DOE Bioenergy Technologies Office (BETO)
2023 Project Peer Review

Advanced Sensing for Characterization and Sorting of Non-Recyclable Plastics Using Sensor Fusion with Artificial Intelligence

April 4, 2023
Feedstock Technologies

Nalin Kumar, Ph.D.
UHV Technologies, Inc (aka nanoRANCH)

This presentation does not contain any proprietary, confidential, or otherwise restricted information

Project Overview

Rationale: Non-recyclable Municipal Solid Wastes (NMSW), particularly #3-7 plastic bottles are sent to landfill

Project Goal: The **project goal** is to advance state-of-the-art plastic sorting capabilities by employing cutting edge technologies such as sensor fusion and artificial intelligence based deep learning algorithms.

Specific Aims:

To develop a technology to create novel fractions within the waste stream

To develop a novel classification system geared towards product creation

To develop a novel fraction geared towards product creation

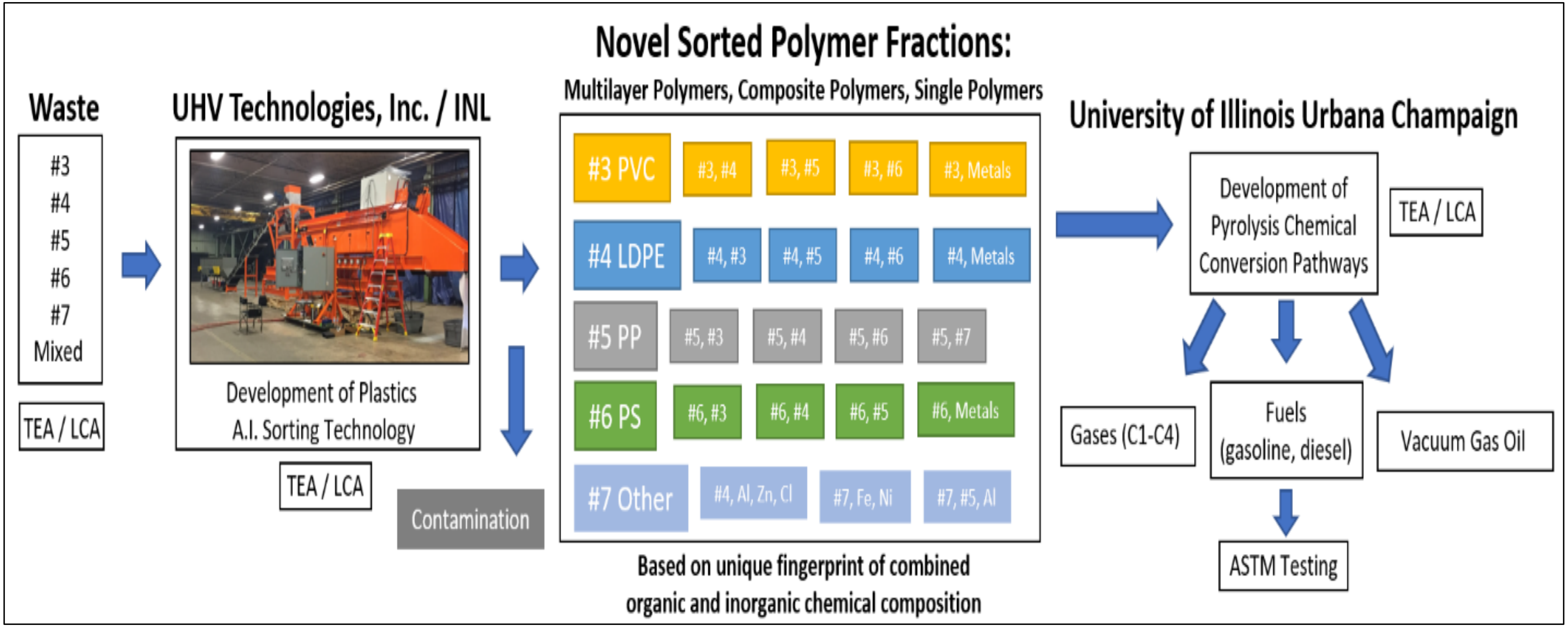
To develop low cost decontamination methods for specific items

