DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

High Precision Sorting, Fractionation, and Formulation of Municipal Solid Waste for Biochemical Conversion

April 4, 2023
Feedstock Technologies

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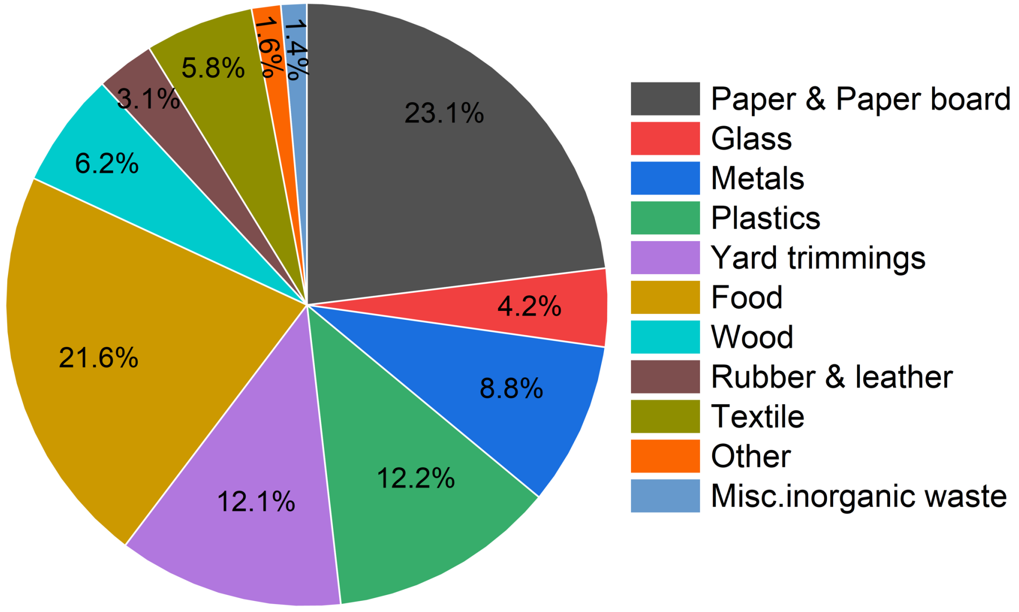
Project Overview

- Total annual MSW generation in the U.S. has increased by 93% since 1980, to 292 million tons/year in 2018

- 50% of the generated MSW was disposed of in 1,278 landfills

- Landfills were the third largest source of U.S. anthropogenic CH_4 emissions in 2020

- MSW represents a valuable source of low-cost feedstock for the development of biofuels and bioproducts



Total US MSW generation by category in 2018

- Heterogeneity and variability of MSW components are major bottlenecks for MSW use as bioenergy feedstocks

- Sorting and removing plastics produces a high-purity organic stream for MSW use as conversion-ready feedstocks

https://www.epa.gov/

Project Overview

- **Goal:** Develop an advanced sorting and fractionation technology that can separate the organic fraction waste from municipal solid waste (MSW) to achieve 95% purity, and to blend and formulate the sorted organic waste (95% purity) with lignocellulosic biomass for biochemical conversion.

- **Objectives:**

1. **Design and test** 1st stage pre-screening devices to separate 95% of ferrous metals and 80% of plastics from MSW (by magnetic separator and dynamic disc screen);

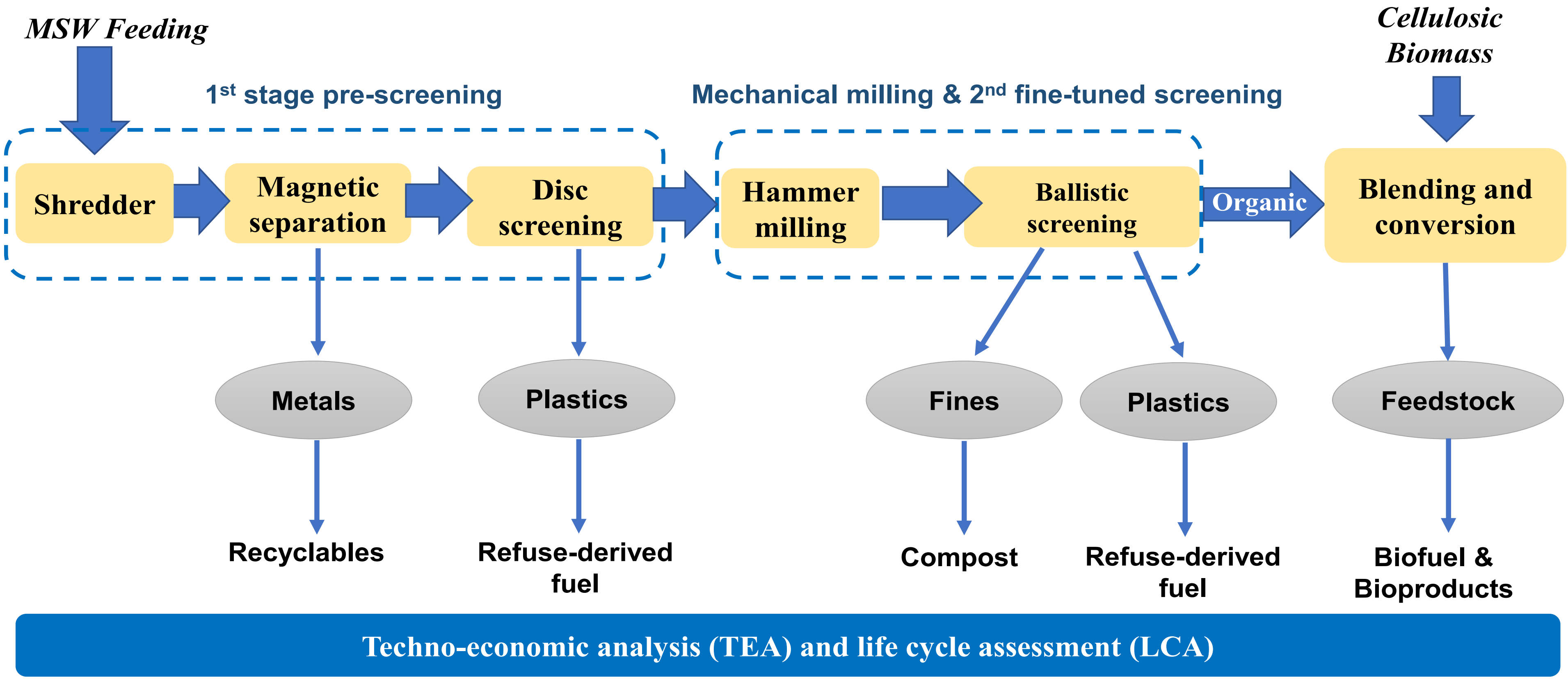
2. **Conduct** mechanical milling (<50 mm) and evaluate 2nd stage screening devices (>4 mm) to obtain uniform feedstocks;

3. **Blend and formulate** screened organic fraction MSW (OFMSW) with lignocellulosic biomass for conversion testing;

4. **Conduct** techno-economic analysis (TEA) and life cycle assessment (LCA) of the proposed sorting and fractionation process.

