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DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review Feedstock Technologies Session

Decontamination of Non-Recyclable Municipal Solid Waste (NMSW) and Preprocessing for Conversion to Jet Fuel

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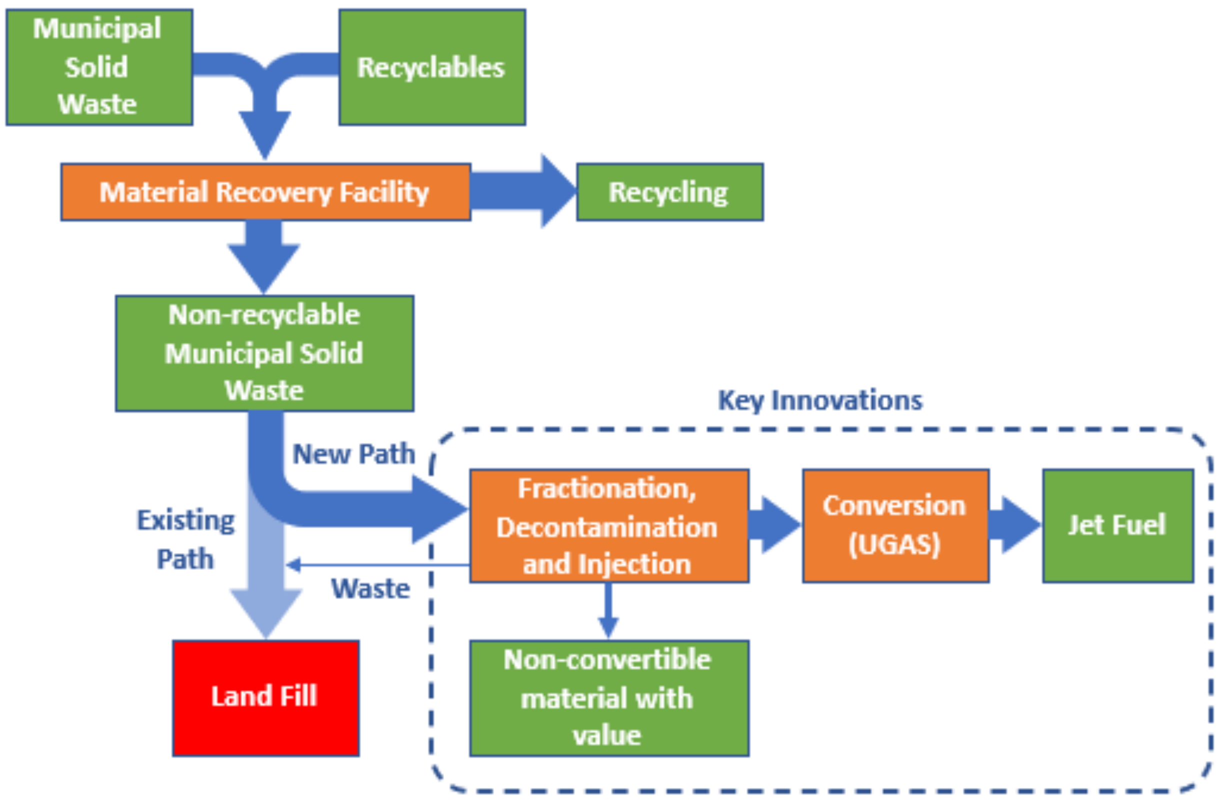
Tim Saunders

GTI Energy

Project Benefit Overview

- Convert NMSW to jet fuel instead of landfill
  - Today all Material Recovery Facility (MRF) residue (NMSW) goes to landfill
    - NMSW is contaminated and heterogenous
    - NMSW constituents and properties are not well characterized
    - NMSW has handling, decontamination and injection challenges project will solve
  - This project will create a new path for NMSW to produce jet fuel, capture secondary value streams, and minimize land fill



Project Team and Overview

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1. Decontamination (nanoRANCH - NR)
   - Artificial Intelligence (AI) sorting algorithm development for removal of constituents harmful to gasification
2. Preprocessing (INL Idaho National Laboratory – INL)
   - Preparation, sizing and blending to meet feed, injection and conversion specification
3. Injection (Gas Technology Institute – GTI GTI ENERGY solutions that transform and PRIME ENGINEERING)
   - Dry Solid Pump (DSP) key to reducing variation in injected feedstock and reducing conversion costs

Key support activity

NMSW sample (Waste Management – WM) WM

Physical and chemical characterization of NMSW (Georgia Institute of Technology – GIT)

Georgia Tech

Numerical modeling (GIT) and predictive algorithms (INL)

Cost assessment of decontamination, pre-processing, feed, injection and gasification (GTI)

Project Goals

- BETO goal: <$3.00 gasoline gallon equivalent (GGE)
  - Funding Opportunity Announcement (FOA) topic metrics
    - >95% feedstock purity
    - >50% reduction in feedstock variability
    - >80% decontamination efficiency
    - <$30/ton cost added to $86/ton delivered cost
  - Team specific goals
    - Demonstrate NMSW injection into 150 psi (pressure for target gasification process)

