WTE Research in USA

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Presentation to:

ARPA-E

CONVERTING SOLID WASTE TO ENERGY-INTENSIVE MATERIALS

November 7th, 2019
Newark, NJ

Outline

- General perspectives
- Thermal Conversion Overview
- Process Operation Impacts on Final Effluents
  - Sulfur/Chlorine Effects
  - Emissions Impacts from Combustion Adjustments
  - Process Adjustments Enabling Beneficial Ash Use
  - Some Specifics on Plastics
- A word about non-combustion technologies

These slides are a launching point for discussions – not a one-sided presentation

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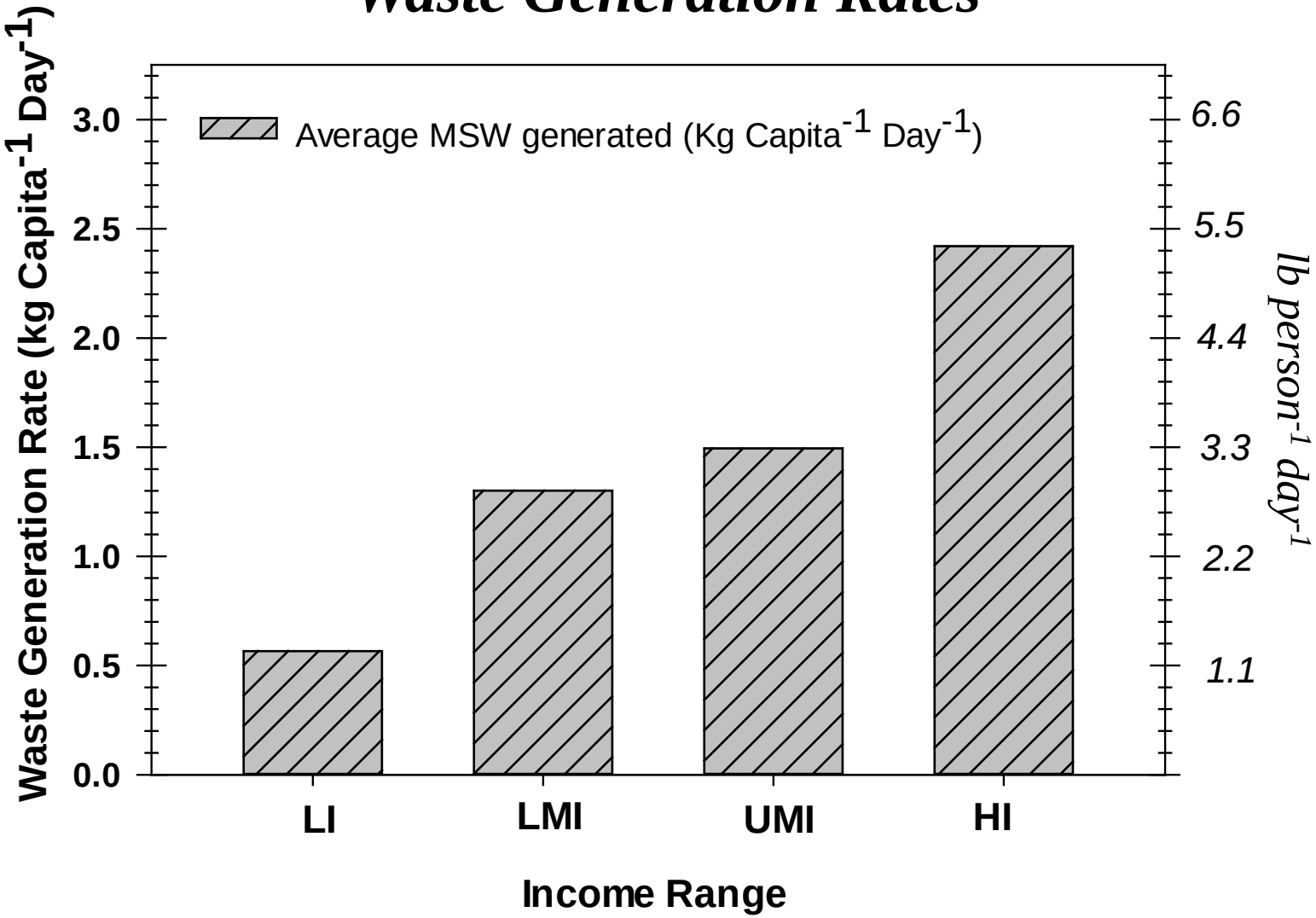
disclaimer

