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WBS 1.2.1.4 Thermal Conditioning for Development of Co-products for Carbon Cycle Sequestration

DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Feedstock Technologies Panel

Project Overview

Project Lineage

- New AOP that started about 18 months ago
- Developed from a BETO Lab call that was focused on understanding MSW variability, and torrefaction as a homogenization tool (WBS 5.1.2.101)
  - Produced some initial data and samples from MSW
  - Promising characteristics in terms of waste densification and compounding (physical strength, durability, rheology) led to the proposal of this AOP topic
- That project contributed to 7 peer reviewed scientific manuscripts, and an invention disclosure that was filled as a provisional patent

Idaho National Laboratory

Michigan Technological University 1885

CONVERGEN ENERGY

University of Idaho

Project Overview

- Project Objective
  - Develop strategies to utilize materials from waste streams that do not meet the specifications for sustainable aviation fuels.
- Technical Approach
  - Evaluate the embodied carbon of wastes for near-term biogenic or fossil sources. This will inform decisions for SAF generation or sequestration in low CI co-products.
  - Apply thermal and mechanical pretreatments to waste material fractions and partially transform the wastes to enhance their formulation to functional proof-of-concept product intermediates.
  - Use TEA and LCA alongside the project to inform feasible strategies.
- Initial co-products: thermal insulation, high surface area carbon, compounded plastics for durable goods

1 – Approach

- This work contributes to BETO's goal to decarbonize energy intensive industry through production of low-carbon intensity goods, with a stretch goal of performance-advantaged bioproducts. As a step toward these goals the foundations of this work will establish a baseline set of required attributes and product pathways that can achieve the goals of GHG emissions (>50% by 2030).
- Major Tasks/Thrusts
  - Hyperspectral Carbon Characterization and Biogenic Labeling
  - Thermal and Mechanical Waste Modification
  - Coproduct Formulation and Extrusion
  - Coproduct Technoeconomic Assessment

1 – Approach

- Go/No-Go Decision: Viable co-product pathways
  - Go: **TEA from experimental and literature data conclude** that coproduct production for at least one identified **material is within 10% of the market value** of an available market alternative (**On-Track!**)
  - No-Go: Use different processing and conditioning strategies on concentrated material fractions to maximize economic potential

Name	Description	Severity	Mitigation
Expensive coproducts	Coproducts identified have prohibitively expensive process requirements compared to market alternatives	High	Consider alternative pathways or separations for various pathways
Poor performing products	Quality of feedstock materials prevents hitting quality targets for market alternatives	Medium	Consider alternative pathways or separations for various pathways
No reasonable online characterization	Existing techniques for identifying radiocarbon properties are not compatible with online characterization	Low	Couple with visual data and offline characterization for indirect biogenic analysis

1 – Approach

Collaboration and Stakeholders

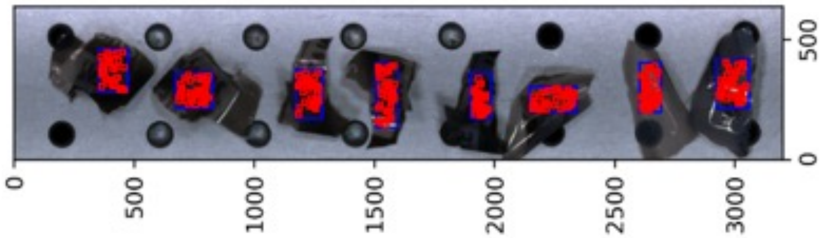
- Real wastes are being used in partnership with WBS 1.2.1.7 and Resource Recycling Systems
- Industry collaboration on targeted coproducts evaluation
  - Quarterly update meetings keep the research team engaged with industry perspective
  - Thermal insulation as a coproduct to be produced from waste streams from suppliers/processers such as Bulk Handling Systems
  - Waste characterization with IR and visual sensors in collaboration with AMP Robotics (WBS 1.2.2.1051 & WBS1.2.2.2051).
- Understanding industry perspective on SAF generation from MSW, and how coproducts fit in with GTI Energy (WBS 1.2.2.1061)
- Project works with two universities with diverse graduate student support