Awarded through FY20 BETO FOA subtopic 2a: Advanced fractionation and decontamination of MSW for improved conversion efficiency

1 – Approach



- Integration of dynamic disc screening, mechanical milling and ballistic screening to address the feedstock variability issue and effectively separate the organic fraction from MSW;
- Blending sorted organic waste from MSW with cellulosic biomass to reduce the variability of MSW for biochemical conversion

1 – Approach

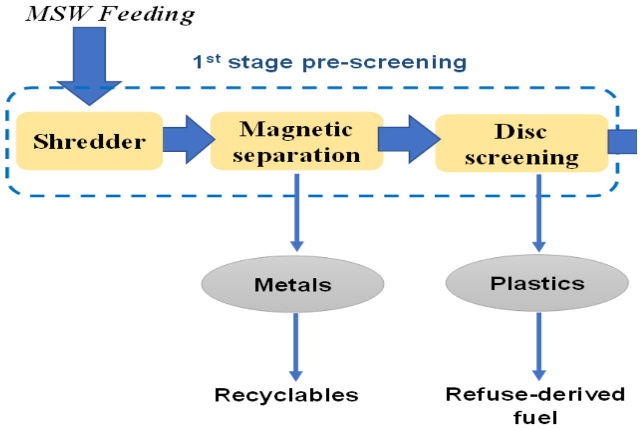
Design and test 1st stage pre-screening devices to separate 95% of ferrous metals and 80% of plastics from MSW (by magnetic separator and dynamic disc screen)

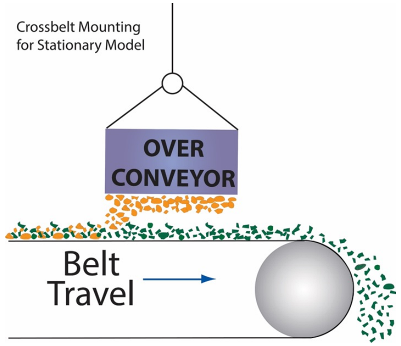
Challenges:

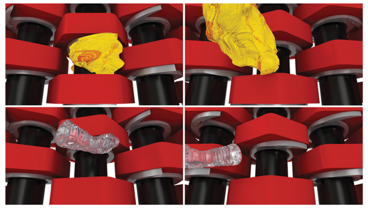
- *Shredder may break glass and complicate the later disc screening*
- *Disc screening is based on the size of items and not all plastics can be separated.*

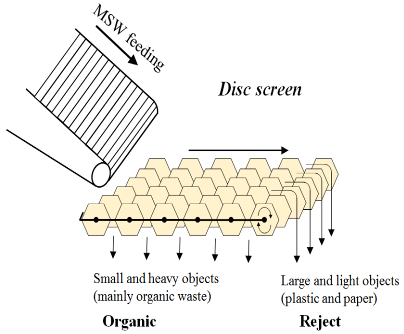
Technical approaches:

- *Magnetic separator to recover ferrous metals*
- *Dynamic disc screen to remove plastics from MSW*









1 – Approach

Mechanical milling and fine-tuned screening

Challenges:

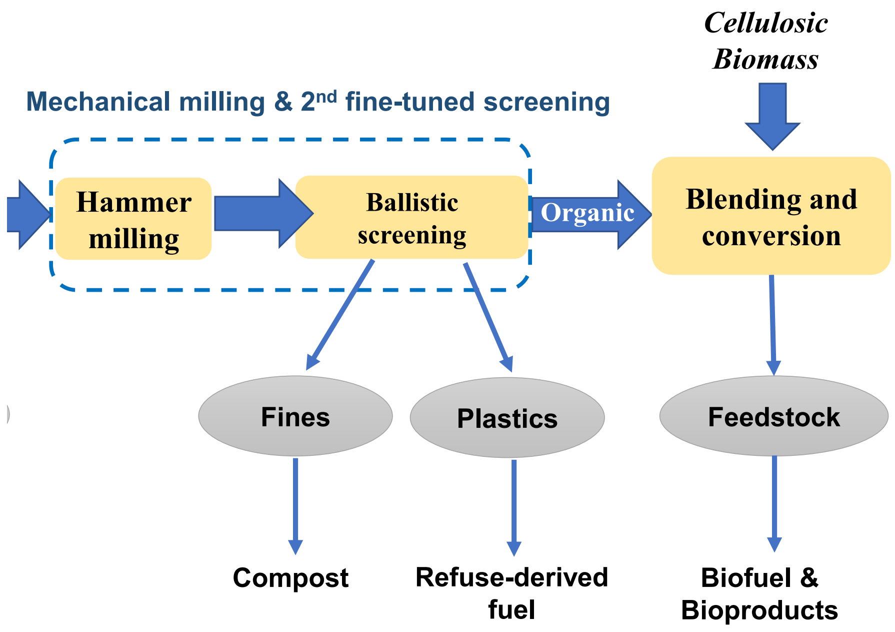
- *Moisture content (MC) is not uniform in MSW, hard to determine the effect of MC on milling process*

Technical approaches:

- *Conduct size reduction and fractionation of MSW by using mechanical milling and ballistic screening*
- *Identification of process parameters for mechanical milling and ballistic screening*

Go/No-Go Decision Point 2:

- Achieve a >90% purity of sorted organic stream & 40-50% recovery rate through initial optimization of sorting and fractionation processes



Ballistic Separator https://stadler-engineering.com/

1 – Approach

Blending and formulation of OFMSW with biomass

Challenges:

- The low carbohydrate content in OFMSW could result in low sugar yield in blended feedstock

Technical approaches:

- Prepare binary blends of OFMSW and corn stover (or aspen chips) by weighing the amount of each respective feedstock to achieve the designed weight ratio
- Palletization to increase bulk density and stability of blended biomass
- Characterization of blended OFMSW-Biomass