1 – Project Approach

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- Obtain actual NMSW batches from a commercial recycling facility
  - Provided by team member Waste Management
- Analyze the NMSW, determine constituents, evaluate variability
- Identify best methods of separation and processing
  - Fractionate into major material components using a combination of air-classification/air-column, density table, forage separator to generate pure (or enriched) fractions for Quality-by-Design testing
  - Constituent fractions will be preprocessed through size reduction or formatting techniques to meet conversion and handling requirements

Project Approach (continued)

- Develop AI based method to remove contaminants that are detrimental gasification (e.g., chlorine)
  - Screen with non-destructive sensing techniques to identify differential characteristics for the development of automated decontamination (removal) methods
- The final decontamination and pre-processing methods will inform technoeconomic analysis (TEA) and life cycle analysis (LCA) of commercial scale plant for added cost and $GGE

Project Approach (concluded)

- Characterize NMSW and its constituents
  - Chemical analysis to determine suitability for gasification
  - Physical property measurement
    - Develop advanced constitutive laws to numerically represent the feed handling and consolidation characteristics of NMSW
- Numerically model the physical behavior of NMSW
  - To assess materials handling equipment such as active mass flow hoppers and the final fuel injection system
- Adapt feed and solids injection system to demonstrate NMSW injection for gasification
  - Test using continuous-feed Dry Solids Pump

Key Challenges and Risk Mitigation Strategy

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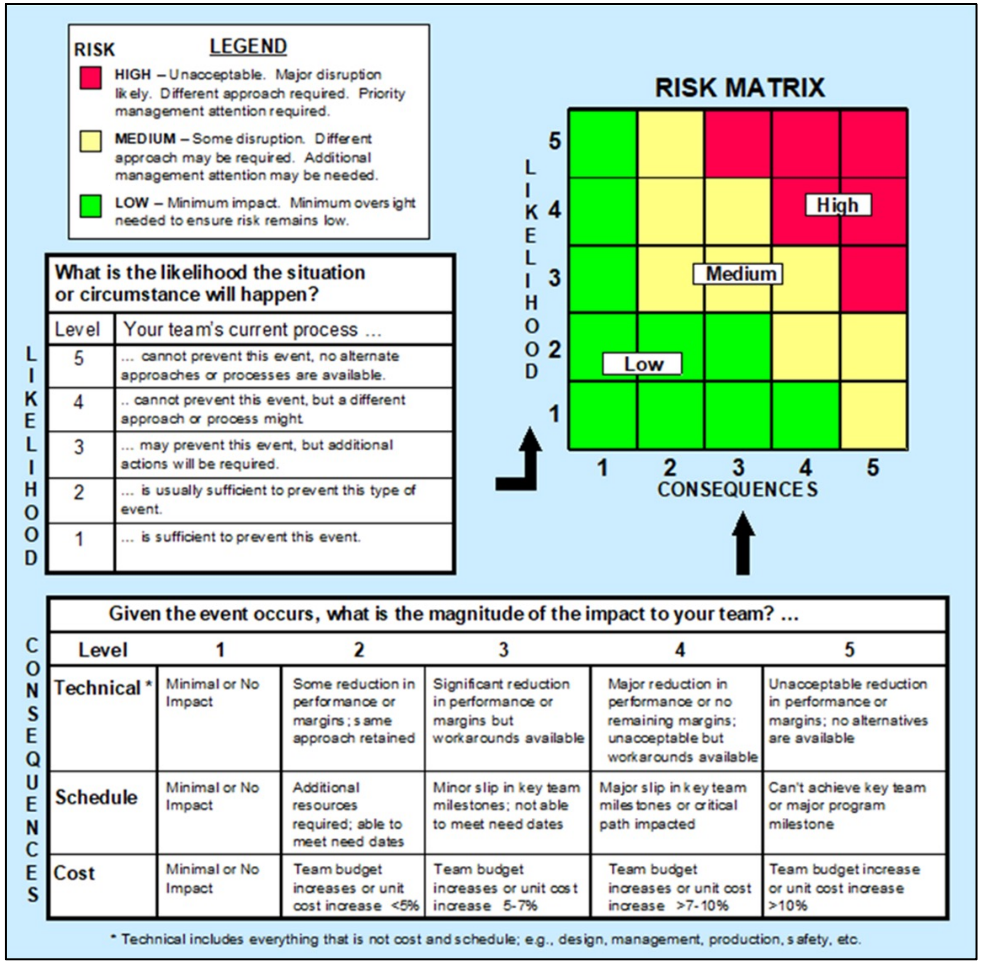
Risk	Conse-quence	Like-lihood	Mitigation
The feedstock cannot be processed to achieve physical and chemical properties necessary for successful pump or gasifier operability	5	3	Quantify properties early and quantify impact on performance and cost. Use results for go/no go decision point. Evaluate additional processing, such as tempering, added moisture, multi-stage material size reduction. WBS 2.3.1, 2.4.1
Inefficient separations reduce ability to meet targets for purity or decontamination efficiency	3	2	Increase preprocessing intensity, add secondary recovery line. Transition to different size reduction method and switch to a more distributed feed to improve efficiency. WBS 2.3.2, 2.4.2
Excessive material rejected from feed reduces ability to meet $86/ton cost target or decontamination efficiency	3	2	Consider co-production of fuel pellet or generation of steam to still utilize the materials. WBS 2.3.2
Sensor limitations reduce ability to meet targets for decontamination efficiency, cost or feedstock variability	4	2	Evaluate current XRF, IR and vision sensors to distinguish spectral material properties. If unsuccessful, utilize destructive methods (LIBS for example) to obtain direct chemical information about the feed. WBS 2.6.0
The solids pump is unable to show a path to achieve goal of 150 psi injection pressure, resulting in reduced system performance	4	2	1) Characterize material and process to achieve feed specs, 2) Design with margin to achieve >200 psi, 3) Parametric component/pump configuration test approach to achieve optimal performance. WBS 2.5.1, 11.1 (Hopper); 2.4.1, 2.5.2, 11.2 (Scraper); 2.5.2, 2.5.3, 11.2 (Moving wall)



