Earth Engineering Center
CITY COLLEGE of NEW YORK

WTERT
Waste-To-Energy Research and Technology Council

The Solution to Managing Plastic Waste in the United States of America

Marco J. Castaldi

Professor, Chemical Engineering

Director, Earth System Science and Environmental Engineering

Director, Earth Engineering Center | CCNY

Director, WTERT-U.S.A.

City College, City University of New York

Presentation at:

Heraklion, Crete, Gr, June 27th, 2019

the City College of New York

Combustion & Catalysis Laboratory

Introduction

- Plastic Recycling Situation in New York City
- Perspective on benefits and recyclability of plastic
- Technologies that can solve the non-recyclables

Earth Engineering Center
CITY COLLEGE of NEW YORK

Plastic Situation in NYC

WIERT
Waste-To-Energy Research and Technology Council

Total MSW (2017) = 3,121,471 tons

MGP (-15% AD)= 451,053 tons

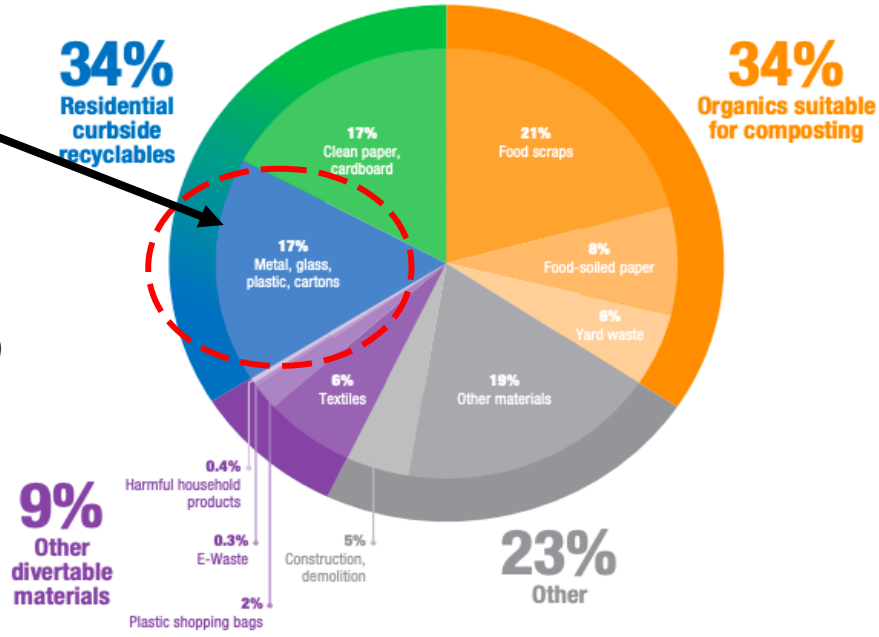
Blue bin plastics collected = 81,679 tons (18%)

Recovered from blue bin = 39,834 tons (48%)

If all recovered plastics are recycled = 8.8%

U.S. EPA states = 9.1%

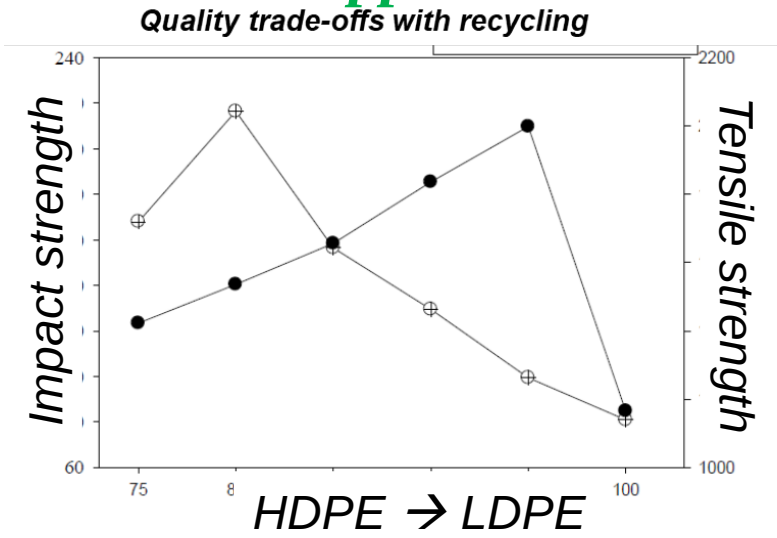
biocycle states = 7.5%



Only 48% recovered from blue bins due to market opportunities.

Based on literature survey: 73% recovery rates have been realized for plastic waste streams in the U.S.A.

→ 83,846 tons of waste left in this ideal community (~15 %)



Plastics recycling: ~8% → 73%

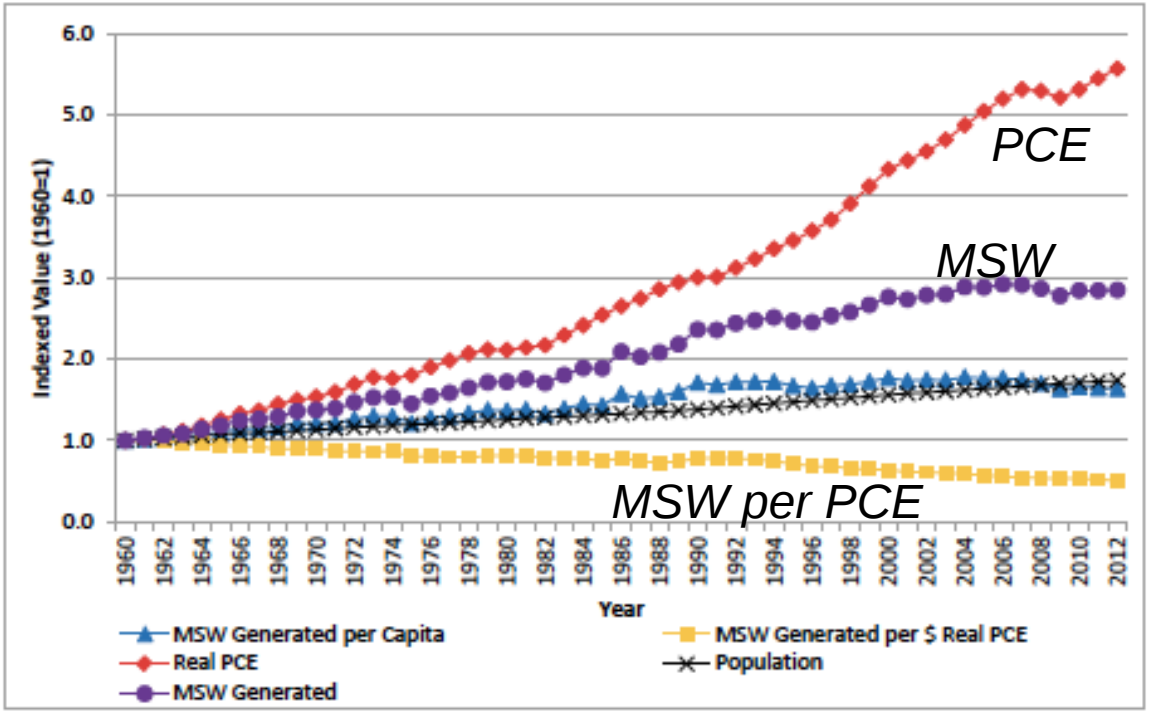
Remember: Recovery is not recycling

the City College of New York

Decoupling of Municipal Solid Waste (MSW) from Personal Consumption Expenditure (PCE)