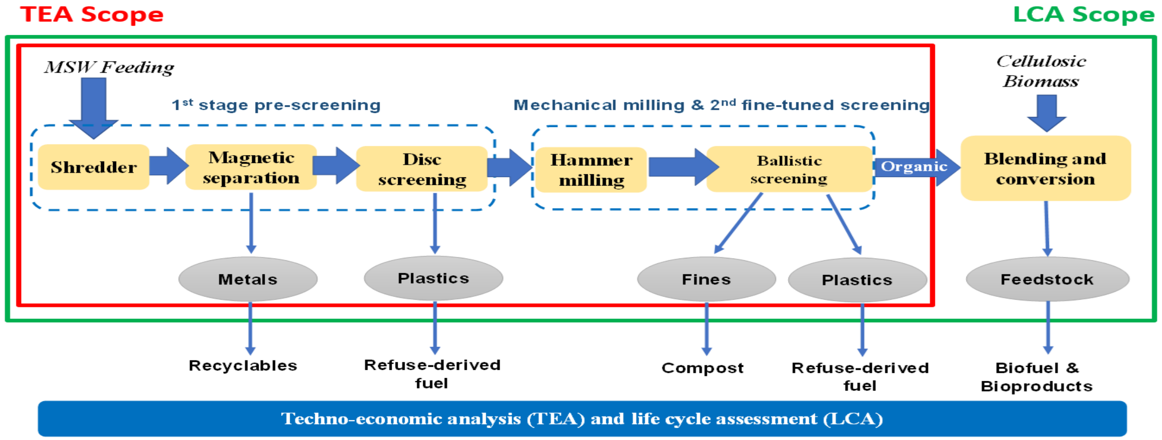
TEA and LCA on the proposed process

Challenges:

- TEA boundaries are difficult to define
- Energy consumption in the process hard to calculate

Technical approaches:

- Evaluate the technical and economic feasibility of the proposed novel MSW sorting, fractionation & blending pathway
- Tradeoffs between utilization of OFMSW feedstocks for biofuels & bioproducts vs. existing practices for MSW disposal and landfill



1 – Approach

Project management

Project team:

- University of Cincinnati (Maobing Tu, Drew McAvoy, Janet Dong, Akashdeep Singh Oberoi)
- Idaho National Laboratory (Ling Ding, Yingqian Lin)
- Tuskegee University (Marceline Egnin, Osa Idehen)
- Industrial collaborators (Terri Ward, Michael Drolet)

Project organization and management:

- Monthly meetings via Zoom or Teams
- Annual meeting at UC and INL, respectively
- Project files uploading to a cloud-based file share (box.com) for storage and use by the project team
- Quarterly reporting of progress to DOE, assessment of project management plan & key milestones

Diversity, Equity and Inclusion

Enhance diversity and inclusion via collaborating with faculty and students from HBCU

Recruit and engage minority students to pursue research in the thematic areas of the project

- Students will participate and will be trained in sample analyses and other characterization of MSW, OFMSW, and OFMSW-Biomass as well as biochemical conversion
- Each summer, students from TU will visit UC and/or INL and participate in the project and for training in the project tasks.

2 – Progress and Outcomes

Initial verification of MSW sorting by vibratory screening

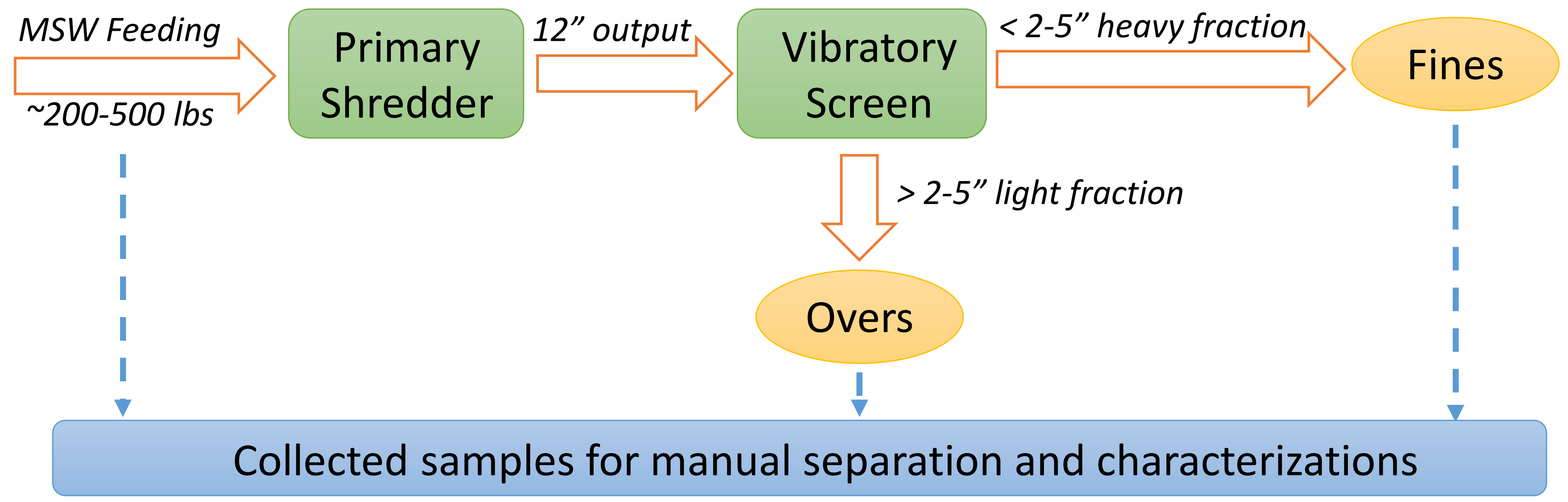
- Establish the baseline of traditional screen
- Organic fraction of sorted MSW (fines) with a purity of 50-70%
- Contamination reduction percentage (plastic removal) reached ~50%.

Green Separation System with Vibratory Screen in Cartersville, GA

2 – Progress and Outcomes

Initial verification of MSW sorting by vibratory screening

- *Milestone 1.1 :* Verification of MSW sorting using vibratory screen and trommel screen.