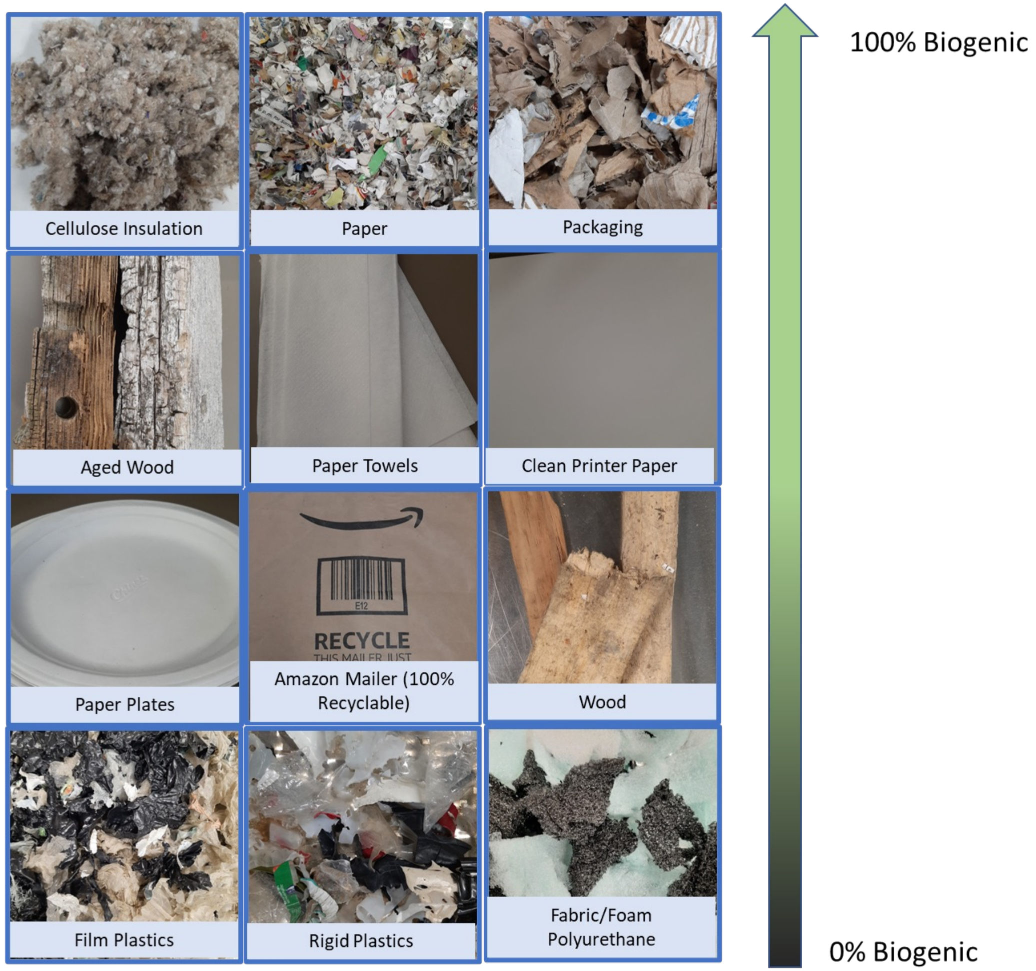
DEI Objectives

- Internship and job shadowing opportunities with underserved/rural schools
- Several schools with largest participation by local Shoshone Bannock high school (9-12 grade), serving the Fort Hall Indian Reservation

2 – Progress and Outcomes

- **Goal:** Use radiocarbon analysis to examine the relative concentration of 14C in waste components. Determine which components have at least 75% biogenic carbon
- Biogenic materials can be used toward SAF pathways
  - Inflation Reduction Act of 2022
  - SAF credit is $1.25 for each gallon of SAF
  - SAF must have ≥50% GHG reduction
  - Supplemental credit of $0.01 for each percent exceeding 50%