- EPA and several other sources in the literature have reported a decoupling of MSW generation from economic growth indictors, such as GDP and PCE

Figure A-1. Indexed MSW Generated, Real PCE, and Population over Time (1960-2012)

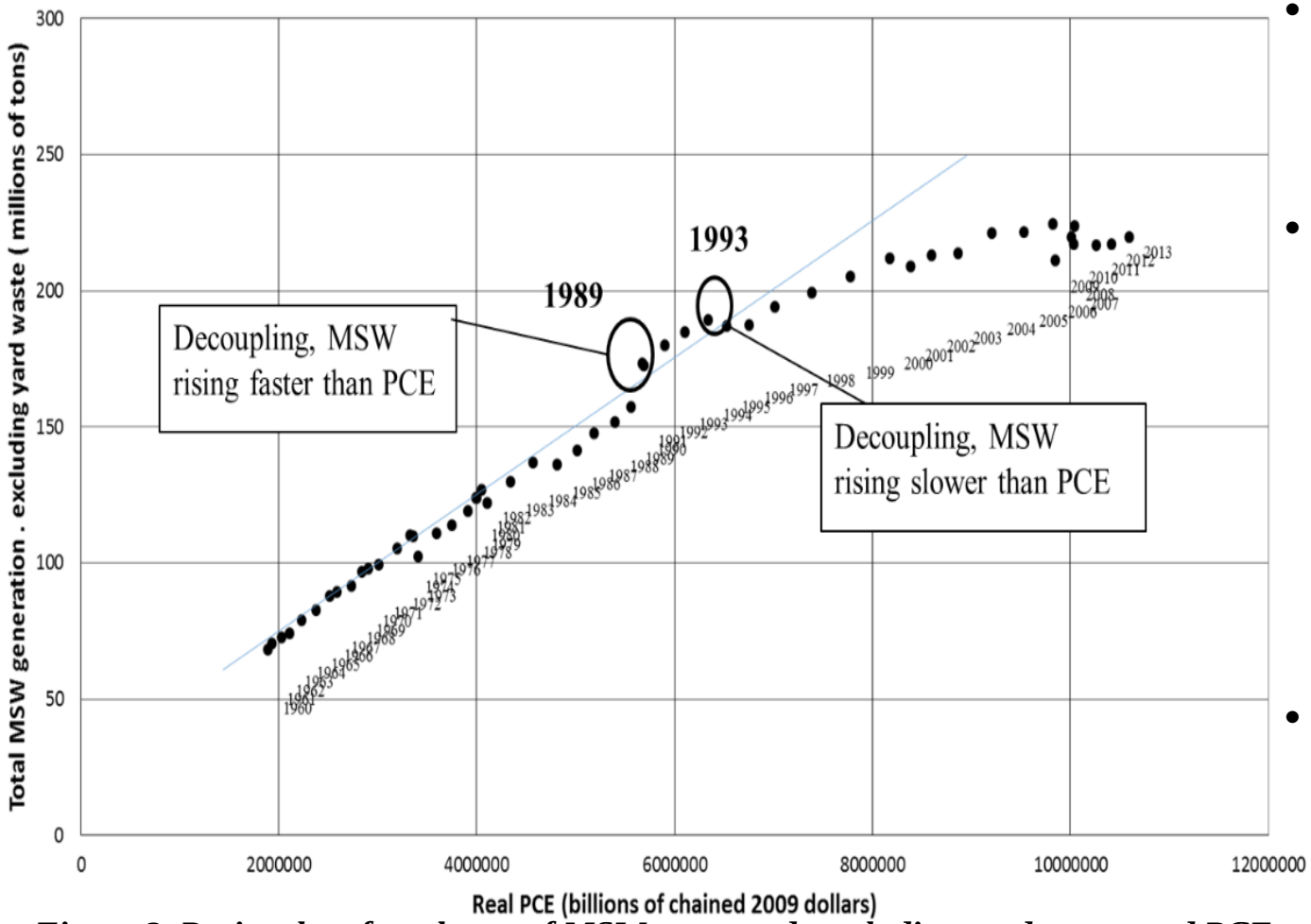


Source: Economic Data and Indicators Scoping Analysis, December 2013, US EPA

- ***Generation**: materials that enter the waste management system from the MSW source, after reduction and reuse*
- ***PCE:** US household spending on goods and services such as food, clothing, and vehicles and recreation services, accounts for 70% of GDP*

Why has this decoupling occurred?

Decoupling of MSW vs PCE due to Plastic Use in U.S.



- *Decoupling is estimated to have begun in the late 1990s*
- *Yard trimming legislation implemented in 1992 to encourage residents to dispose of yard waste in back yard i.e. reduction of yard waste in MSW*
- *Yard waste excluded from overall MSW generation tonnage*

Figure 3. Parity plot of total tons of MSW generated, excluding yard waste, and PCE
Source: Tsiamis, Torres, Castaldi. Waste management 77 (2018): 147-155.

Even though Plastic Use has been increasing much faster than other material use

Plastic in the MSW Stream is Rising

- **Reduction of plastic waste in U.S. MSW does not seem likely in the near future:**
  - No plastic bag bans, Styrofoam ban in NYC overruled
  - MSW decoupling from PCE may be attributed to plastics → seen as positive impact of plastics

- **Main Driver for Thermal Conversion in U.S.: Zero Waste Initiatives**
  - i.e. NYC's OneNYC plan aims to send zero waste to landfills by 2030
  - **Zero waste is not possible without energy recovery.**
    - Ideal recycling scenario for paper and plastics, 15% residual generation
  - **Gasification and pyrolysis are attractive technologies to decision makers compared to WTE but not fully proven yet.**

Plastics cannot be 100% recycled
Benefits of plastic use are real
Export market constraints