To develop and identify chemical conversion pathways for product creation using these novel fractions

To perform TEA and LCA to direct this technology towards economic viability

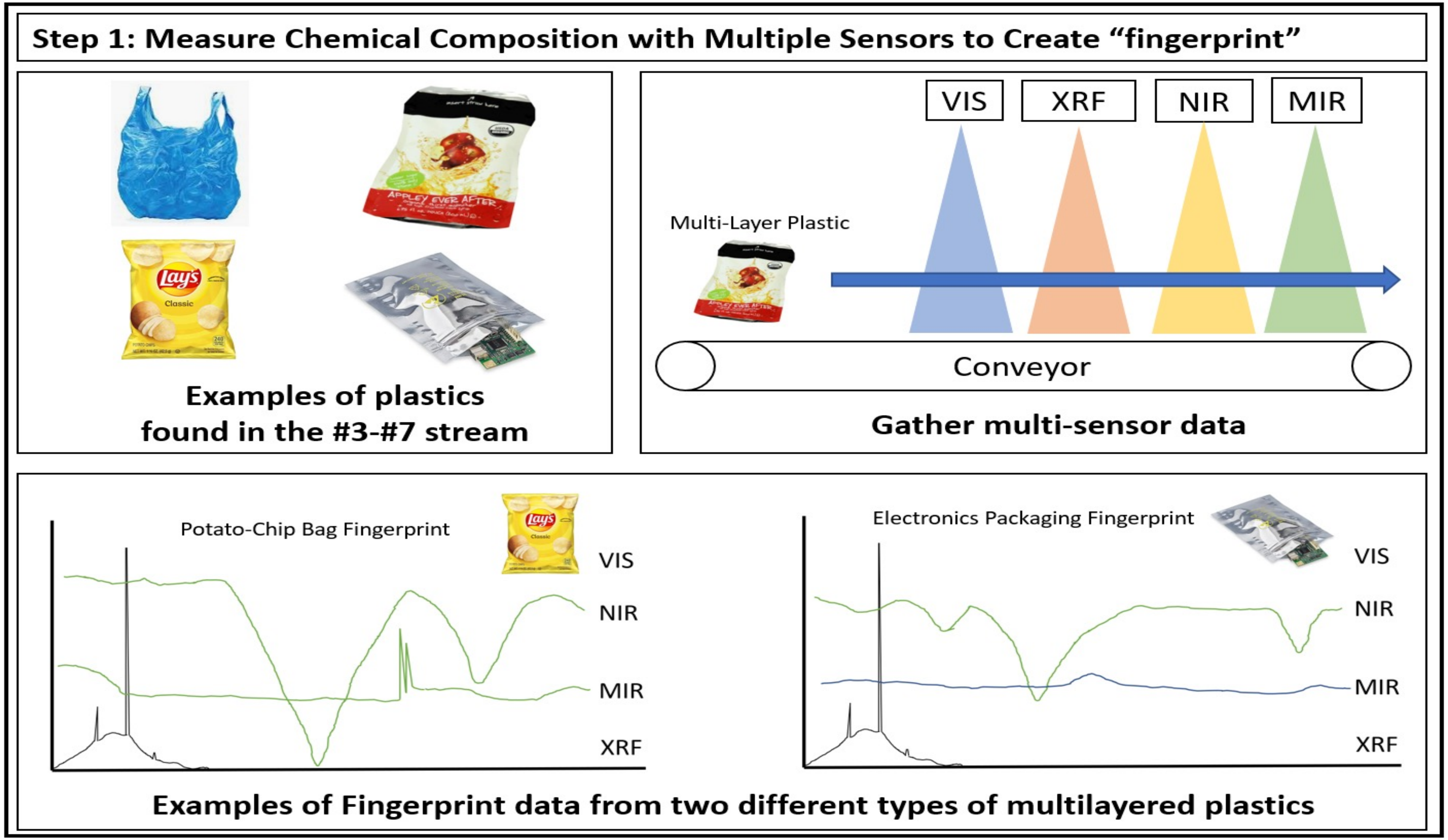
UHV Technologies, Inc. Perfection in Advanced Materials and Devices
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
SWA SOLID WASTE AUTHORITY of Palm Beach County
PennState Behrend
INL Idaho National Laboratory
nanoRANCH arnessing Science for the Benefit of Humanity

