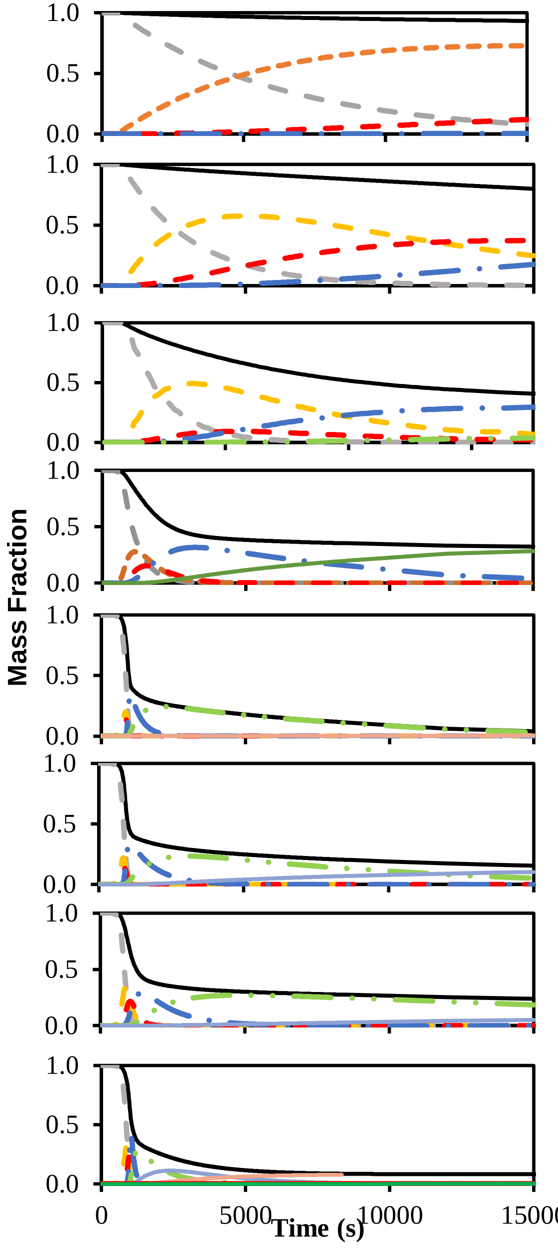
Predict quality (composition, heating value, chlorine content) based on chemical understanding