Vibratory screening of MSW in test experiment

2 – Progress and Outcomes

Non-recyclable MSW

Primary shredder

Feeding system

Vibratory screen

2 – Progress and Outcomes-vibratory screening

MSW feeding material composition was analyzed: 30.79% OFMSW

MSW composition and purity after vibratory screening: 42.93% OFMWS

Batch 1-1 Feeding	Wet Weight Samples (lbs)	Moisture Content (%)	Dry Weight (lbs)	% each category (Dry Weight)	OFMSW (%, Dry Weight)	Average OFMSW (%, Dry weight)
Food wastes	0.6414	36.85	0.4050	6.83	34.41%	30.79±5.12%
Gardening wastes	0.0000	0.00	0.0000	0.00		
Paper	3.0865	46.95	1.6373	27.59		
Plastics	1.5543	26.10	1.1487	19.36		
Metals	0.5868	10.23	0.5268	8.88		
Textiles	0.9649	26.76	0.7067	11.91		
Glass	0.9535	1.01	0.9439	15.90		
Others	0.9800	42.21	0.5663	9.54		
Total	***8.7674***	***32.31***	***5.9347***	***100.00***		
Batch 1-2 Feeding						
Food wastes	1.2859	56.74	0.5563	10.77	27.17%	
Gardening wastes	0.0000	0.00	0.0000	0.00		
Paper	2.0334	58.32	0.8476	16.40		
Plastics	1.7052	29.12	1.2086	23.39		
Metals	0.5658	10.55	0.5061	9.79		
Textiles	0.2922	28.05	0.2102	4.07		
Glass	0.9084	1.20	0.8975	17.37		
Others	1.5918	40.88	0.9411	18.21		
Total	***8.3827***	***38.36***	***5.1674***	***100.00***		

Batch 1-1 Fines	Wet weight samples (lbs)	Moisture content (%)	Dry weight (lbs)	% each category (Dry weight)	OFMSW (%, Dry weight)	Average purity (%, Dry weight)
Food wastes	1.0706	35.34	0.6923	16.22	36.03%	42.93±9.75%
Gardening wastes	0.1686	34.22	0.1109	2.60		
Paper	1.7995	59.15	0.7351	17.22		
Plastics	0.5213	16.89	0.4332	10.15		
Metals	0.4503	6.24	0.4222	9.89		
Textiles	0.1087	46.15	0.0585	1.37		
Glass	1.8440	1.47	1.8169	42.56		
Others	0.0000	0.00	0.0000	0.00		
Total	***5.9630***	***28.41%***	***4.2692***	***100.00%***		
Batch 1-2 Fines						
Food wastes	1.0062	33.62	0.6679	17.97	49.82%	
Gardening wastes	0.0984	34.70	0.0643	1.73		
Paper	2.7117	58.71	1.1197	30.13		
Plastics	0.7387	19.77	0.5926	15.94		
Metals	0.2907	5.69	0.2742	7.38		
Textiles	0.3654	47.29	0.1926	5.18		
Glass	0.8277	2.68	0.8055	21.67		
Others	0.0000	0.00	0.0000	0.00		
Total	***6.0388***	***38.45***	***3.7167***	***100.00***		

- OFMSW is enriched in the fines fraction over the feed
- Plastics are preferentially removed in the overs fraction

2 – Progress and Outcomes-vibratory screening

MSW purity and denomination efficiency after vibratory screening

- The organic fraction purity was 50%-70% after vibratory screening.

Go/No-Go Decision Point 1:

- Verify the baseline values for the obtained organic fraction with a purity of 50-70% and decontamination efficiency of 50% (contamination reduction percentage)

Trommel screening

- High purity and decontamination efficiency, but low recovery rate
- Recovery rate bearing on the economic viability

Organic fraction of MSW - Purity and Decontamination

	Purity (%, OFMSW, dry basis)	Purity (%, OFMSW, wet basis)	Decontamination efficiency (%, plastic removal, dry basis)	OFMSW recovery (% dry basis)	Reduction of Variability of OFMSW (dry basis)
Batch 1	42.93±9.75	57.08±8.65	77.38±3.31	55.79±22.26	
Batch 2	49.06±2.53	61.06±1.92	89.67±2.97	61.34±17.05	64.98%
Batch 3	44.85±1.91	60.24±2.88	70.45±26.88	72.24±69.54	

$$Purity_{fines} = \frac{w_{organic\ fraction\ in\ fines}}{w_{fines}} \times 100\%$$

$$\eta = 1 - \frac{w_{plastics\ in\ fines}}{w_{plastics\ in\ feeding}}$$

Trommel Screening

	Purity (%, OFMSW)	Decontamination efficiency (%, plastic removal)	Decontamination efficiency (%, Inorganic removal)	Recovery (OFMSW in the Fines /Total OFMSW)
Wet basis	76.73%	93.44%	93.13%	16.94%
Dry basis	70.48%	87.82%	87.82%	12.18%

2 – Progress and Outcomes

Target Performance Metrics

Go/No-go & FOA metric baseline	Units	¾" Trommel Screen	2-5" Vibratory Screen	BP-1 GNG	Project Final target	FOA Metric
Feedstock		Non-recycled "black bag" MSW			Blended	
Stream purity, % biogenic organic in fines	wt.% db	70%	46%	50-70%	>95%	>95%
Decontamination efficiency, % plastics removal	wt.% db	87%	79%	>50%	>80%	>80%
Decontamination efficiency, % non-convertible removal	wt.% db	87%	69%	>50%	>80%	>80%
Reduction in variability of OFMSW	%	NA	65%	NA	>60%	>50%
Added cost of technology over $86/ton baseline	$/ton	NA	NA	NA	<$30	<$30
OFMSW recovery rate	wt.% db	12%	63%	NA	TBD	NA

BP-1 Go/No-Go has been met and key milestone regarding evaluation of the traditional sorting process has been completed

2 – Progress and Outcomes-disc screen

Pre-screening equipment procurement, installation and initial test

- This subtask is to complete the procurement, installation, commissioning, and start-up of dynamic dis screen and conveyor.
- Ecostar disc screen has been ordered and shipped from Italy