Project Overview



UHV Technologies, Inc. Perfection in Advanced Materials and Devices
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
SWA SOLID WASTE AUTHORITY of Palm Beach County
PennState Behrend
INL Idaho National Laboratory
nanoRANCH Harnessing Science for the Benefit of Humanity

Approach (Data Gathering by Multiple Sensors)



Approach (A.I./ML Concept)

- Signals from XRF, NIR and MIR will be gathered for each piece to create a **“fingerprint”** which measures the organic and inorganic content within the plastic to determine the ‘**Ground Truth**’. (what type of plastic it is)
- This fingerprint will be correlated to the visible image taken by a low cost camera
- The innovation is to use the camera image with visible wavelength light to train a convolutional neural network (CNN) to identify those classes.
- We expect to classify >95% of plastic pieces from the low cost camera images.

Approach (A.I./ML Concept)

Approach (Mass Flow & Value Proposition)

TARGET : Cost Target $20-30 per ton

NMSW from MRF
-$6-10 /Ton
+ $40/T

(#1-#7 + Cont.)

UHV SORTER

#1
$250/T
12.5c/lb

#2
$900/T
45c/lb

Al
$1,000/T
50c/lb

Waste
-$40/T

(#4,5,6
)

PRICE
?

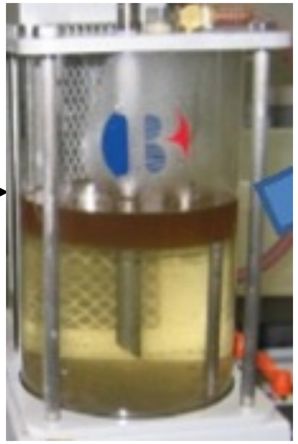
Cleaning +
PYROLYSIS

70% Conversion
To FUEL

Processing Cost
XX/T

FUEL

FUEL



$3 per gl

UHV Technologies, Inc. Perfection in Advanced Materials and Devices
ILLINOIS University of Illinois at Urbana-Champaign
SWA Solid Waste Authority of Palm Beach County
PennState Behrend
INL Idaho National Laboratory
nanoRANCH Harnessing Science for the Benefit of Humanity

Progress and Outcomes
(Created a Baseline in BP1)

	Name	Weight (Lb)	Percent (%)
1	PET	598.82	47.5
2	HDPE	43.1	3.4
3	PVC	2.2	0.17
4	LDPE	0.588	0.05
5	PP	432.9	34.3
6	PS	0	0
7	Other	107.5	8.5
8	Unknown	43.8	3.5
9	Metal	3.11	0.25
10	Mix	26.1	2.17
11	With residue	2.11	0.17
Total		1146	100

UHV Technologies, Inc. Perfection in Advanced Materials and Devices
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
SWA SOLID WASTE AUTHORITY
PennState Behrend
INL Idaho National Laboratory
nanoRANCH Harnessing Science for the Benefit of Humanity

Progress and Outcomes (Multi-Sensor UHV Sorter at INL)

UHV Technologies, Inc. Perfection in Advanced Materials and Devices

ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

SWA

PennState Behrend

INL Idaho National Laboratory

nanoRANCH Harnessing Science for the Benefit of Humanity

Progress and Outcomes
Preliminary A.I./ML Results

Model	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	SC10	SC11	SC12	SC13
CNN	60	25	20	40	20	100	40	20	20	0	0	60	60
CNN +RFC	100	25	20	80	0	100	40	80	20	25	0	100	60
Inception	**100**	**50**	**20**	**80**	**100**	**100**	**80**	**80**	**80**	**50**	**100**	**100**	**60**
Inception + RFC	100	25	20	40	20	50	20	60	40	20	0	100	0
VGG16 + XGB	100	25	20	60	40	100	60	20	80	50	25	80	20