4 – Progress and Outcomes



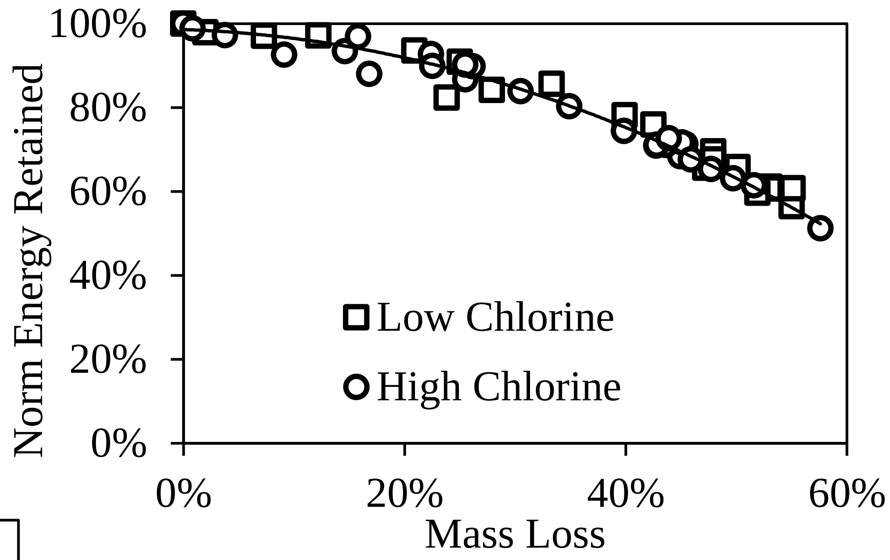


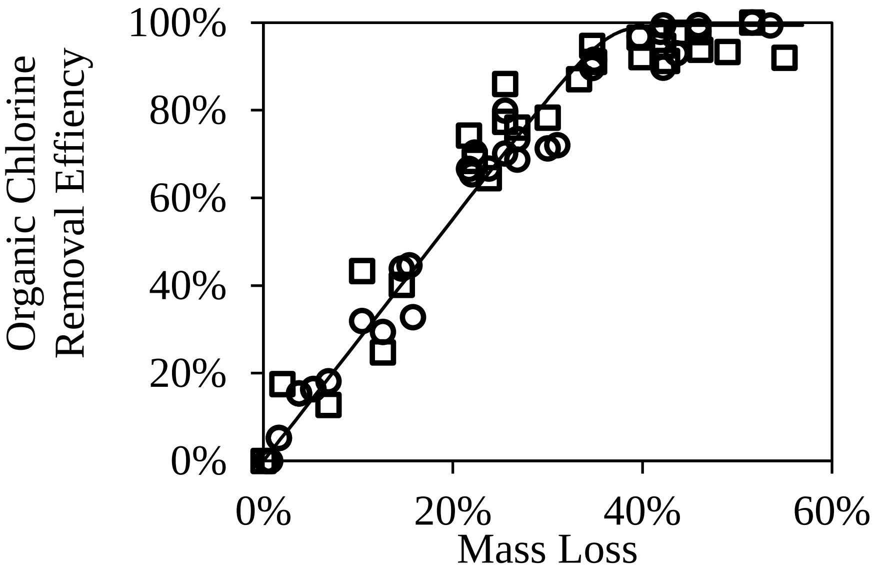


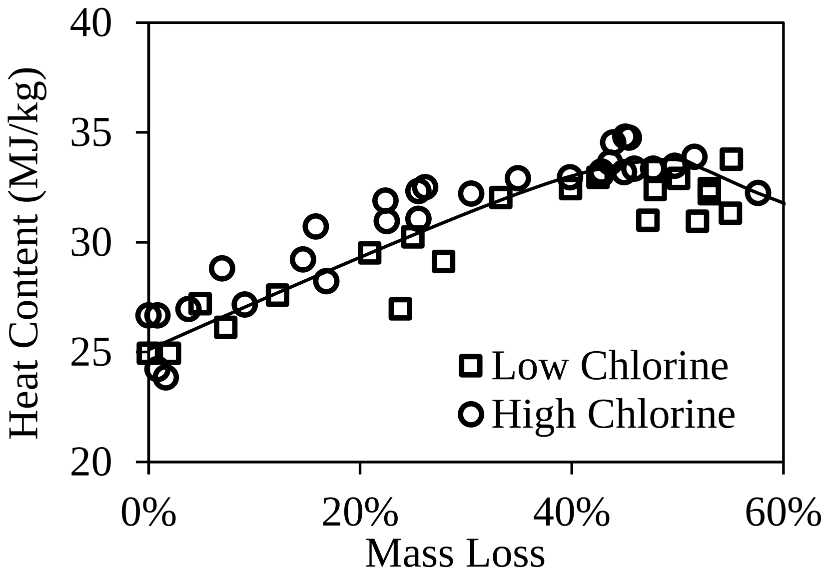


4 – Progress and Outcomes

- Demonstrated product characterization along the degradation pathway also connection material and processing conditions
  - up to 100% chlorine removal
  - energy density up to 40% higher







Xu, Zhuo, et al. "Properties of torrefied US Waste blends." *Frontiers in Energy Research* 6 (2018): 65.

Xu, Zhuo, et al. "Chlorine Removal from US Solid Waste Blends through Torrefaction." *Applied Sciences* 10.9 (2020): 3337.

Summary

Goal: "Develop innovations in the use of biomass, municipally-derived biosolids, and sorted municipal solid waste to improve the economic potential of biopower production and use in the United States."

- This work has:
  1. Shown improvements to homogeneity (>90% improvement)
  2. Discovered interaction between material components to accelerate conversion leading to reduced processing costs
  3. Developed advanced models to represent the chemical kinetics of the process to inform industrial operation, and predict product quality attributes from fundamental experiments and models
  4. Demonstrated pilot scale production and novel process configuration

- Process development and TEA in partner project has shown and technical and economically feasible way to generate a uniform feedstock and fuel from wastes

Publications and Presentations

Publications

Accepted

1. Xu, Z., Kolapkar, S. S., Zinchik, S., Bar-Ziv, E., Ewurum, L., McDonald, A. G., Klinger, J., Fillerup, E., Schaller, K., Pilgrim, C. (2021). Bypassing energy barriers in fiber-polymer torrefaction. *Frontiers in Energy Research.* Just accepted.
2. Zinchik, S., Xu, Z., Kolapkar, S. S., Bar-Ziv, E., & McDonald, A. G. (2020). Properties of pellets of torrefied US waste blends. Waste Management, 104, 130-138.

Under Review

1. Xu, Z., Kolapkar, S. S., Zinchik, S., Bar-Ziv, Klinger, J., Fillerup, E., Schaller, K., Pilgrim, C. (2021). Kinetic Study of Paper Waste Thermal Degradation. *Polymer Degradation and Stability.*

In Preparation

1. Maintaining structural properties of recycled carbon fiber composites.

Presentations

2020, BETO Waste Workshop

Advancing the Bioeconomy: From Waste to Conversion-Ready Feedstocks Workshop

1. Klinger, J. Quality by Design Case Study: Densification of Municipal Solid Wastes and Residues.
2. Bar-Ziv, E. Feedstock Preparation for MSW Valorization.
3. Hansen, T. MSW Handling and Feedstock Challenges.

Quad Chart Overview (Competitive Project)

Timeline

- Project Start: 10/1/2019
- Project End: 9/30/2021

	FY20 Costed	Total Award
DOE Funding	*$246,500*	*$495,615*
Project Cost Share	$105,643	$212,406

Project Partners

- Michigan Technological University
- Convergen Energy

Project Goal

Use preprocessing to make non-recyclable wastes clean and resemble the fuel properties of coal for use as a solid fuel

End of Project Milestone

Optimize continuous torrefaction and pelletization at >10 kg/hr scale for the same Year 1 MSW composition range to match or exceed heat content of sub-bituminous coals (24-35MJ/kg) as well as 50% reduction in sulfur and chlorine content compared to non-torrefied MSW. Determine conditions that achieve product uniformity (+/-10%) as determined by measuring the heating value and composition of 10 random samples. Developed methods will be applied to at least 1 mixed biomass feedstock.

Funding Mechanism

DE-LC-000L045

Topic Area 1: Advances in Biomass and MSW Torrefaction

Additional Slides