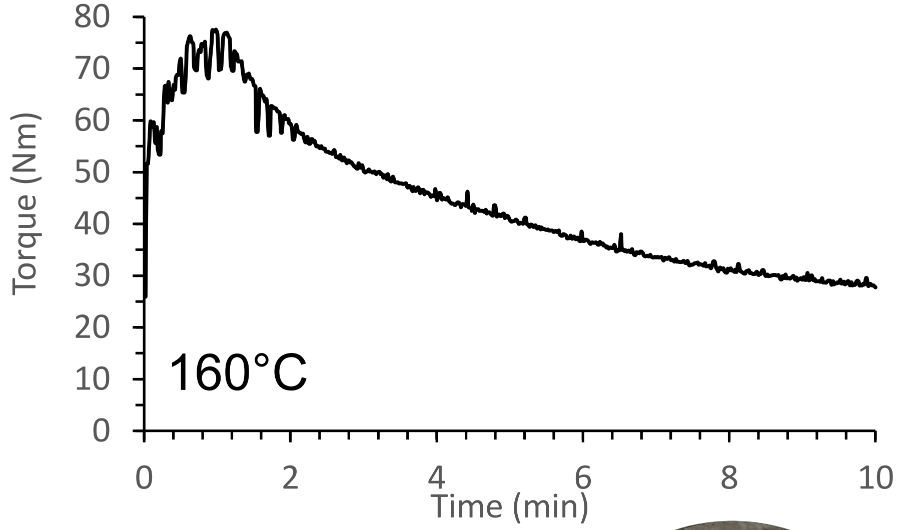
2 – Progress and Outcomes

- 14C strongly differentiated between organic (wood, paper, fiber products) and plastics, fabric, and foams
- The unsorted MSW measure suggests higher proportionate of biological carbon in MSW stream compared to fossil-based
- Nearly binary association as biological- or fossil-based carbon sources supports strategies for identification/utilization
- Complex or multi-component products could be the exception, and need further characterization (milling/separations?)

	Waste Fraction	% Total Bio Carbon
Unsorted MSW		68%
MSW Major Components	Paper	100%
	Packaging	100%
	Fabric/Foam – PU rich	1%
	Film plastics	3%
	Rigid Plastics	1%
	Wood materials	95%
	Fabric/Foam	3%
Other organic products	Cellulose Insulation	100%
	Aged wood	99%
	Amazon Mailer (100% Recyclable)	95%
	Paper Towels	98%
	Clean Printer Paper	98%
	Paper Plates	96%
Solvent-based recovery	Organic-rich after extraction	77%
	Plastic-rich after extraction	4%

2 – Progress and Outcomes

- **Goal:** Lightweight structural components from MSW
- MRF residues from WBS 1.2.1.7 size reduced to <3mm in the Forest Concepts Crumbler
- Samples were tested for compoundability, and extruded prior to injection molding
- Flexural (bending strength) modulus of 2.15±0.26 GPa
- Tensile (pull apart) strength of 8.34±0.44 MPa



MSW Pressed for Rheology

15lb 150C

Typical Flexural Strength and Flexural Modulus of Polymers

Polymer Type	Flexural Strength (MPa)	Flexural Modulus (GPa)
ABS	75	2.5
ABS + 30% Glass Fiber	120	7
Acetal Copolymer	85	2.5
Acetal Copolymer + 30% Glass Fiber	150	7.5
Acrylic	100	3
Nylon 6	85	2.3
Polyamide-Imide	175	5
Polycarbonate	90	2.3
Polyethylene, MDPE	40	0.7
Polyethylene Terephthalate (PET)	80	1
Polyimide	140	3
Polyimide + Glass Fiber	270	12
Polypropylene	40	1.5
Polystyrene	70	2.5

Injection molded micro tensile test coupon of MSW

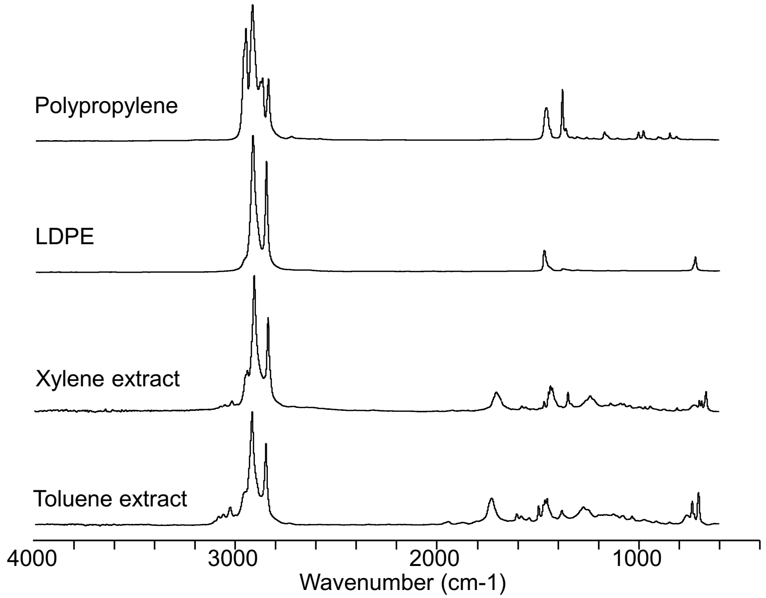
2 – Progress and Outcomes

- Solvent extracted plastic solids were extracted from the MSW to investigate the application toward composites
- Toluene and xylene extractions yielded 16 and 21% yields respectively from whole MSW
- DSC revealed two melt transitions at 125°C and 163°C were assigned to polyethylene (PE) and polypropylene (PP)