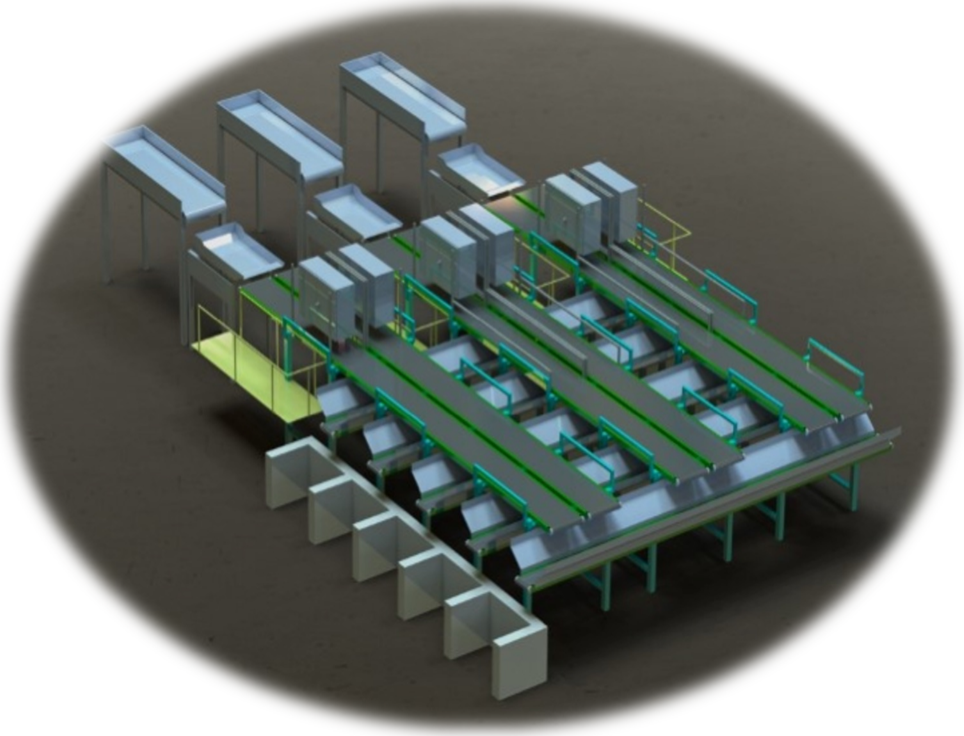
UHV Technologies, Inc. Perfection in Advanced Materials and Devices
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
SWA
PennState Behrend
INL Idaho National Laboratory
nanoRANCH ssing Science for the Benefit of Humanity

Progress and Outcomes
Pyrolysis Results

Run No.	PTF-15	PTF-72	PTF-69	PTF-73	PTF-74	PTF-77
Feed	INL-PS	INL-PS	INL-PS	INL-PS	INL PS	INL-PS
Catalyst	None	None	None	None	$MgSO_4.7H_2O$	None
Feed (g)	500	500	100	100	100	100
Catalyst (g)	0	0	0	0	10	0
Anhydrous catalyst weight	0	0	0	0	4.883	0
Total in (g)	500	500	100	100	104.883	100
Mode	mixing	mixing	mixing	mixing	mixing	Mixing
Temp. (°F/°C)	850/454	850/454	850/454	750/399	750/399	850/454
Time (min)	60	60	60	60	60	60
Liquid Yield (wt. %)	84.09	81.21	71.76	27.32	31.95	69.81
Solid Yield (wt. %)	2.5	9.01	7.34	57.29	64.54	24.18
Gas- Difference (wt. %)	13.41	9.77	20.9	15.41	3.50	6.01
Operator	Ravindra	Ruchitha	Ruchitha	Ruchitha	Ravindra	Ravindra

UHV Technologies, Inc. Perfection in Advanced Materials and Devices
ILLINOIS UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
SWA SOLID WASTE AUTHORITY of Palm Beach County
PennState Behrend
INL Idaho National Laboratory
nanoRANCH Harnessing Science for the Benefit of Humanity

Progress and Outcomes
Preliminary TEA/LCA Results



Concept of 60,000 TPY Facility

TABLE 3: REVENUES FROM THE BASELINE CASE

	PP_pyro ($/ton)	PP_recy ($/ton)
Recycling revenue	90.02	147.09
Landfilling cost	12.57	12.58
Breakeven pyrolysis sale price	-66.76	-290.06