Ecostar HEXACT 5000

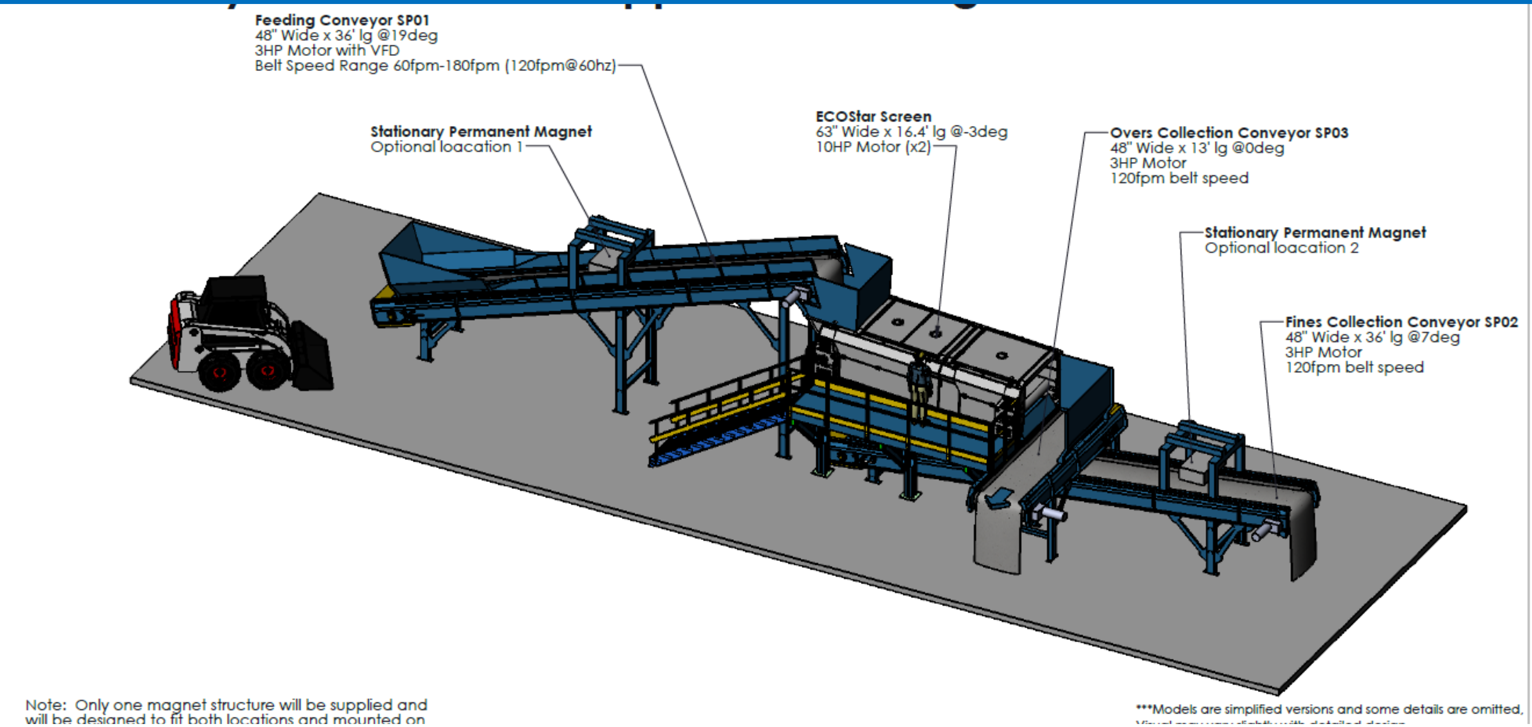
2 – Progress and Outcomes-disc screen

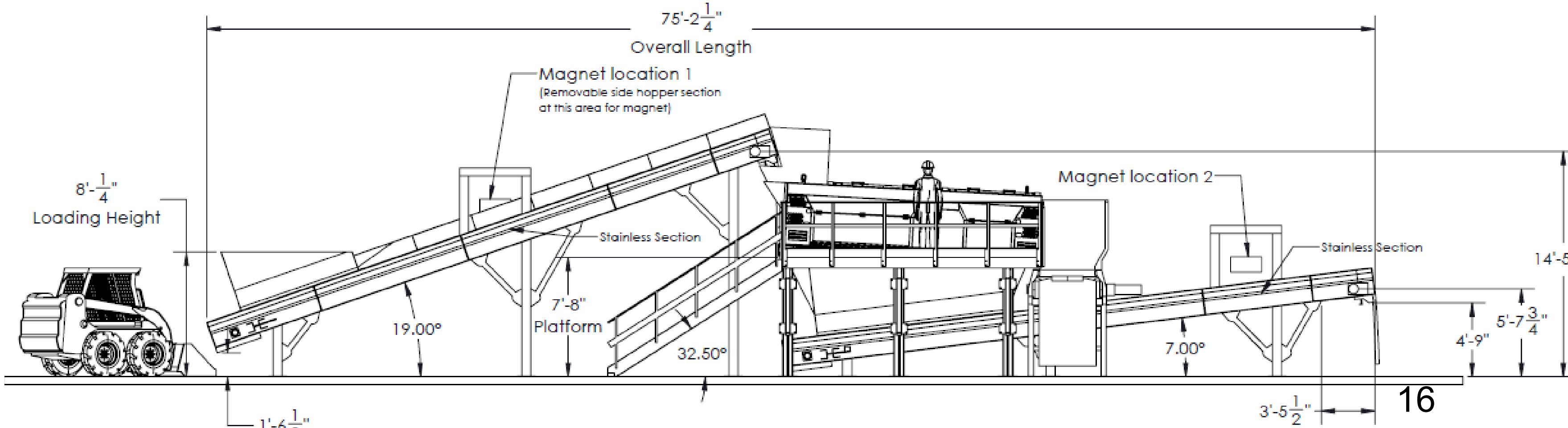
Pre-screening equipment procurement, installation and initial test

- Coordinating with the UC planning, design, construction & electrical team for site preparation & equipment installation
- Conveyor system - finished layout drawings
- Standard operating procedures developed for manual sorting of MSW

The equipment will be placed on the **concrete slab** (81´x 30´)

Site preparation for equipment installation is currently on-going





Schematic layout of the MSW screening plant with the Ecostar DDS and conveyor belt system

3 – Impact

Scientific

- Develop better MSW sorting and fractionation technology with Dynamic Disc Screen and Ballistic Screen
- Reduce heterogeneity and variability in MSW for biofuels and bioproducts
- Produce high-purity of organic feedstock from MSW

Industrial

- Produce conversion-ready feedstocks in support of the BETO waste-to-energy development
- Reduce the landfilling of MSW and environmental issues including GHG emissions
- Impact MSW management and waste-to-energy industries

Publication targets and development of workforce

- Disseminate through peer-reviewed publications, patents and presentations
- Generate Patents on MSW sorting technologies, sorting equipment & low-cost conversion-ready feedstock development
- Serve as platform to train minority & graduate students & postdoctoral researchers and develop young professionals to work in the area of waste-to-energy