Metrics and Go/No-Go

- 15 Key Performance Parameter (KPP) metrics used to track incremental progress to meet project goals tied to specific tasks
  - FOA Required Metrics
  - Pump Specific Metrics
  - Physical and Numerical Modeling
  - Gasifier Specific Feedstock Metrics
- Go/No-Go used to evaluate achievement of the most critical FOA KPP before proceeding

Parameter/Performance			Benchmark (Current)	Initial Verification Attained Value	Baseline (measured)	Baseline Attained value	Intermediate Target	Intermediate Attained Value	Final Target	Final Attained Value
FOA Required KPP Metrics										
Purity of Stream Relative to the Proposed Baseline	$PURITY = M_{CONVERT}/M_{TOTAL}$ *A feedstock stream having a >95% purity for gasification (95% of material being convertible with specified physical and chemical properties). This is primarily accomplished through the removal of substantial inorganic and unconvertable materials in the NMSW. This includes rocks, soil, etc. and other components that do not meet minimum quality specifications for the gasification process (decontamination). Such materials will be processed through simple rock traps, size exclusion, and screening techniques, as well as materials fractionation. This is performed through density-based separations and AI control mechanical picking arms as a last separation.*	wt. %	72	Literature	Unknown prior to sampling	WBS 3.1: Receive/analyze/prepare/distribute initial NMSW sample(s)	85.8	WBS 6.0: AI Sorting Algorithm Devlopment; GNG#2 Milestone	>95%	WBS 9.3: Final feedstocks characterization
Reduction in variability of feedstock for an end use	$V.R. = \left[\frac{\Phi_{MAX0} - \Phi_{MIN0}}{\Phi_{MAXF} - \Phi_{MINF}}\right]^{-1}, \Phi \leftarrow \rho, VM, ash$ *>50% reduction in feedstock variability as fed to the reactor (a consequence of compaction and compounding in the dry-solids pump). One major challenge in feeding and handling of NMSW are the non-ideal properties leading to inability to convey material or handle material uniformly due to the tendency to segregate during transport leading to dynamic material properties changes [5]. Upon material flow segregation, this can impart significant variability of material composition as-fed to the gasifier. With incorporation of the active hopper and solids pump, the material is effectively compounded into a uniform feed unit and allowed for process optimization around consistent properties. In comparison to the NMSW baselining activity, the densified material plug is expected to achieve this reduction in material variability with respect to the overall material bulk density as well as the chemical composition as determine by proximate and ultimate analysis.*	%	N/A	No historic value, variability will be assessed for incoming stream as well as preprocessed material for physical, chemical and pump testing	0	Ratio of incoming and outgoing samples, target insensitive to actual magnitudes. Denominator will be identified once NMSW samples obtained	75.1	WBS 3.3: Implement and validate predictive tools for blending fractions into feedstock	>50%	WBS 9.3: Final feedstocks characterization
Decontamination Efficiency Over Proposed Baseline	$\eta_{DECON} = \eta_{FPOSITIVE}\eta_{FNEGATIVE}$	%	80	Has been attained with select clean materials using NIR	50	WBS 3.3: Implement and validate predictive tools for blending fractions into feedstock; WBS 6.1-6.2: Initial AI Sorting Algorithm Development	75-100	WBS 6.2: AI sorting algorithm training.	>80	WBS 9.1: Validate decontamination and final sorting algorithm
Added Cost of Technology	$Cost = \sum n_{\$}$ *over Delivered Cost Goal of $86/ton, including collection, handling, preprocessing, and transportation costs*	$/dry ton	15	Developed for pine	<40	WBS 3.2: Fractionation and sizing of NMSW fractions	<35	WBS 12.1: Update commercial scale processing cost	<30	WBS 12.2: Final TEA and LCA

2 – Progress and Outcomes

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- Project has completed all contracted tasks (2 through 6) and achieved all three milestones to date

Task Number	Task or Subtask	Milestone Number	Milestone Description
2.3.1	Receive/prepare/distribute initial feedstock samples	M3.1	Composition of the as-received NMSW identified
2.4.2	Characterization of individual NMSW fractions	M4.2	Chemistry and permeability of fractions identified
2.5.4	Component testing of blended feedstocks	M5.4	Solids pump dimensions for NMSW identified