Progress and Outcomes

- Project is on schedule and on budget
- Engineering design of the sorters is complete and construction of low cost AI Sorter has started
- 60,000 image dataset has been developed to demonstrate the sorting algorithms. The number of images will increase to ~1million during this project.
- We have already started developing fuels from #4,5,6 plastics.
- A preliminary TEA/LCA has been performed to demonstrate capability of building a facility for 60,000 tons/yr at a cost of $20-30 per ton.

Impact

- The creation of a novel sorting technology for non-recyclable plastics
- The ability to create novel valuable fractions from a waste stream
- Less material is sent to the landfill
- This sorting technology will enable a cost-effective production of gases, fuels and oils from an existing waste stream
- Creation of new products from waste streams
- Multiple sorting model designs proposed geared to meet techno economic goals to lower the obstacle for risk averse organizations to use this technology (Co-location with MRFs to reduce transportation costs)

Summary

- Project is on schedule and on budget
- Detailed analysis of NMSW bales performed to determine baseline
- We found the there is significant #1 and #2plastics going to the landfill
- Designed a low cost AI sorter with a 60,000 TPY sorting capacity at $20-30 per ton cost, that can be co-located with MRFs to reduce transportation costs
- Preliminary TEA/LCA shows that the sorting facility can be profitable

Quad Chart Overview

Timeline

- *Project start date: 10/01/2021*
- *Project end date 12/31/2024*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *$125,000*	*$2,500,000*
Project Cost Share *	$31,250	$625,000

TRL at Project Start: 2

TRL at Project End: 4

Project Goal: Advance state-of-the-art plastic sorting capabilities by employing cutting edge technologies such as sensor fusion and artificial intelligence based deep learning algorithms.

End of Project Milestones: The end of project goal is to create at least one fraction from the #3-#7 waste stream which has a purity of 95-99%, to decontaminate that steam with an efficiency ranging from 80-95%, and also deliver the cost of sorting to less than $30 per ton.

Funding Mechanism *FOA* 0002203; Area of Interest AOI 2: Waste to Energy Strategies for the Bioeconomy

Project Partners*

- UHV INL UIUC PSU SWA

UHV Technologies, Inc. Perfection in Advanced Materials and Devices | ILLINOIS University of Illinois at Urbana-Champaign | SWA Solid Waste Authority of Palm Beach County | PennState Behrend | INL Idaho National Laboratory | nanoRANCH ...nessing Science for the Benefit of Humanity

Additional Slides

INNOVATION: Core Intellectual Property Behind Proposed Project

- 6 Issued US Patents, 14 International Patents, 25+ Patent Applications
- **Earliest Priority Date in the World** for AI-ML Sorting of mixed Streams
- Patents cover Metals, Plastics, MSW and Bio-Mass among other mixed streams
- **'Holy Grail'** Patent Issued on March 1, 2022. Extremely Broad Claims. Application filed in July 2015.

1. An apparatus for handling a first mixture of materials comprising a plurality of different classes of materials, the apparatus comprising:
   an image sensor configured to capture visually observed characteristics of each of the first mixture of materials; and
   a data processing system comprising a machine learning system implementing a neural network configured with a previously generated set of neural network parameters to classify a first plurality of materials of the first mixture as belonging to a first class of materials based on the captured visually observed characteristics, wherein the previously generated set of neural network parameters are uniquely associated with the first class of materials, wherein the plurality of materials of the first mixture classified as belonging to the first class of materials possess a chemical composition that is different from the materials within the first mixture not classified as belonging to the first class of materials.