Summary

Approach

- Integration of dynamic disc screening, mechanical milling and ballistic screening
- Blending of the sorted OFMSW with cellulosic biomass to reduce MSW variability
- TEA and LCA to evaluate the technical & economic feasibility of MSW sorting, fractionation & blending pathways

Progress & Outcomes

- Performance of conventional vibratory & trommel screen to handle heterogenous MSW has been evaluated
- Procurement & Installation of the DDS and conveyor belt system at the project site

Potential Impacts

- High purity (>95%) organic fraction of MSW for biochemical conversions
- Address MSW heterogeneity & variability issues
- Waste management & waste-to-energy industries – new sorting and milling technology

Quad Chart Overview

Timeline
- *Project start date: 10/01/2020*
- *Project end date: 03/31/2025*

	FY22 Costed	Total Award
DOE Funding	*$123,071*	*$2,479,040*
Project Cost Share *	*$96,392*	*$676,603*

TRL at Project Start: TRL - 2
TRL at Project End: TRL - 4

Project Goal
Develop an advanced sorting and fractionation technology to separate the organic fraction waste from MSW and to blend and formulate organic waste (>95% purity) with lignocellulosic biomass for biochemical conversion.

End of Project Milestone
- Demonstrate novel sorting and fractionation process that can obtain high purity (>95%) organic fraction from MSW as feedstock for bioconversion
- Reduce feedstock variability for an end use by 60% compared to the baseline value
- Produce conversion ready feedstock at a cost of <$ 30/dry ton that will meet the BETO cost target of $ 73/dry ton

Funding Mechanism
DE-FOA-0002203 Bioenergy Technologies Multi-Topic (2020), Topic Area 2: Waste to Energy Strategies for the Bioeconomy.

Project Partners*
- Idaho National Laboratory
- Tuskegee University

Additional Slides

Responses to Previous Reviewers’ Comments

- If your project has been peer reviewed previously, address 1-3 significant questions/criticisms from the previous reviewers’ comments which you have since addressed
- Also provide highlights from any Go/No-Go Reviews

Publications, Patents, Presentations, Awards, and Commercialization

Presentations

- **M. Tu** and Y. Zhang (2022) Effects of Vibrating screen sorting on chemical composition and calorific value of organic fraction of MSW. IBE 2022 Annual conference, April 7-9, 2022, Athens, Georgia.

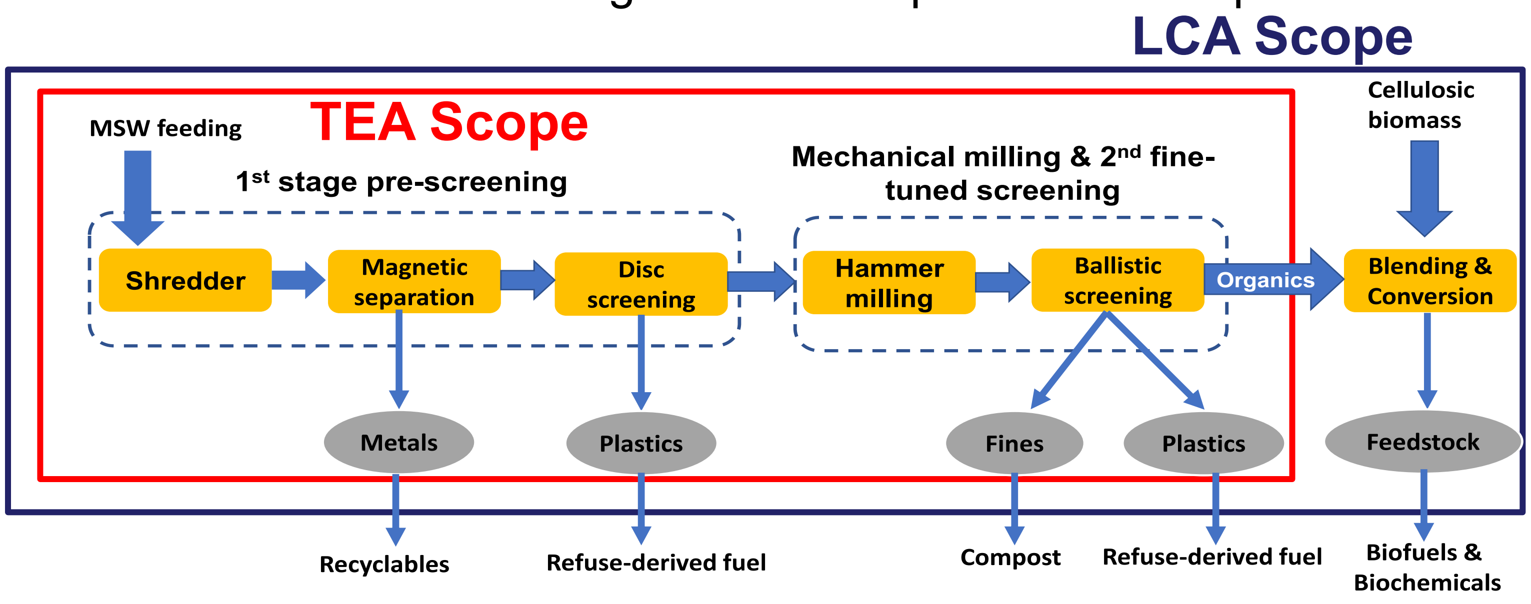
1 – Approach

Model Development for Initial TEA and LCA Analysis

- Develop a model framework for the TEA/LCA analysis;
- Collect parameter values and define key assumptions for the initial TEA/LCA;
- Conduct a sensitivity analysis to identify which factors cause the greatest effect on system cost, energy use, and environmental impacts.

Key Milestone: Complete an initial TEA/LCA that quantifies total cost, energy use, and GHG emissions for the proposed system.