Research presented here is summary of work from CCNY
Many others doing research with waste, such as…

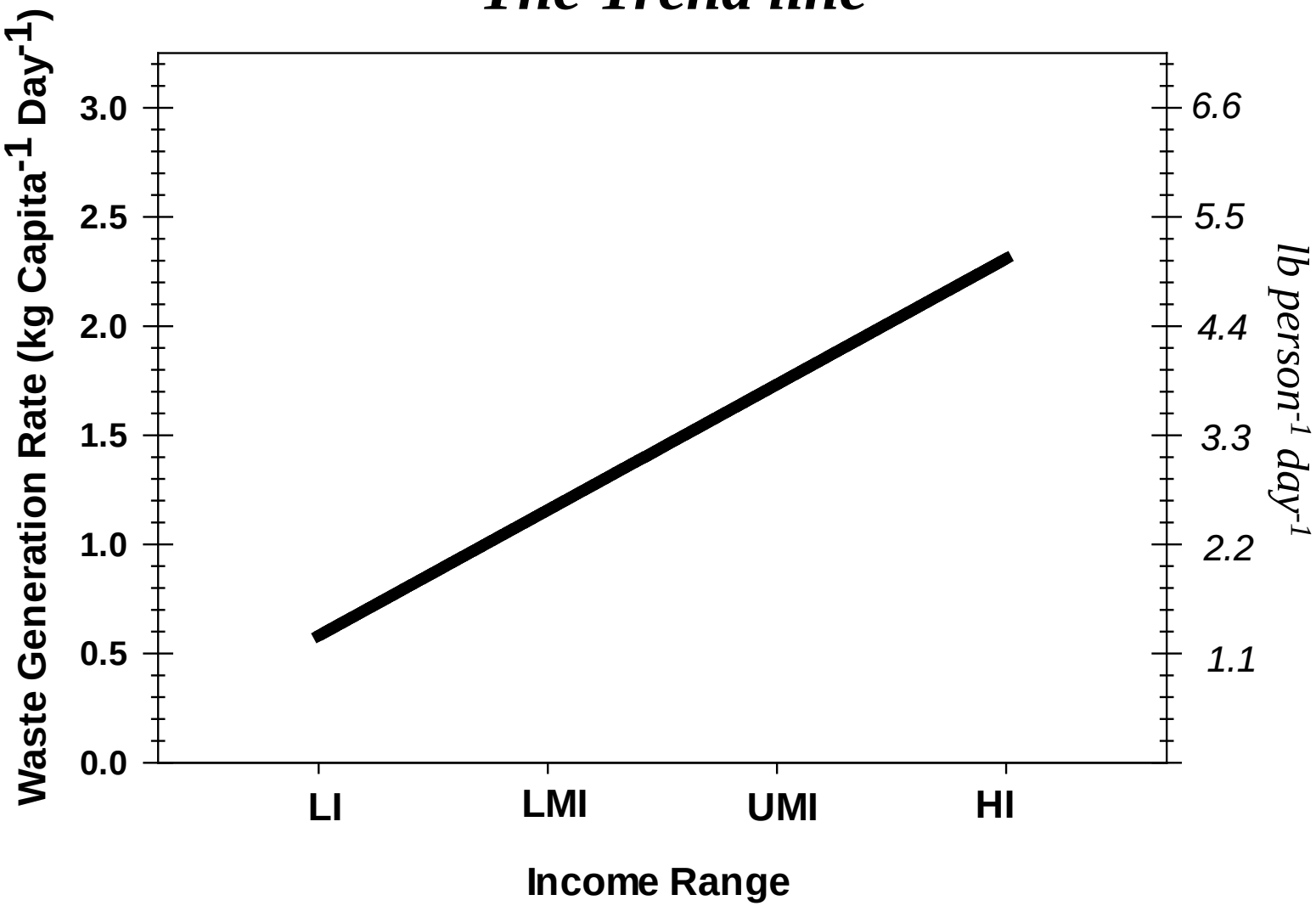
WTE Companies
EREF(https://erefdn.org/)
Solid Waste Association of North America (SWANA)
Hinkley Center (https://www.hinkleycenter.org/about-the-center.html)