Key Aspects of UHV’s IP

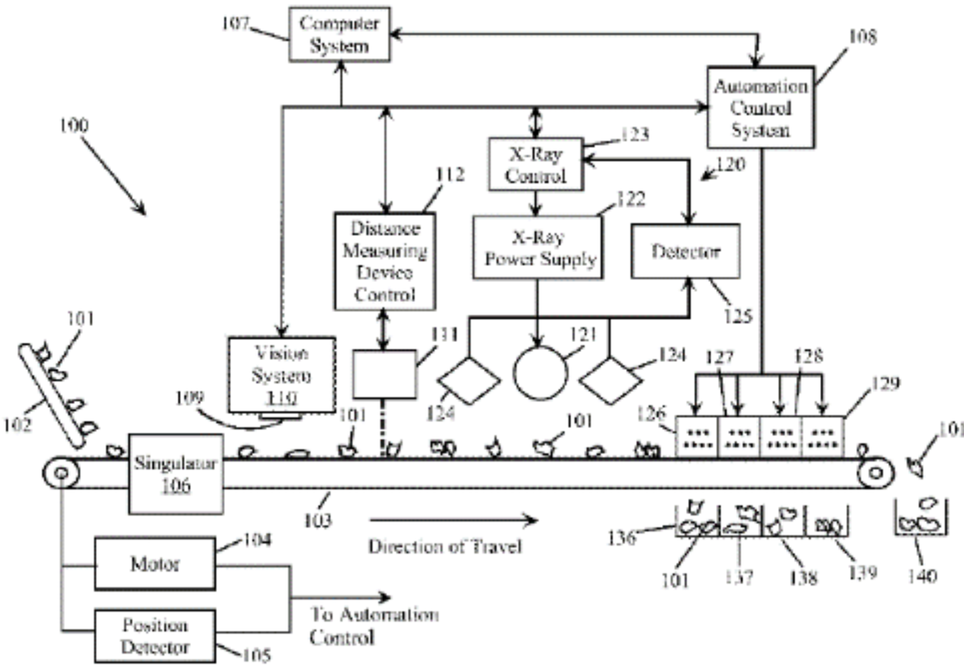
- 16 output stream A.I. Proprietary Sensor sortation system
- A.I. Sortation
- A.I./XRF/NIR/MIR In-line Soı

We build our own Hardware, Software, and A.I.

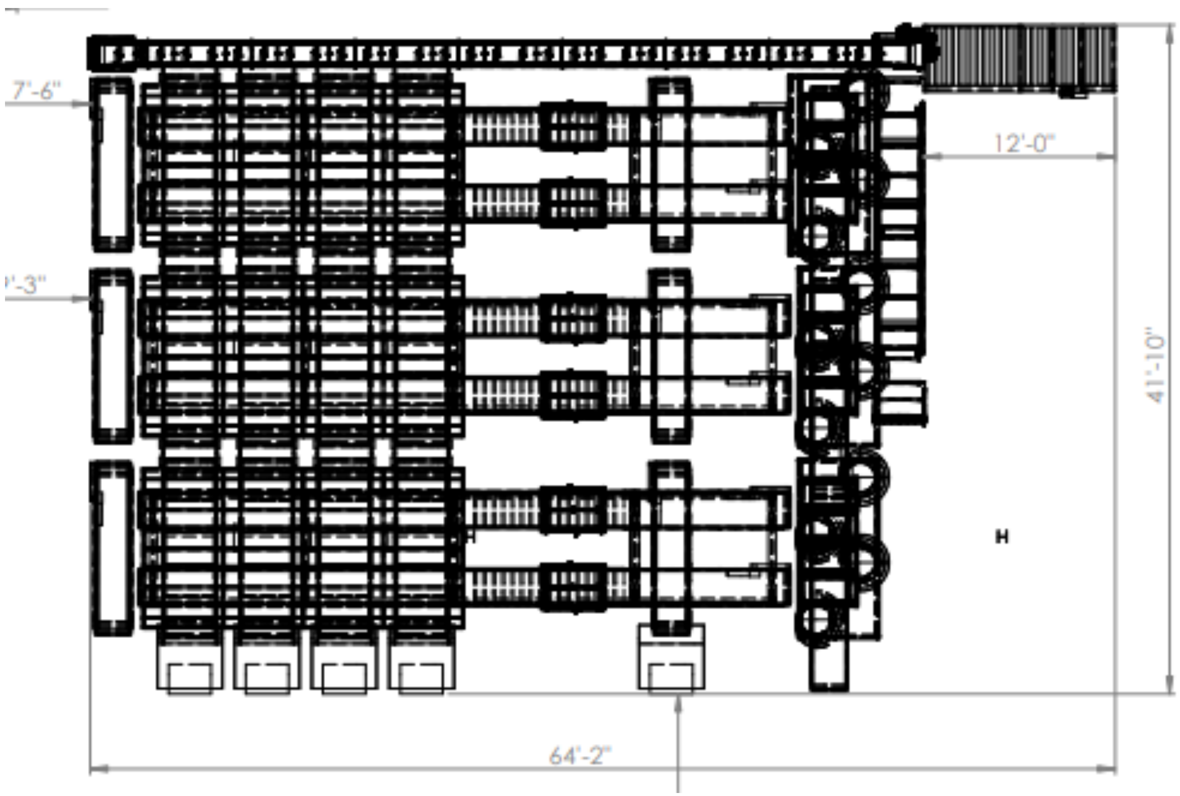
Over 30 Critical Patents filed
6 Awarded, 25 pending