This information will be used to guide the unit process development efforts



System feed rate/throughput: 2.25 wet tons/hr
(Moisture content is about 30%~40%, equivalent to **1.35 to 1.58 dry tons/hr)**

Techno-economic analysis (TEA) and Life-cycle assessment (LCA)

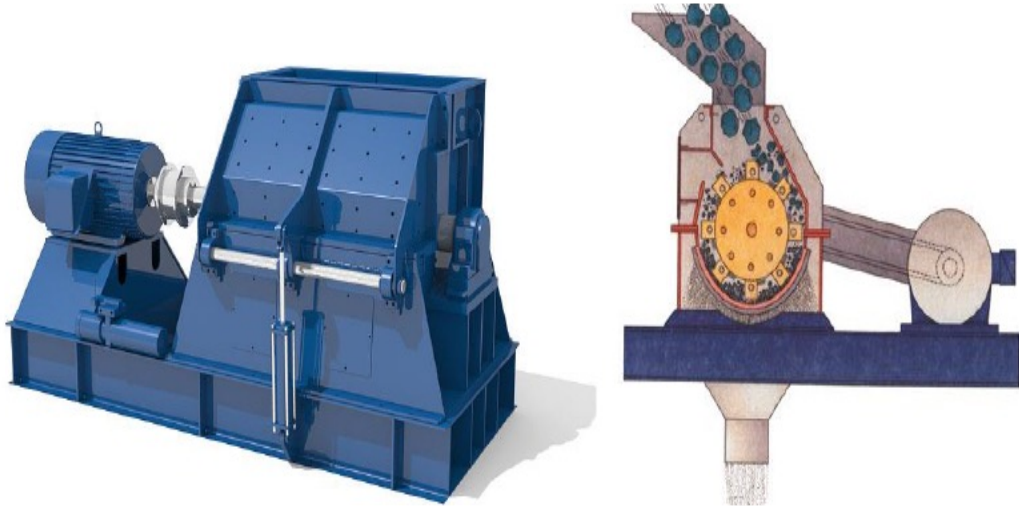
1 – Approach

Task 3.0 Mechanical Milling and Fine-tuned Screening

- Size reduction and fractionation of MSW
- Mechanical milling, ballistic screening/air classifier
- Rapid analytical tool for process integration and high precision quality management

Key deliverables:

- Identification of process parameters for mechanical milling
- Shearing force & compression impact analysis on size reduction & separation
- Impact of MSW moisture content on mechanical milling
- Impact of throughput, shaft speed and grate spacing on mechanical milling
- Fine-tuned screening of milled OFMSW using ballistic screen
- Analysis of impact of vibration speed & MSW moisture content on ballistic screen
- Real-time measurement and control of MSW screening and milling processes PAT-NIR



Bliss Eliminator E-4424-TF hammer mill (Ponca City, OK, USA)

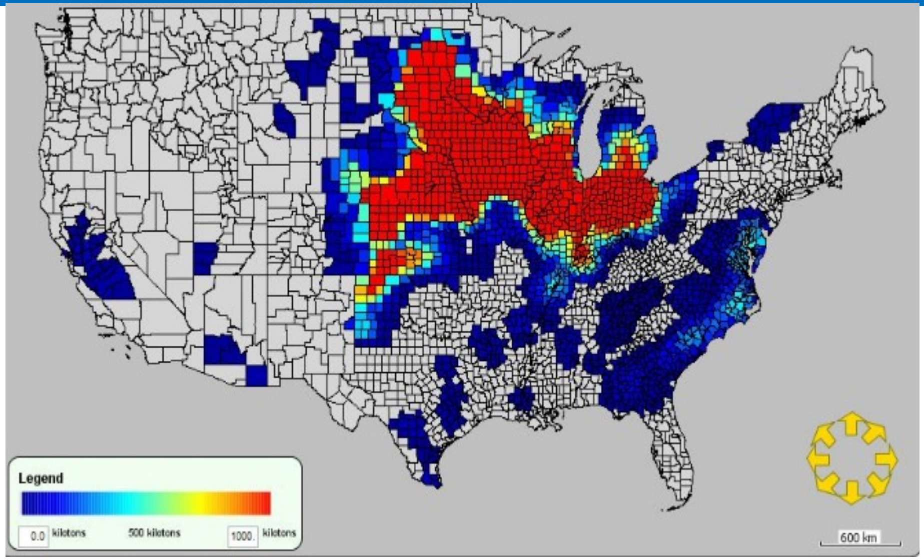
<u>Go/No-Go Decision Point 2</u>: Achieve a >90% purity of sorted organic stream & 40-50% recovery rate through initial optimization of sorting and fractionation processes

Task 4.0 Blending and Conversion

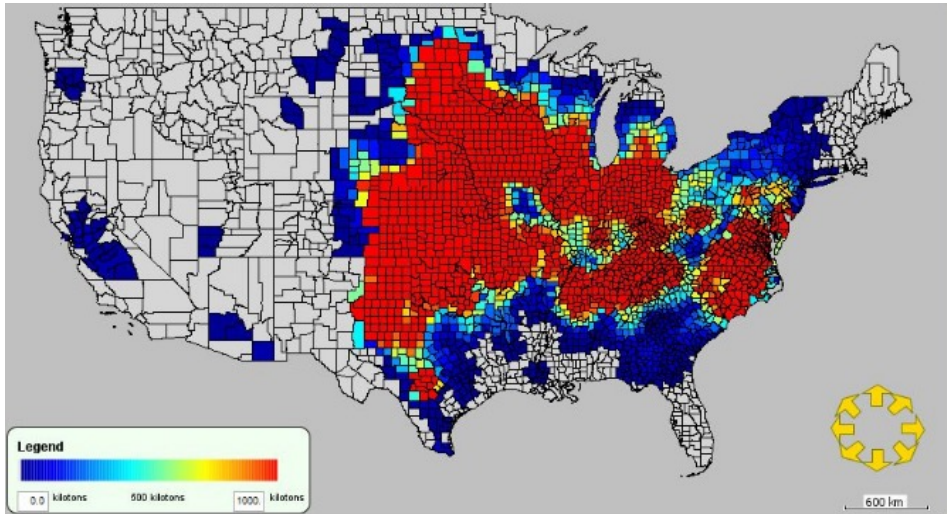
WHY BLEND???

- Diversifies biomass supply to reduce cost and risk to the supply chain
- Bridges seasonal gaps in availability
- Incorporates low-cost, low-quality biomass resources to reduce cost
- Overcomes biomass variability challenges related to feedstock handling and conversion performance

A successful blending strategy has to meet cost, volume, and performance targets AND be relevant to industry. This project is focused on performance.



Projected corn stover density in 2030, available for $50/DMT and 50-mile harvest radius.



Projected density for corn stover and perennial grass **blend** in 2030, available for $50/DMT and 50-mile harvest radius.