	Tensile strength (MPa) *Pull apart strength*	**Young's modulus (MPa)** *Reversable stress/strain*
Toluene extract	4.75 ±0.8	679 ±200
Xylene extract	6.20 ±1.3	590 ±120
LDPE	7.58 ±1.1	170 ±17
HDPE	19.7 ±1.2	785 ±74
PP	33.1	1325
Whole MSW	8.34±0.44	2150±0.26

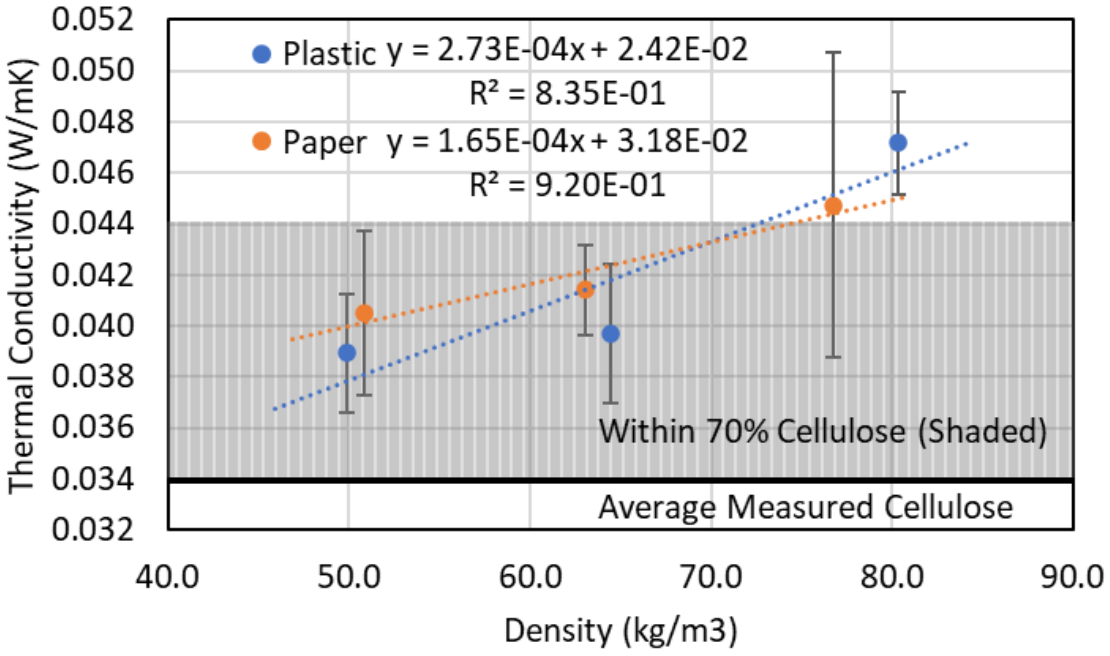
Toluene Extract

Xylene Extract



2 – Progress and Outcomes

- **Goal**: Determine if MSW components and preparations can achieve performance parity to that of traditional products
- Hypothesis: MSW can be prepared and formatted (particle sizes, consolidation ratios, or component blends) in a fashion that can achieve the thermal conductivity of commercial cellulose insulation