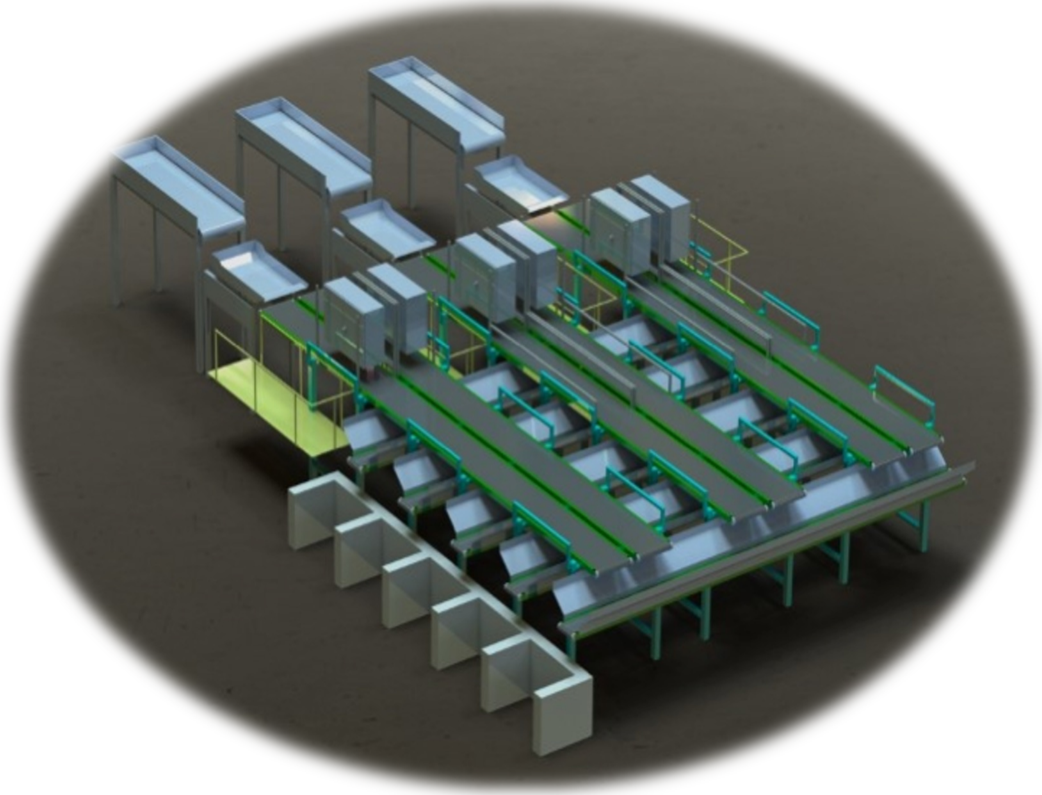
Detail sent in PDF with package

Priority Date of April 26, 2017



Industrial Scale Sorter (10TPH) for High Volume Sorting





Publications, Patents, Presentations, Awards, and Commercialization

Penn State University: TEA/LCA for Plastics Sorting: Submission of ASME paper in 2022 Q4 and presentation in 2023 Q2.