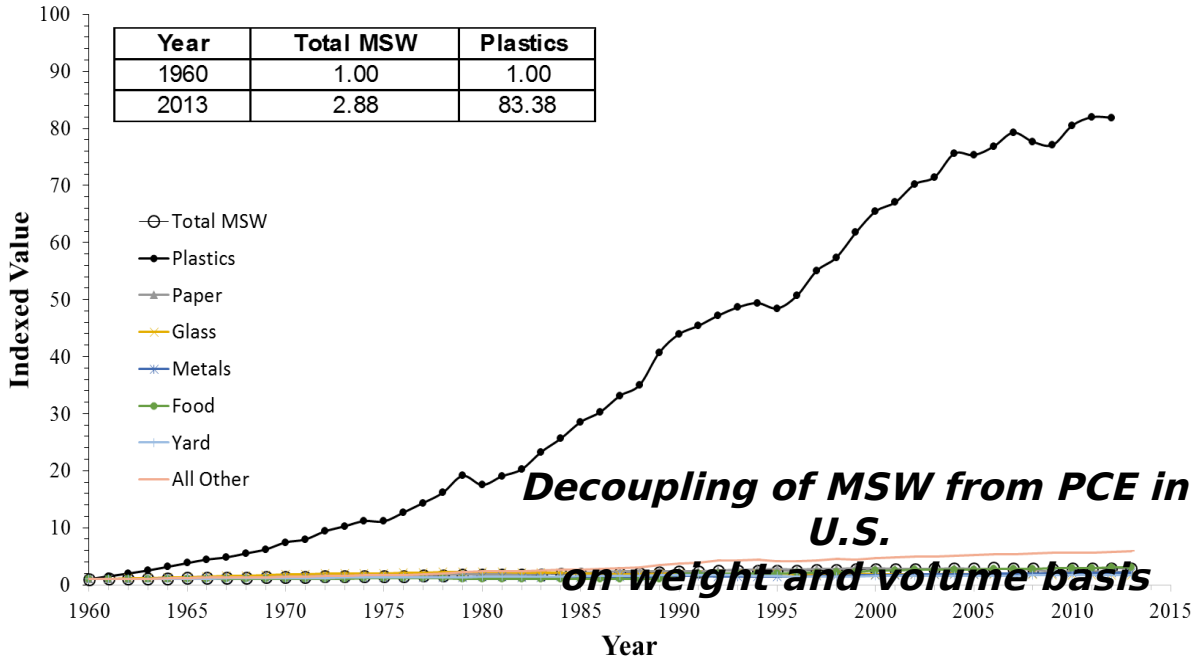
↓

ore plastics in US MSW

↓

nly solution is thermal conversion

Year	Total MSW	Plastics
1960	1.00	1.00
2013	2.88	83.38



Decoupling of MSW from PCE in U.S. on weight and volume basis

Fuel Production from Pyrolysis of Non-Recyclable Plastics (NRP)

- ***Golden Renewable Energy (GRE)*** *has a continuous process that pyrolyzes non-recyclable plastics (NRP) and produces a fuel product to be sold on the wholesale market*

- *EEC|CCNY conducted due diligence testing at a GRE's pilot facility in Yonkers, New York*

Golden Renewable Energy

Pyrolysis

Earth Engineering Center
CITY COLLEGE of NEW YORK

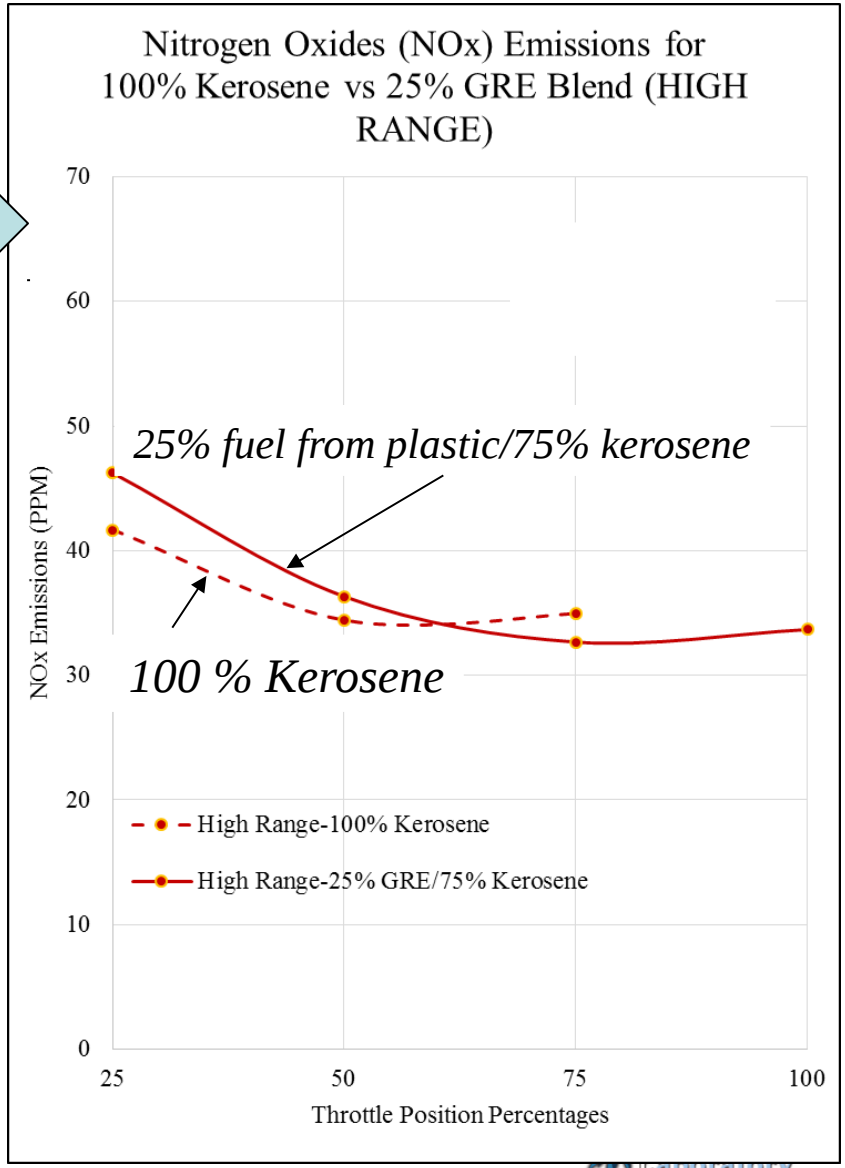
GRE Plastic to Fuel Performance

WIERT
Waste-To-Energy Research and Technology Council

- ***Continuous plastics pyrolysis process***
- ***Processing capacity:*** *~300 kg/hr*
- ***Final oil product has similar properties to traditional petroleum based fuels***
  - *Higher Heating Value ~ 37 MJ/kg*
- ***High BTU gas recycled to fuel burners of process***
  - *BTU value: ~900 Btu/ft³ (~34 MJ/m³)*
- ***Air emissions testing met local health regulatory standards***
- ***Solid residual generated was approximately 5.6% of total mass of plastics fed to process***
- ***Yields of pyrolysis processes range from 2-6 bbl* of oil/ton of plastics***