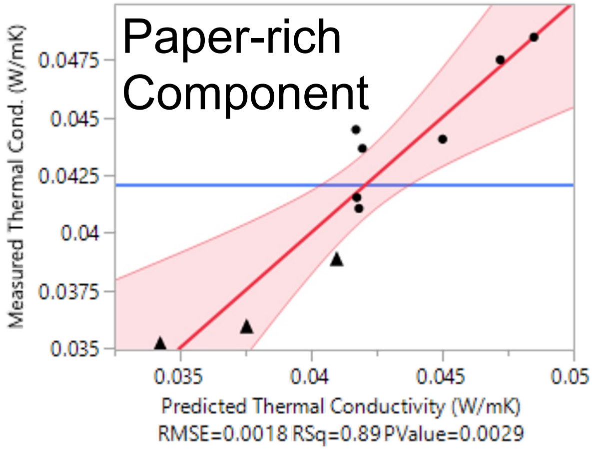


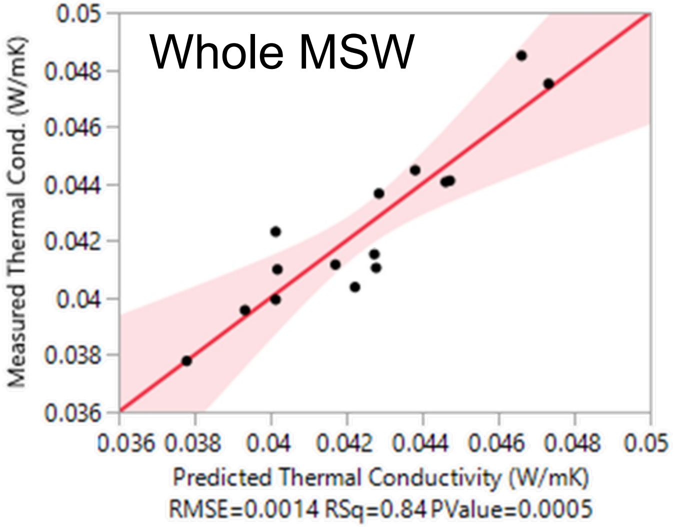
DOE Parameters:

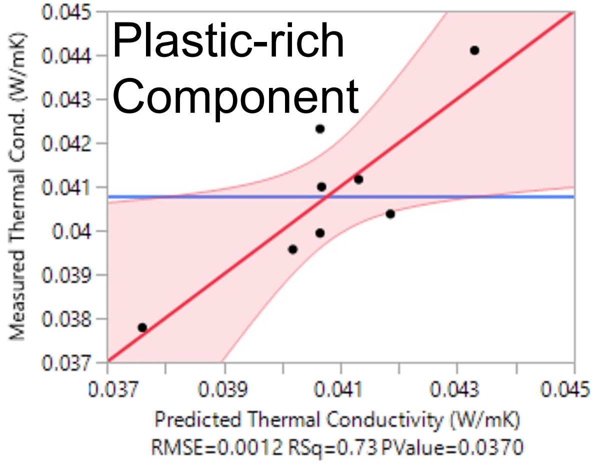
Level	1	2	3	4	5
Paper:Plastic (g/g)	1:0	0.66:0.33	0.5:0.5	0.33:0.66	0:1
Nominal Size (mm)	2	6	20		
Relative Density	1	1.15	1.3	1.45	1.60

2 – Progress and Outcomes

- These measurements were further explored with stepwise regression to hypothesize relative importance of the processing factors.
  - modest differences in thermal conductivity values between the paper and the plastic
  - blend ratio or the composition of the MSW insulation does not significantly impact the performance
  - Most significant performance predictors were the grind size of the material, the test or initial packing density of the material







2 – Progress and Outcomes

Market Research and TEA

- Target market comparison to cellulose insulation, which is produced from around 85% recycled paper material
- The building and thermal insulation market is forecast to reach $13.83 billion by 2027, with market volume for the thermal insulation is forecast to grow to 8.5 million US short tons/year
- Current cellulose insulation Initiatives like the Weatherization Assistance Program (WAP) and certifications such as the Leadership in Energy and Environmental Design (LEED) can also potentially support growth in this industry

Shredded MSW, ~2mm

2 – Progress and Outcomes

GNG Milestone - Viable co-product pathways

- Goal: Determine if the pursued coproducts identified have a pathway to market feasibility.
- Criteria: TEA from experimental and literature data conclude that coproduct production for at least one identified material is within 10% of the market value of an available market alternative.
- TEA of MSW preprocessing, with adding biological inhibitors (boric acid) and flame retardants (HBCDD, Hexabromo-cyclododecane)
- Coordinate and leverage PDU processing data with WBS 1.2.1.2

Greenfiber 25 lbs. Cellulose Blown-In Insulation or Spray Applied Insulation

Model# INSSANC

★★★★☆ (158)

$14.98 (31¢ /sq.ft.) ~~$16.97~~ Save $1.99 (12%)

$1321/tonne !!!