TEA Development

- Technoeconomic Analysis used GTI confidential and proprietary methods and data sets
  - Developed block diagram with team input for process flow
  - Applied National Energy Technology Laboratory Cost Estimation Methodology and Quality Guidelines for Energy System Studies (QGESS)
  - Estimated total plant cost using Fischer-Tropsch liquids yield
  - Conducted sensitivity analysis on key assumption parameters
  -

Fractionation and Decontamination Development

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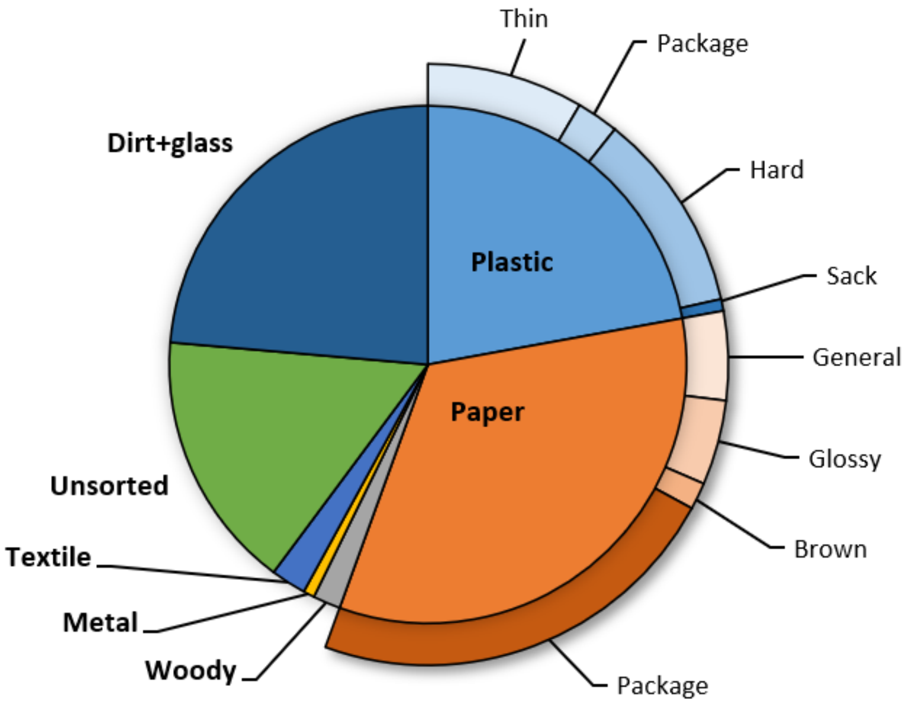
- NMSW and fractions sterilized, analyzed, pre-processed and distributed

Milestone	Description
Milestone 3.1	Composition of the as-received NMSW identified. Sample collected, processed, analyzed and distributed to project partners. Analysis identified the composition of the as-received NMSW for the entire project. Verified by analysis report.

Truckload of NMSW from Waste Management Salt Lake City MRF



Fractionation and Decontamination (concluded)

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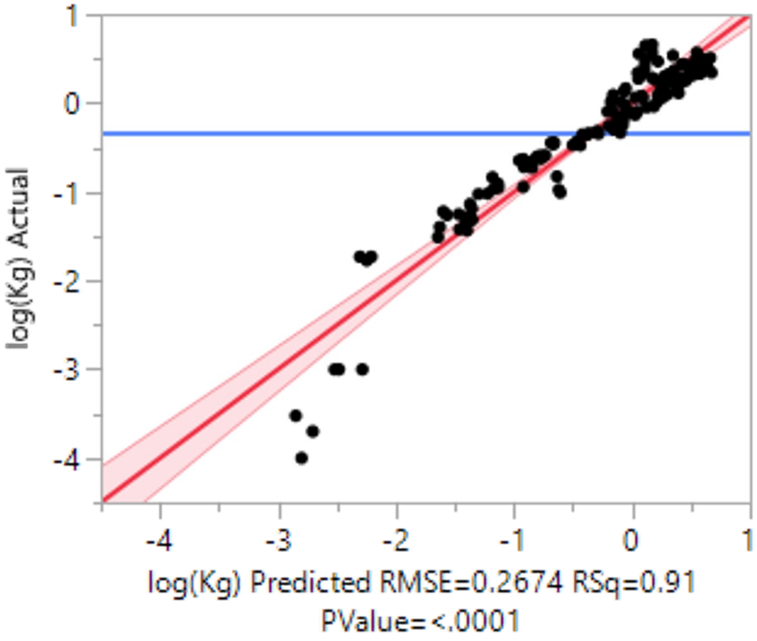
- Developed predictive model
  - Permeability of blend accurately predicted based on constituent fractions



- Purity and variability KPPs on track

Goal: 75% toward final metric

$$PURITY = M_{CONVERT}/M_{TOTAL}$$

Baseline	48.5% 61.2% processable, 20.9% avg ash 72% initial literature benchmark	
Intermediate	**85.8% (achieved)**	83.4% (target)
Final	95%	