Task 4.0 Blending and Conversion

Task Summary:

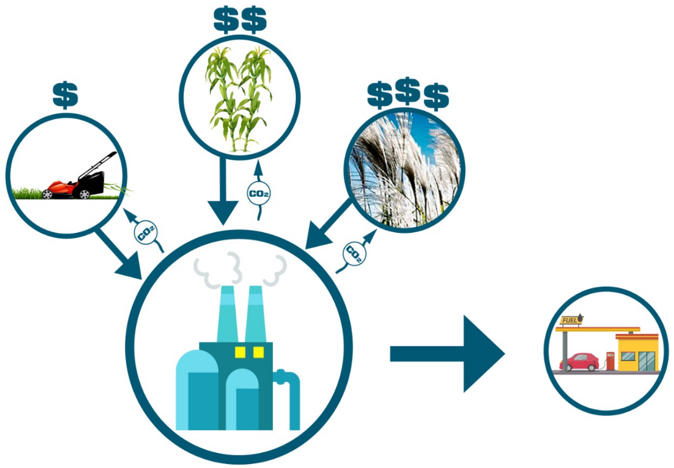
- Blend and formulate the sorted OFMSW with cellulosic biomass (e.g., corn stover, aspen chips, switch grass)
- Reduce the cost of conversion-ready feedstock.
- Determine the feasibility and performance of blending and formulation of the sorted OFMSW with cellulosic biomass

Key objectives/deliverables:

- Generation of blending feedstock from OFMWS and biomass
- Analysis of the effects of blending on quality and conversion performance

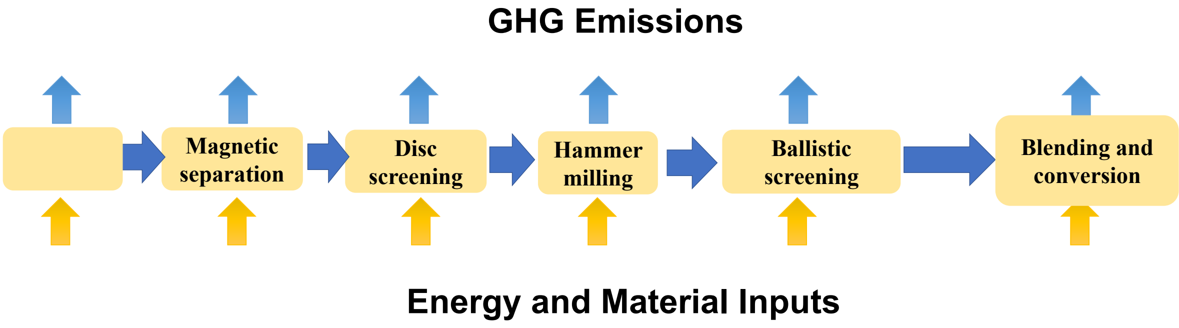
blended OFMSW-biomass feedstocks to achieve low variability in chemical composition (specify CMAs such as glucan content, biomass size, moisture content, and lignin content)

- Achieving >90% hydrolysis yield for blended OFMSW-biomass



Task 5.0 TEA and LCA on the proposed process

- Evaluate the technical and economic feasibility of the proposed novel MSW sorting, fractionation & blending pathway
- Tradeoffs between utilization of OFMSW feedstocks for biofuels & bioproducts vs. existing practices for MSW disposal and landfill



Life Cycle Inventory (LCI)

openLCA
@openLCA

2 – Progress and Outcomes

Trommel Screen for MSW Sorting

Trommel screen with 3/4” screen

2 – Progress and Outcomes

MSW Chemical Composition

- Proximate – (Fixed C, Ash, moisture, and volatiles) – ASTM D3172
- Volatile matter – ASTM D3175
- C, H, N, (and S &O) – using CHNSO elemental analyzer – ASTM 5373
- Protein - Protein Col/Fluo Assay Kit from Sigma-Aldrich/ ASTM D5712
- Starch - Colorimetric/Fluorometric Assay Kit from Sigma-Aldrich
- Fats – Extraction by using petroleum ether/ ASTM D6584

OFMSW powder sample	C content (%)	N content (%)	H content (%)	S content (%)	High heating value (kJ/g)	Ash content (%)
Batch 1 Feeding	45.84±1.07	1.20±0.12	6.47±0.02	0.11±0.01	16.82±0.63	4.60±1.78
Batch 1 Overs	37.18±0.39	0.79±0.08	4.99±0.11	0.96±0.13	13.95±0.74	4.42±0.79
Batch 1 Fines	30.33±4.75	0.86±0.08	4.08±0.71	0.78±0.08	11.35±1.36	8.07±3.01
Batch 2 Feeding	46.62±1.56	2.22±1.82	6.65±0.18	0.16±0.16	16.73±0.24	4.86±1.10
Batch 2 Overs	40.49±1.34	0.51±0.06	5.38±0.38	0.16±0.06	14.77±1.11	5.06±0.66
Batch 2 Fines	22.81±6.68	0.78±0.06	3.02±0.88	1.10±0.26	8.73±2.35	23.14±13.78
Batch 3 Feeding	41.77±7.57	0.78±0.20	5.74±1.24	0.10±0.01	15.44±2.87	3.36±0.69
Batch 3 Overs	43.09±0.11	0.72±0.17	5.95±0.09	0.12±0.01	15.92±0.15	3.81±0.38
Batch 3 Fines	40.72±0.21	1.27±0.19	5.49±0.16	0.24±0.04	15.37±0.36	5.00±2.08

OFMSW powder sample	Total carbohydrate content (%)	Protein content (%)	Crude fat content (%)	Starch content (%)
Batch 1 Feeding	71.60±8.21	7.47±0.75	20.22±3.53	11.73±4.63
Batch 1 Overs	53.14±2.82	4.94±0.53	16.60±1.76	2.54±1.26
Batch 1 Fines	**41.88±7.96**	5.38±0.53	14.85±4.05	1.70±0.00
Batch 2 Feeding	65.29±3.26	13.88±11.40	5.24±2.14	8.66±7.76
Batch 2 Overs	62.68±0.56	3.16±0.40	5.79±0.35	1.12±0.27
Batch 2 Fines	**26.24±9.06**	4.84±0.40	6.07±0.56	2.67±0.25
Batch 3 Feeding	65.66±1.43	4.88±1.24	13.00±2.32	4.68±1.16
Batch 3 Overs	63.61±2.14	4.50±1.06	16.55±3.89	4.03±3.63
Batch 3 Fines	**55.04±3.48**	7.91±1.19	13.39±0.25	8.41±1.55

The fines fraction of the MSW averaged 40% carbohydrate concentration, indicating only 40% of the OFMSW is accessible for biochemical conversion