www.homedepot.com

	Total cost of processing MSW ($/dry tonne)		
	Energy Usage	Purchase Price	Throughput
25% below baseline	$ 53.13	$ 54.90	$ 58.24
Baseline	$ 55.28	$ 55.28	$ 55.28
25% above baseline	$ 57.43	$ 55.64	$ 52.33

(Kolapkar et al., 2022; https://doi.org/10.1016/j.fuproc.2021.107094)

Insulation	Material Cost ($/ft^2)
Cellulose	$ 0.31
Pest Control	$ 0.52
R-13 Fiberglass	$ 0.69
R-30 Fiberglass	$ 1.06
Denim	$ 1.49

3 – Impact

- Strong collaboration with other BETO programs and industry collaborators

AMP ROBOTICS RRS WBS 1.2.1.7

GTI ENERGY solutions that transform WBS 1.2.2.1061

- 3 Manuscripts currently under review for publication:
  - Advanced biorefinery feedstock from non-recyclable municipal solid waste by mechanical preprocessing (Accepted)
  - Thermal insulating behavior of municipal solid waste and its components (Under Review)
  - Performance of biomass and waste coal co-fired power generation (Under Review)
- Invention disclosure record submission at INL to document novel processing route of MSW/fractions
  - “Cryo-milling of non-recyclable municipal solid waste via co-feeding of dry ice”. IDR# 12801. Docket BA-1421.

Summary

Project Objectives

- Develop strategies to utilize materials from waste streams that do not meet the specifications for sustainable aviation fuels.

Technical Approach

- Evaluate carbon source to inform decisions for SAF or coproduct generation
- Apply thermal and mechanical pretreatments to modify waste material fractions
- Use TEA and LCA alongside the project to inform feasible strategies.

Outcome and Impact

- Generate low-CI, cost-competitive routes for wastes using materials that don’t meet specifications for SAF
- Successfully demonstrated an economic pathway for MSW use as a thermal insulation

Next Steps

- Move into lightweighting components and composites
- Investigate the LCA and societal impacts for coproduct pathways

Quad Chart Overview

Timeline
- *10/01/2021*
- *09/30/2024*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022) $600,000*	*(negotiated total federal share) $1,800,000*
Project Cost Share *		

TRL at Project Start: 3
TRL at Project End: 5

Project Goal
Develop strategies to utilize materials generated for non-recycled waste stream preprocessing that do not meet the specifications for sustainable fuels.

End of Project Milestone
Economically viable coproduct from unrecycled waste. *Match market alternatives within 90% for combined cost, energy usage, and life cycle emissions. To show feasibility toward a competitive market product, potential coproducts should be less expensive, less capital/energy intensive, and/or consider more environmentally conscious practices and life cycle impacts. This EOP milestone will demonstrate that, for at least one of the studied pathways, there are improvements in at least one of these core areas to support and justify feasibility.*

Funding Mechanism
AOP

Project Partners
- University of Idaho
- Michigan Technological University

INL

Idaho National Laboratory

Battelle Energy Alliance manages INL for the U.S. Department of Energy's Office of Nuclear Energy. INL is the nation's center for nuclear energy research and development, and also performs research in each of DOE's strategic goal areas: energy, national security, science and the environment.

Publications, Patents, Presentations, Awards, and Commercialization

- 3 Manuscripts currently under review for publication:
  - Saha, Nepu, Jordan Klinger, Md Tahmid Islam, and Toufiq Reza. "Advanced biorefinery feedstock from non-recyclable municipal solid waste by mechanical preprocessing." *Frontiers in Fuels* 1 (2023). (Accepted)
  - Thermal insulating behavior of municipal solid waste and its components (Under Review)
  - Performance of biomass and waste coal co-fired power generation (Under Review)
- Invention disclosure record submission at INL to document novel processing route of MSW/fractions
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Responses to Previous Reviewers' Comments

- 2021 Peer Review Feedback and incorporation into Approach (WBS 5.1.2.101)
  - Project should expand to non-fuel scenarios
    - This feedback align exactly with this new AOP project that is focused on non-fuel routes for waste materials
  - TEA is not an end-game exercise and should help guide research
    - Data-driven TEA was incorporated in the prior project. This AOP project had market analysis of potential products as the first milestone, technical benchmarking against commercial products throughout the program, a decision gate of product cost as the Go/No-go, and an end of project goal centered around economic and environmental assessment
  - Robust data collection for TEA
    - Technical performance and process mass and energy balances are incorporated into the project test plan to have data-driven TEA analysis