**final value determination is subject to measurement confirmations in progress*

Engine Test data at CCNY

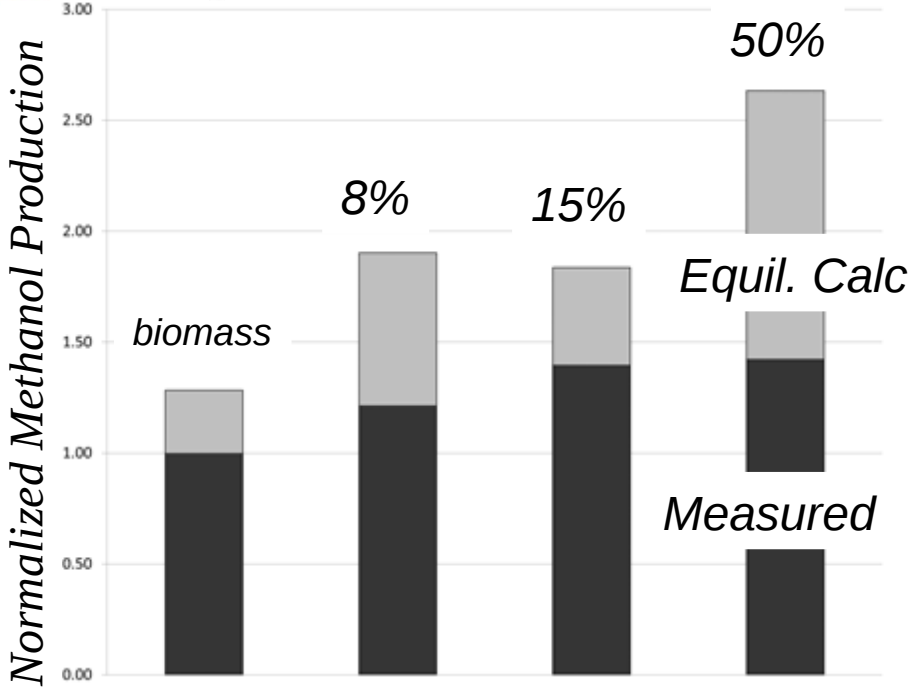


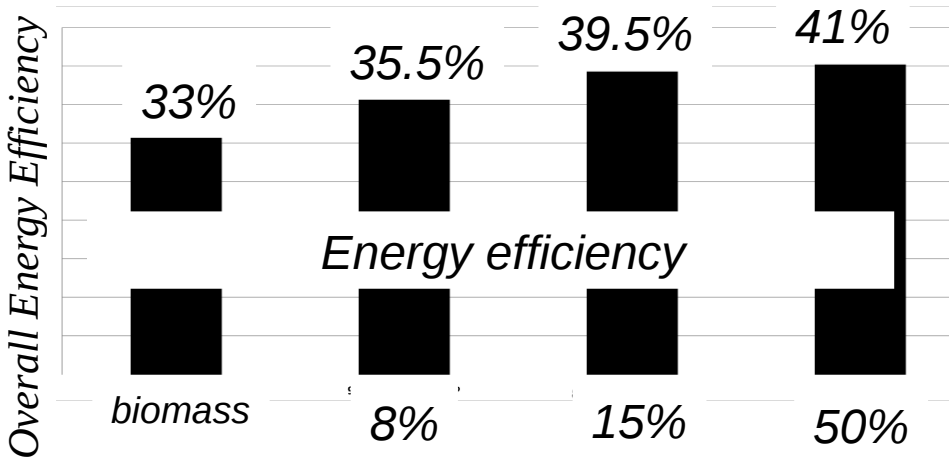
the City College of New York

Earth Engineering Center
CITY COLLEGE of NEW YORK

Plastics co-Gasified with Biomass

WIERT





Carbon efficiency from 66 – 75 %

Improvements are needed

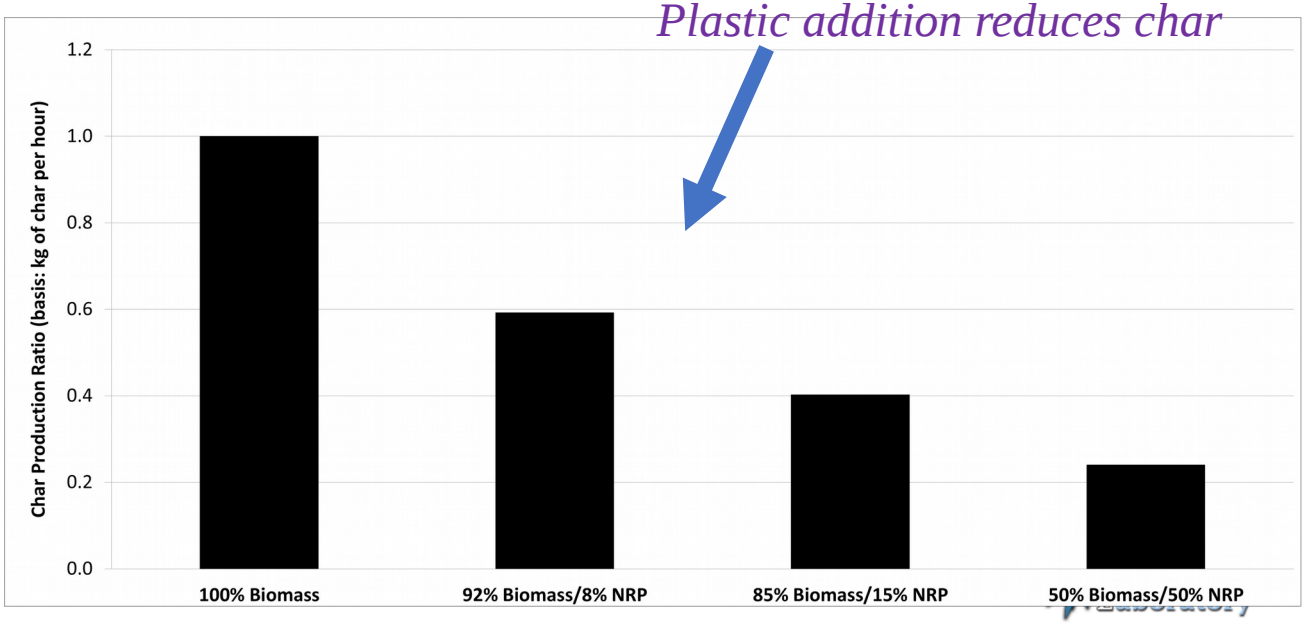
Gasifier produces high CO_2

→ too much combustion

Requires further reaction for proper H_2/CO

Temperature distribution produces high CH_4

Plastic addition reduces char



the City College of New York

NRP Use in Cement/Concrete Production

- ***Primary collection must be improved (recall only 48% of blue bin recovered)***
- ***Cement Kiln (ready now but impact ~30% of NRP to LF can be diverted)***
- ***Energy for heat has the potential to use 100% NRP for coal replacement***
  - ***Will require adaptation of current systems (i.e. boilers, etc)***