Variability Reduction

$$1 - V.R. = \left[\frac{\Phi_{MAX0} - \Phi_{MIN0}}{\Phi_{MAXF} - \Phi_{MINF}}\right]^{-1}$$

$$\Phi \leftarrow OR(\rho, VM, ash)$$

Baseline	0	
Intermediate	**75.1% (achieved)** 75.1% avg for VM 72.3% avg for ash	37.5% (target)
Final	*50%*	

NMSW and Feedstock Characterization Testing

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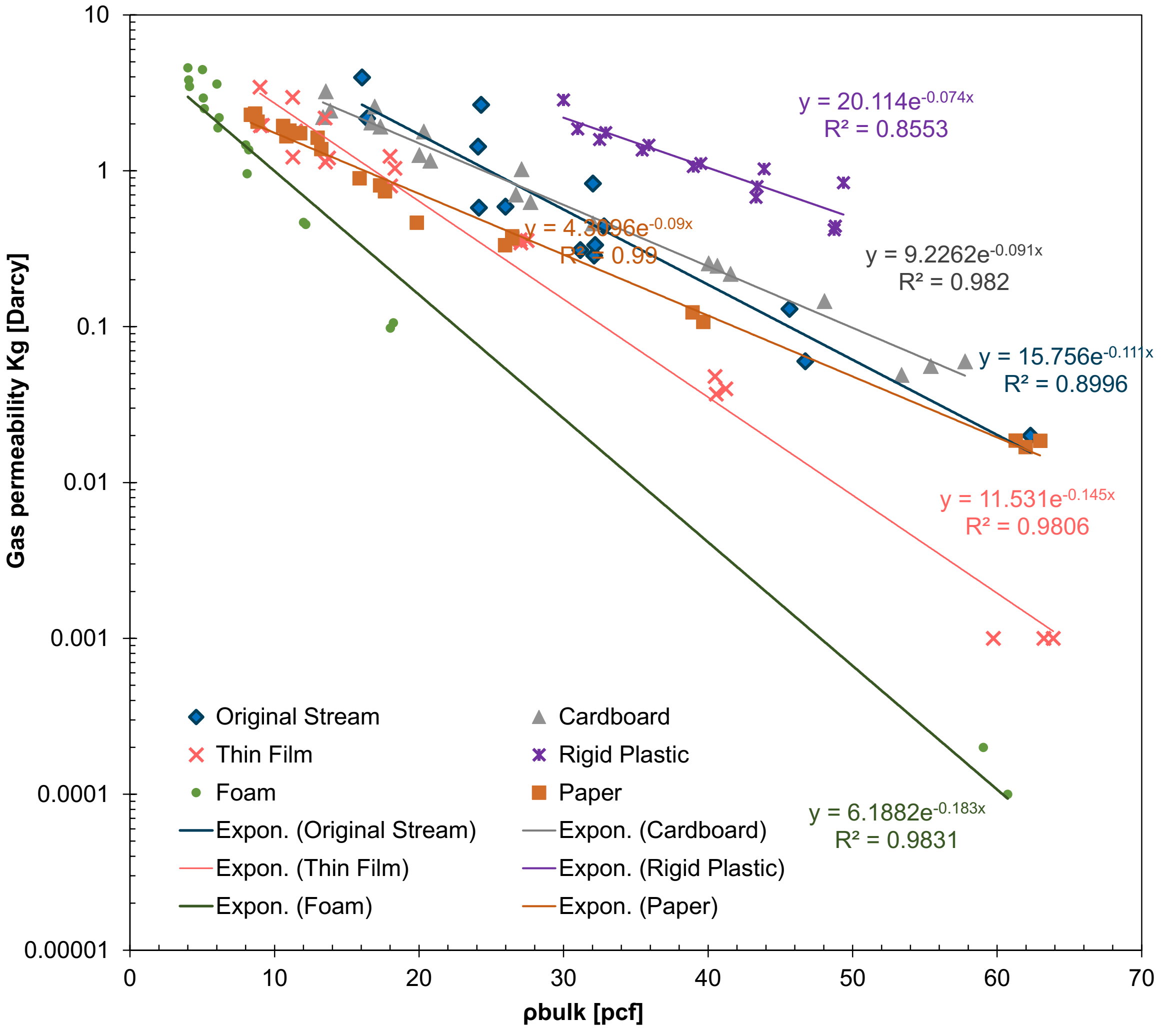
- NMSW and individual fractions were chemically and mechanically characterized