More Perspective, Waste Generation Rates



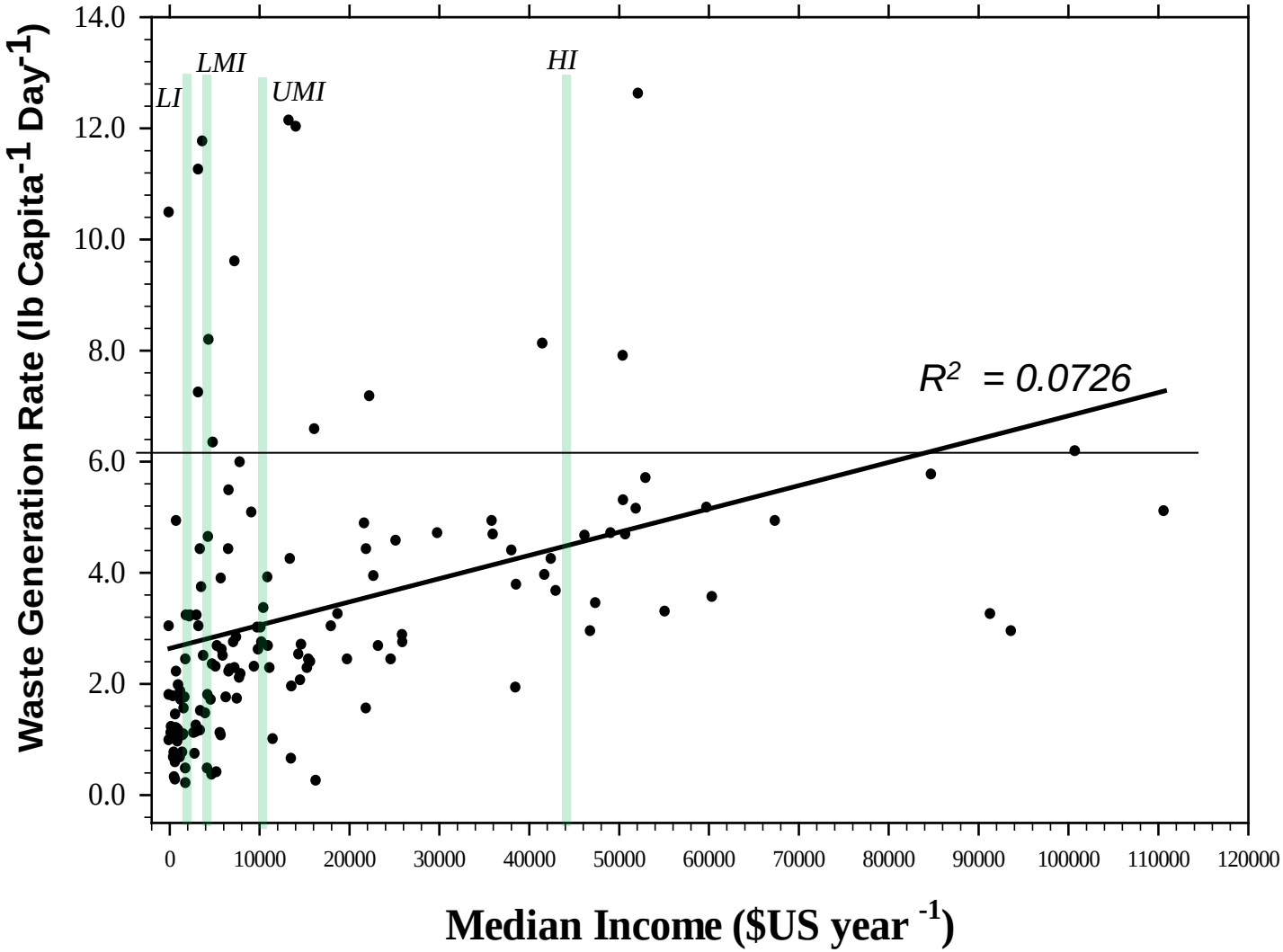
- *Typical data presentation regarding averages shows higher income regions generate more waste*