Possible addition to current solution

Concrete (can consume up to 29 % NRP without changing performance),

demonstrated internationally

*Needs to undergo rigorous testing on a **state by state** basis.*

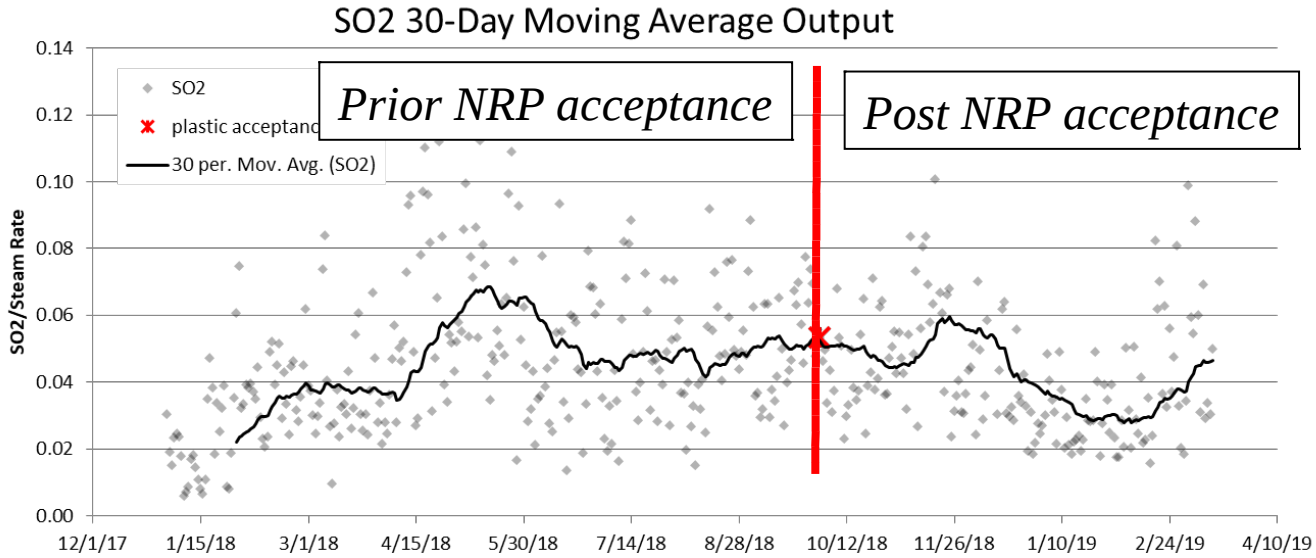
		NJDOT		PENNDOT	
		asphalt	concrete	asphalt	concrete
Gradation	ASTM C136	901.05.02-2	901.06.02-1	B#1, B #3	Type A
Absorption	ASTM C128	<2.0%	<2.0%		
Soundness	ASTM C88	<5.0%	<5.0%	<5.0%	<5.0%
Clay Lumps	ASTM C142	<5.0%			
Chloride Content	AASHTO T260		<0.06%		
Lightweight Pieces	ASTM C123		<0.25%		
Organic Impurities	ASTM C40		lighter than 11		
Uncompacted Voids	ASTM C1252	<40			
Sand Equivalent	ASTM C2419	<45			
Unit Weight	ASTM C29				

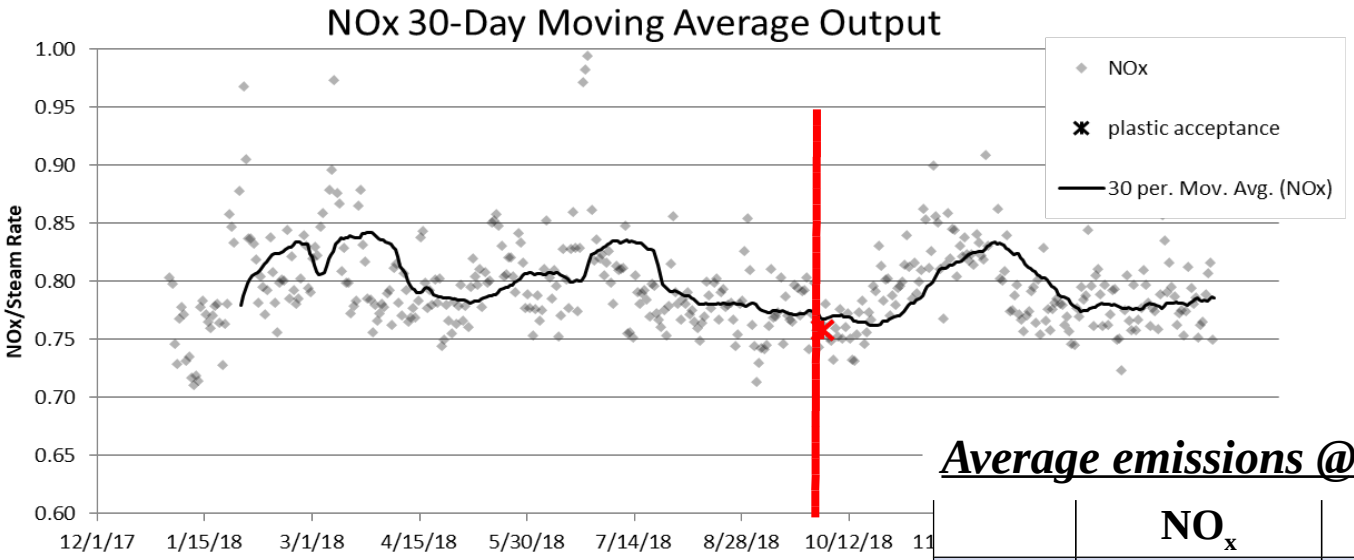
NJ & PA – close but not the same

Earth Engineering Center
CITY COLLEGE of NEW YORK

Plastics in mass-burn WTE

WIERT
Waste-To-Energy Research and Technology Council





While not ideal, energy recovery from NRP in conventional mass-burn combustion WTE does not impact emissions

Average emissions @ 7% O_2 per klb/day steam

	NO_x	SO_2	HCl
Prior	0.80 ± 0.05	0.05 ± 0.02	0.006 ± 0.004
Post	0.79 ± 0.03	0.04 ± 0.002	0.005 ± 0.005

the City College of New York

Earth Engineering Center
CITY COLLEGE of NEW YORK

Possible "Big Idea"

Asphalt Use in Road Construction

the City College of New York

Directly: Asphalt for Roads

encapsulating plastic pellets in asphalt. No direct examples related to plastic.