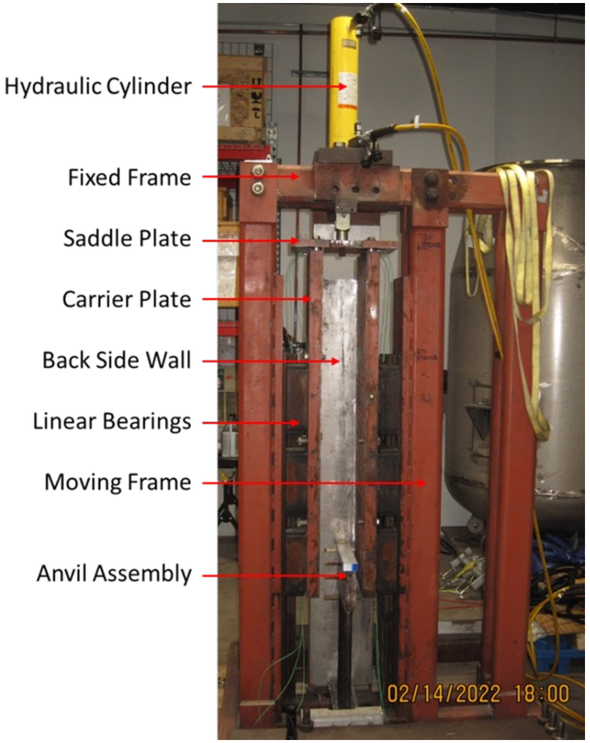
Milestone	Description
Milestone 4.2	Chemistry and permeability of fractions identified
	Fundamental characteristics of initial NMSW and NMSW fractions measured
	Permeability vs consolidation behavior of NMSW fractions is identified

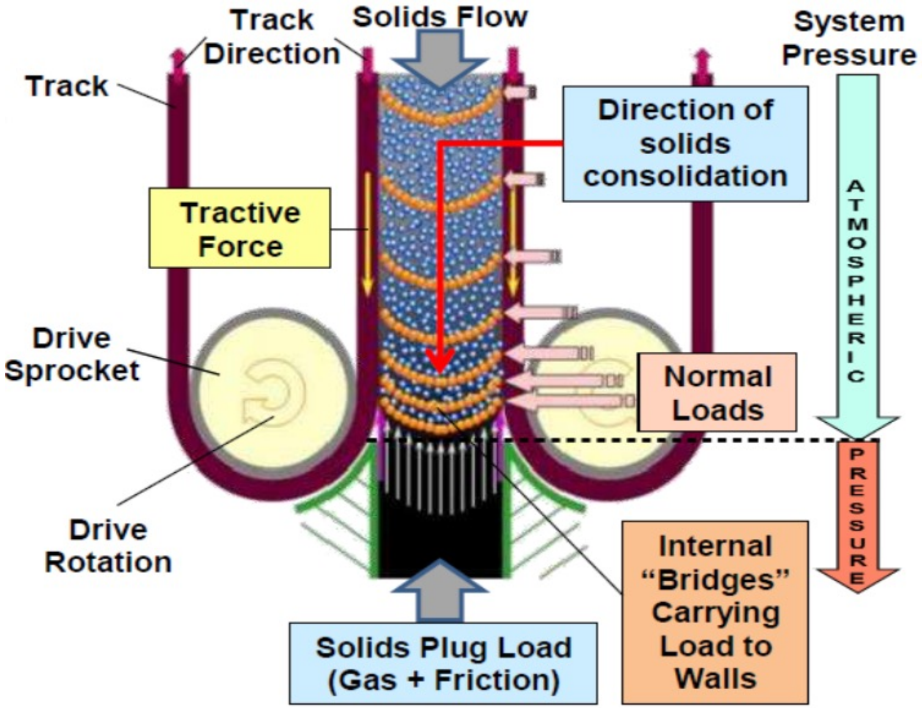
Proximate Analysis Results				
	Paper	Cardboard	Foam	Rigid Plastic
Volatiles	81.17	81.95	97.00	92.03
Fixed Carbon	9.23	9.80	0.30	3.33
Moisture	4.13	4.03	0.60	0.36
Ash	5.46	4.22	2.10	4.28



Solids Pump Component Testing

- Solids Pump heritage component rigs adapted for, and tested with, NMSW
  - Inlet feed (active wall hopper), tractive force (moving wall)