*18% replacement of petro-asphalt could handle **2.95x** the amount of plastics generated currently.*

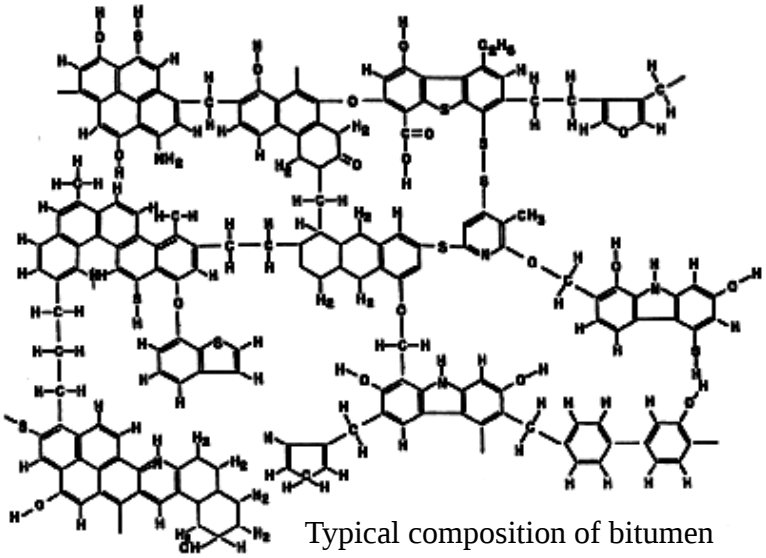
Needs to go through vetting process for each state.

Indirectly

converting plastic into highly priced bitumen-like substance. Conversion is difficult but some companies are tackling the issue internationally.

evizero®
the ecological, transparent binder

Asphalt



Typical composition of bitumen

Combustion & Catalysis Laboratory

Summary

- **Even Ideal Communities Cannot Achieve 100% Recycling Rates**
  - The best → 85%, leaving nearly 85,000 tons
  - Plastic benefits & export constraints will increase amount in U.S. MSW streams
- **Thermal Conversion Must be a Part of the Solution**
  - Mass-burn WTE current has ability to recover energy without emissions impact
  - Plastics to fuels (i.e.Golden Renewable Energy) are well positioned
  - Plastic addition to biomass gasification (certain percentage) shows promise
  - Incorporation into asphalt and concrete should further be developed
- **Setting Bans Will Not Work, Current Technological Infrastructure Will**
  - Combination of recycling and thermal conversion can manage all plastic waste

Earth Engineering Center
CITY COLLEGE of NEW YORK

EEC | CCNY

WTERT
Waste-To-Energy Research and Technology Council

Earth Engineering Center
CITY COLLEGE of NEW YORK

www.ccnyeec.org

WTERT Efforts | Research | People | Sponsors | Publications | Contact

Welcome to the EEC at CCNY!

Engineering of Earth's energy and material resources for responsible utilization and preservation

WTERT

Waste-To-Energy Research and Technology Council

The goal of EEC|CCNY is to bring to bear rigorous engineering solutions that enable responsible use of energy and materials for the advancement of society. Through industry collaborations and research sponsorship EEC|CCNY develops novel solutions to some of the world's most pressing problems. EEC|CCNY routinely engages students with industry professionals enabling a holistic approach to creative realistic, forward-looking applications. The reach of EEC|CCNY is international in scope with many projects connecting international students and companies with a global presence.

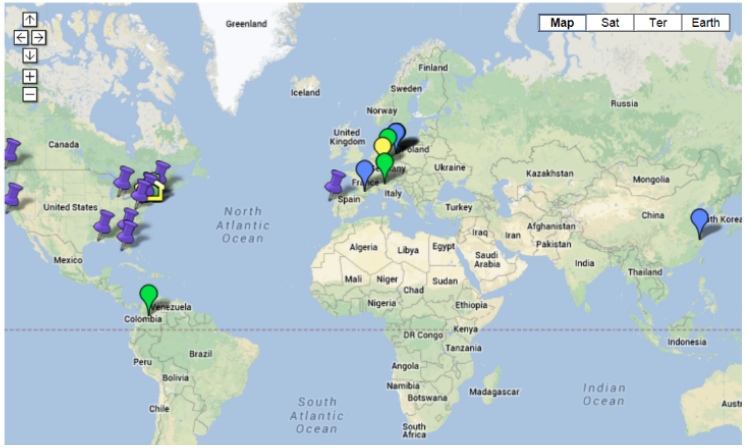
the City College of New York

Combustion & Catalysis Laboratory

Waste-To-Energy Research and Technology Council

Where in the world is CCL?

CCL maintains research collaborations and attends conferences around the world. Click on the map below to see where we've been.



Collaborations

Ecole des Mines d'Albi Carmaux

Zhejiang University

Tokyo Institute of Technology

Adelphi University

CEMEX

Freie Universität Bozen
Libera Università di Bolzano
Free University of Bozen · Bolzano

is/cemex-collaboration/

American Chemistry Council

COVANTA ENERGY
for a cleaner world

The main focus is the thermal and catalytic conversion of carbon based material to desired products

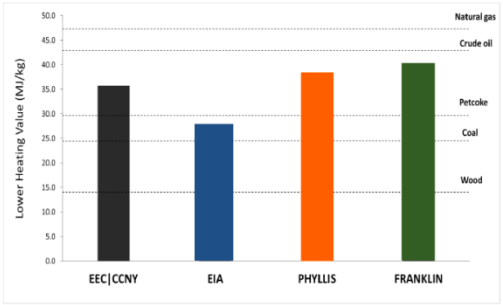
Please come visit us!→

nbustion &
alysis
oratory

Plastics Research at EEC|CCNY

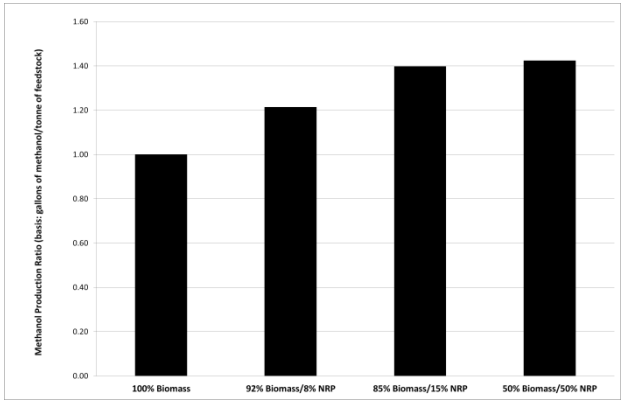
CHARACTERIZATION:

Determine energy value of non-recycled plastics, how does residue impact it? Address discrepancies in the literature



GASIFICATION:

Impact of non-recycled plastics on gasification. Pilot scale testing at Enerkem facility in Edmonton.