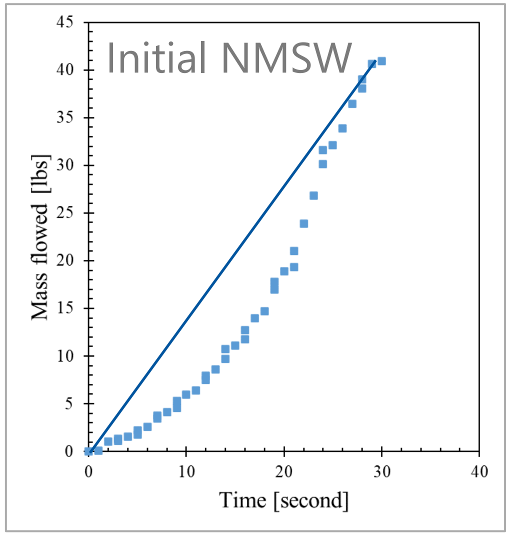




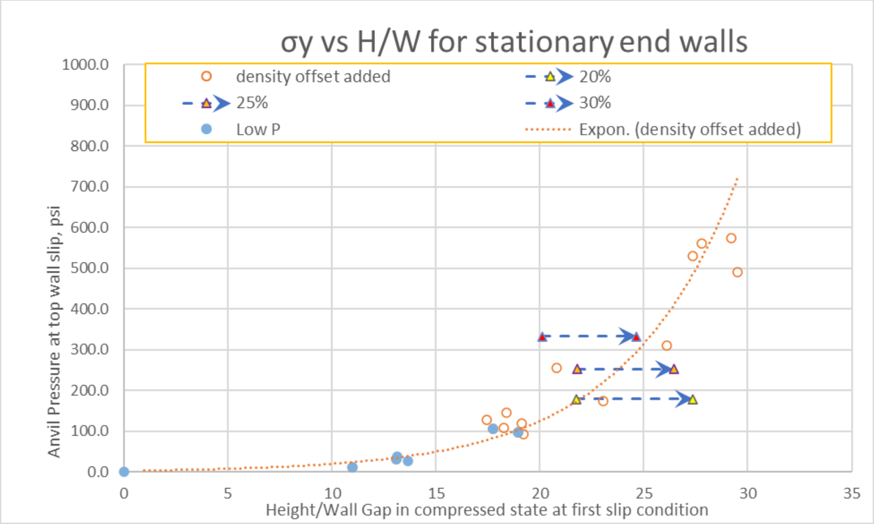
Solids Pump Component Testing (concluded)

- Data and analysis supports KPP metric progress and Milestone 5.4 pump dimensions for NMSW
  - Update permeability target to 0.117 for NMSW measurement
  - Representative data set for initial NMSW

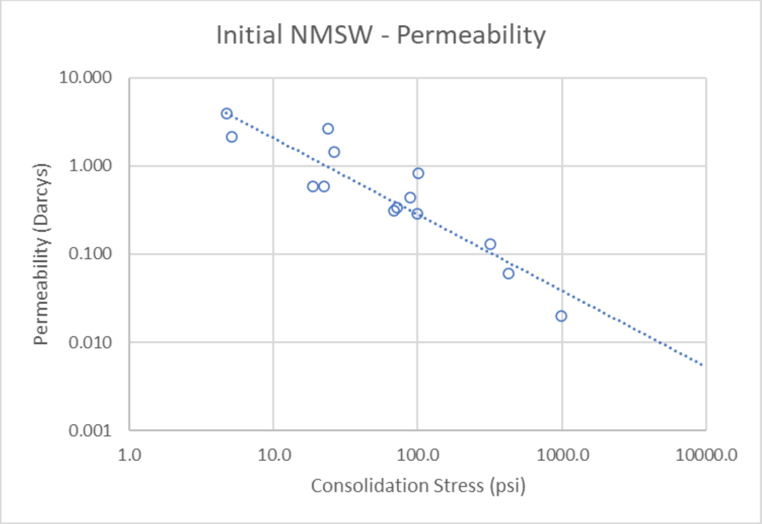
Parameter/Performance		Baseline (measured)	Baseline Attained value	Intermediate Target	Intermediate Attained Value	Final Target	Final Attained Value
Pump Specific KPP Metrics							
Feedstock permeability	*in/sec*	*<0.117 with initial NMSW*	*Intial NMSW result = 0.094*	*<0.117 with NMSW fractions*	*NMSW fractions results = 0.004 to 8.680*	*<0.117 with NMWS blends*	*NMSW blends results = 0.38 to 0.54*
Pump inlet feed rate	*in/sec*	*>0.6 with intial NMSW*	*Initial NMSW result = 5.35*	*>3 in/s for NMSW fractions*	*NMSW fractions results = 1.27 to 26.3*	*>6 in/s for NMSW blends*	*NMSW blends results = 3.02 to 5.91*



Hopper test confirms exit and feedstock size enable feeding at pump speed



Moving wall test identifies pump height to achieve consolidation stress



Permeability data identifies pump speed to prevent reverse gas flow

AI Sorting Algorithm Development

- AI process and algorithms are nanoRANCH proprietary and confidential
- Focused on X-ray fluorescence (XRF) based removal of chlorine (present in polyvinyl chloride – PVC)
- A variety of classifiers were tested to select the ones that provide the best accuracy for overfitting and underfitting
- Sorting algorithms were trained using representative data sets
- **KPP for decontamination efficiency = False Positive x False Negative**
  - **Achieved 75-100%, exceeding intermediate target of 72.5%**