PYROLYSIS:

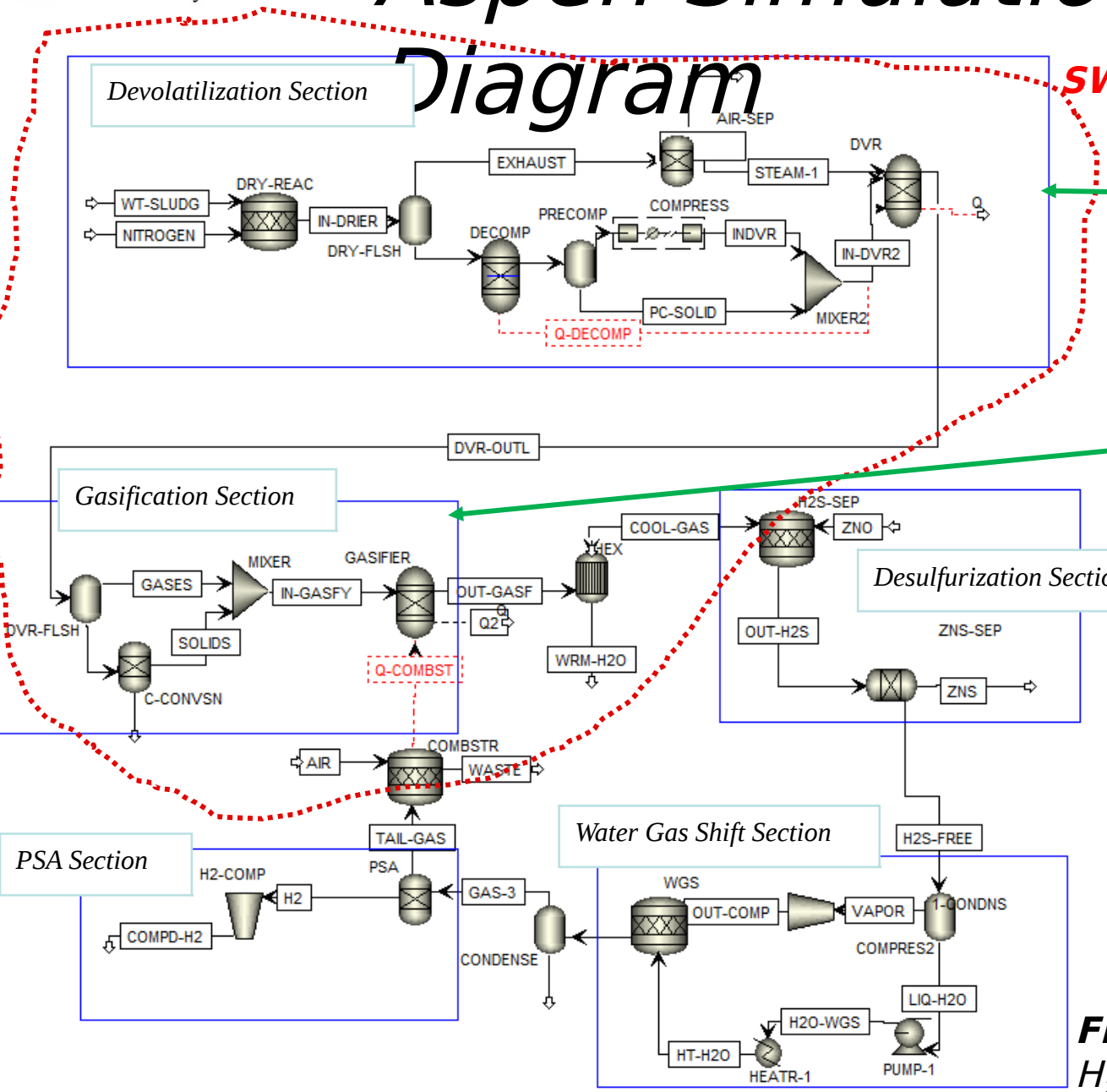
Due diligence assessments and emissions testing at pilot plastics-to-oil pyrolysis technologies in the US and internationally

APPLICATIONS:

Performance testing of waste plastic pyrolysis oils in engines, innovative applications for beneficial reuse of char

Plastic pyrolysis oils	25-40 MJ/kg
Plastic pyrolysis chars	10-25 MJ/kg

Aspen Simulation Diagram



SWPS Process

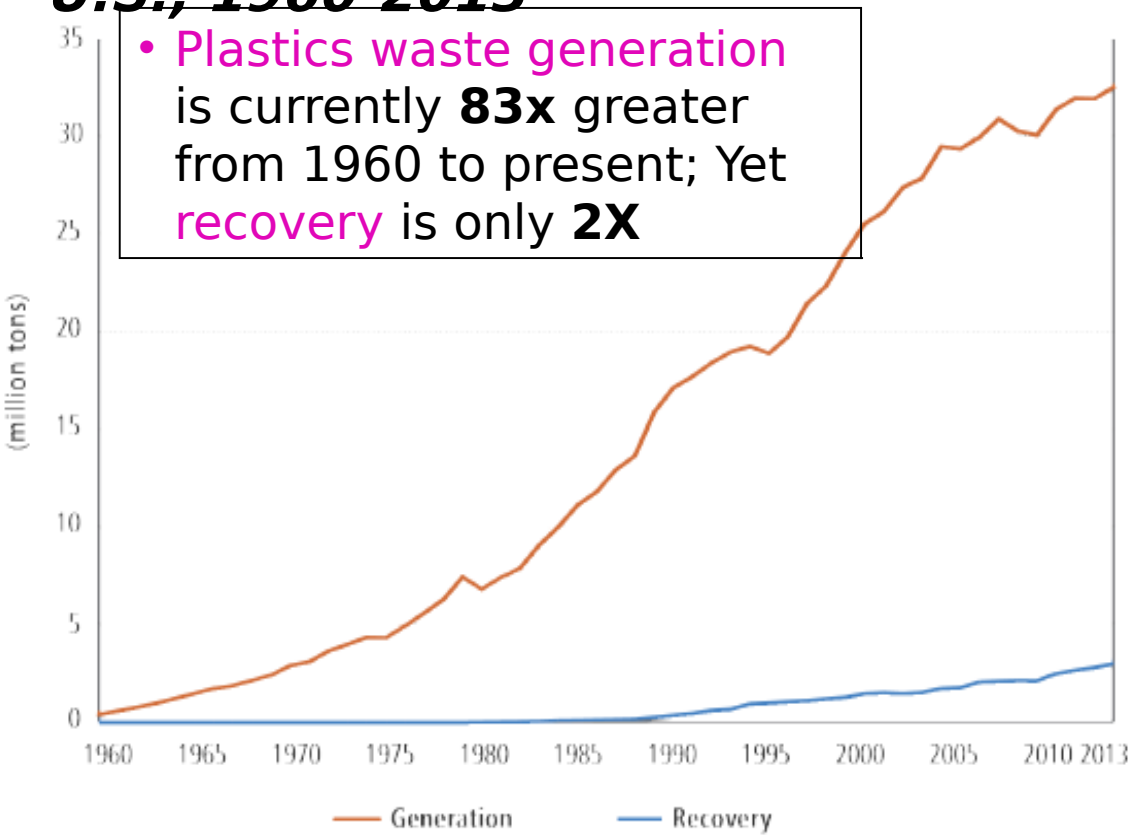
- *Devolatilization efficiency: 75.23%*
- *Gasification efficiency: 86.74 %*
- *Overall Process efficiency: 13 – 42% (wide range → uncertainty in product use)*