NMSW and Feedstock Numerical Modeling

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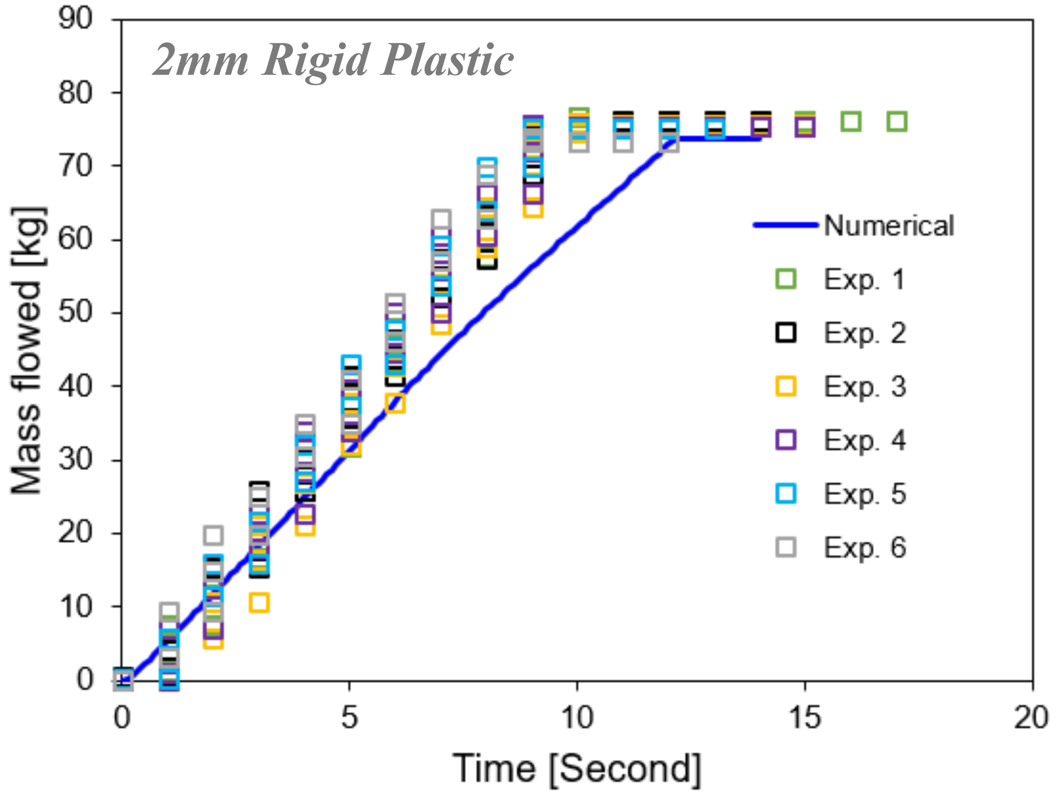
- Key parameters were identified and measured
- Hopper flow model using a hyperplastic model was validated against the test results
- **KPP target of 20% accuracy were met for feedstock permeability and mass flow prediction**

Model parameters determined from physical tests, i.e., dynamic packing, consolidation, and shear testing

Materials	ρ_p [kg/m^3]	φ_c [º]	n [-]	h_s [kPa]	e_{d0} [-]	e_{c0} [-]	e_{i0} [-]	α [-]	β[-]
2mm original stream	350	44.2	0.620	12.824	1.0806	2.3685	3.0790	0.3	0.1



3 – Impact

- Project will develop and advance technology that can reduce landfill use by enhancing NMSW value through enabling conversion to liquid fuel with a minimum selling price of $3/GGE
  - Reducing landfill will significantly reduce greenhouse gas emissions from transportation and landfill processing and decomposition gases
  - Additionally, groundwater pollution from landfills will be significantly reduced
- Project will characterize NMSW and develop processes for efficient sterilization, and handling
  - The ability to prepare NMSW efficiently and effectively is critical for conversion to liquid fuels
  - The project is applying a range of novel approaches in order to meet the overall objective
- Project success in NMSW processing and injection into gasifier operating pressures will provide patentable technologies and commercial opportunities including;
  - A process for sterilization of as-received NMSW
  - A process for separation, sizing and re-blending for optimizing gasifier feed specification
  - A process using AI for removal of contaminants to the conversion process
  - Mechanical devices for promoting flow of NMSW and injecting the processed NMSW into gasifier operating pressure

Summary

- The project is characterizing NMSW to determine purity and quality implications with bench scale testing and component proof-of-concept, targeted to enable GTI Energy U-Gas® gasification conversion technology and identify conversion specifications
- NMSW characterization and variability analysis will indicate potential feedstock supply sources and systems able to deliver at-scale quantities of NMSW for conversion
- The project will develop a novel and unique AI sorting algorithm and implement in a demonstration process system to verify performance for identification and removal of NMSW contaminants which is required to overcome key handling barriers, enable conversion chemistries, and minimize fuel cost,
- The project is remediating physical/mechanical properties of NMSW to address material segregation and flow issues to deliver a homogeneous and pure feedstock for gasification
- The project is developing and testing a novel and unique solids pump for injecting the processed NMSW into the operating pressure of the GTI Energy U-Gas® gasification system. This solids pump injection system will allow conversion solutions for a wide range of materials that currently go to landfill in addition to NMSW

Quad Chart Overview

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Timeline

- *5/1/2021*
- *5/30/2024*

	FY22 Costed	Total Award
DOE Funding	$642,310	$2,500,000
Project Cost Share *	$141,095	$628,383

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

Project Goal

- Develop neural-network based method to identify NMSW gasification contaminants
- Develop advanced constitutive laws to numerically represent the feed handling and consolidation characteristics of NMSW
- Refine preprocessing and solids injection systems to remediate chemical and physical contaminant properties
- Overcome key handling barriers, enable conversion chemistries, and allow a minimum fuel selling price of less than $3/GGE.

End of Project Milestone

- Demonstrate injection into conversion pressure with a range of fractionated and decontaminated NMSW feedstock that meets the physical and chemical specification required for conversion:

Funding Mechanism

DE-FOA-0002203

Area of Interest: 2a – Waste to Energy Strategies for the Bioeconomy

Project Partners*

- Waste Management, Idaho National Lab, NanoRanch, Georgia Institute of Technology, Prime Engineering