Figure 3. *ASPEN SWPS H_2 Generation*

Plastics Waste in the U.S.

- In US, Plastics accounted for approximately 13% of total MSW
- Recyclable plastics are designated as rigid plastics of primarily #1-PET, #2-HDPE, and #5-PP resins
- Non-recyclable plastics are primarily films and multi-layer packaging

Plastics Generation and Recovery in U.S., 1960-2013



Source: US EPA

Impact of NRP on Methanol Production from Waste Gasification

- Conducted pilot testing of Enerkem process at City of Edmonton's Advanced Energy Research Facility (AERF) in Edmonton, Alberta, Canada

- Tested biomass-NRP mixtures of varying plastic concentration and measured syngas composition to quantify impact of NRP on methanol production

**Enerkem commercial facility,
Edmonton, Canada
Design capacity: approx. 300 tpd**

**Enerkem process at Advanced Energy Research Facility (AERF)
Edmonton, Canada
Capacity: 8 tpd**

Earth Engineering Center
CITY COLLEGE of NEW YORK

Contaiminated Non-Recyclable Plastic Heating Value Confirmation

WIERT
Waste-To-Energy Research and Technology Council

American Chemistry Council℠

Grab samples taken directly from unsorted trash bag

- *Experimentally determined LHV for as-received, contaminated, non-recycled waste plastics.*
- *Tests included rigid and film plastics with varied contamination.*
- *Typical NRP mixture in MSW = HHV of 33.5 MJ/kg.*
  Accepted resin HHV = 35 MJ/kg

NRP HHV 15% of virgin resins' heating value at most

On average – within 7%

If all MSW generated per year in US converted to energy → 1/50 electricity demand

Contaminated Waste Plastic	Associate Resin	Measured LHV, MJ/kg	Literature LHV, MJ/kg
Clear cup	PET	21	24
Coffee cup lid	PS	40	41
Flexible mail packaging	mostly PE	40	44
Potato chip bag with metal coating	mostly PE	40	44

Limits to Recycling

Some areas have great **real** *recovery rates*

	Generated waste (Tons)	(Tons)		recycled
Lombardia, Italy (2009)	4403066	538730	12.2	**85**
Lee county, Florida, USA (2012)	1098301	145400	13.2	59
Orange county, Florida, USA (2012)	1881650	306582	16.3	58
Sarasota, USA (2012)	719643	107303	14.9	44

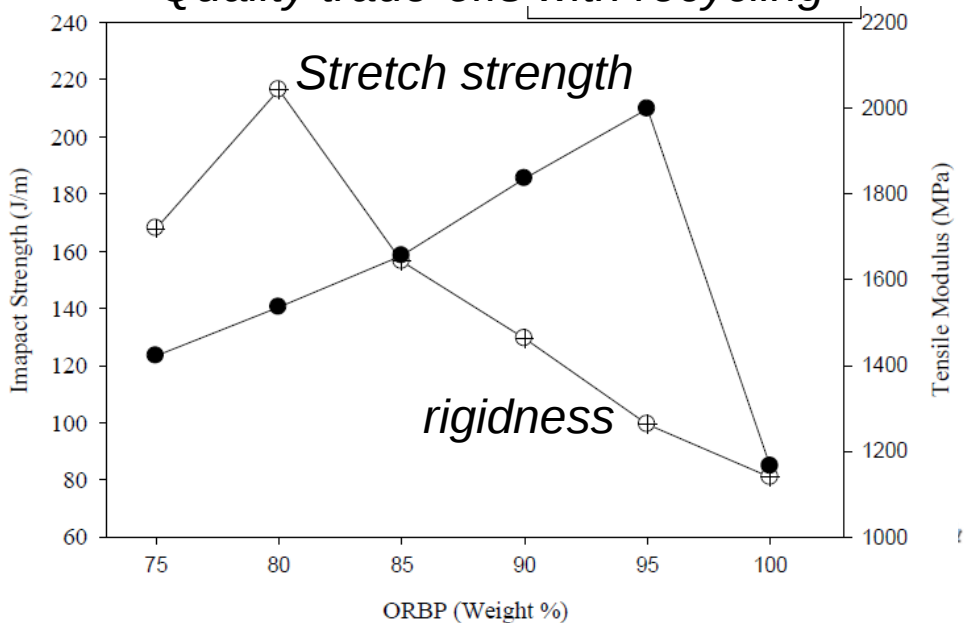
Deepak Sharma et al.

Having ideal recovery of rates of 85% and 73% for paper and plastic waste streams.

Leaves 83,846 tons of waste left in this ideal community (~15 %)

This is only plastic and paper

Quality trade-offs with recycling



Impact of Plastics co-Gasified with Biomass

System uses O_2 and steam as reactants

Plastic addition provides more heating value

Plastic addition reduces char

	100% Biomass (Wood chips)	92% Biomass/8% Plastics Mixture	85% Biomass/15% Plastics Mixture	50% Biomass/50% Plastics Mixture
C	40.30	44.18	44.50	54.36
H	4.94	5.88	6.23	8.02
N	0.56	0.47	0.43	0.46
O	32.98	30.86	26.96	21.64
S	0.05	0.06	0.08	0.06
Ash	12.83	11.26	9.44	7.09
Moisture Content (MC)	8.34	7.29	12.36	8.38
TOTAL	100.00	100.00	100.00	100.00
H/C Ratio (molar)	1.46	1.59	1.67	1.76
Higher Heating Value (Btu/mol)	1,555	2,322	2,495**	2,903**
Empirical formula (molar basis)	$CH_{1.46}O_{0.61}N_{0.01}$	$CH_{1.58}O_{0.53}N_{0.01}$	$CH_{1.67}O_{0.45}N_{0.01}$	$CH_{1.76}O_{0.30}N_{0.01}$