Waste Generation Rates – The Trend line –



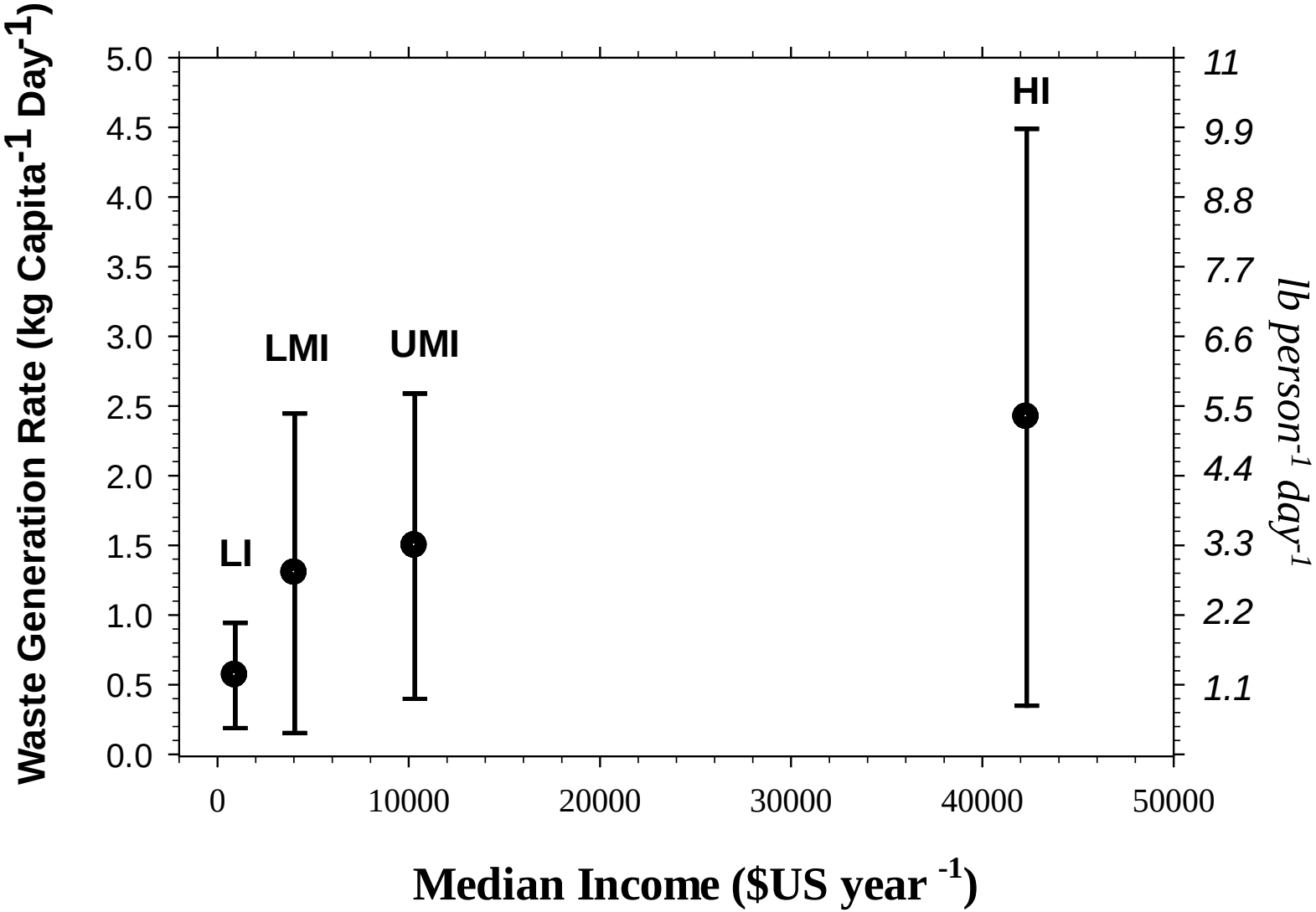
•*Trend line in data does not exactly match average trends*

Waste Generation Rates – Actual Data –



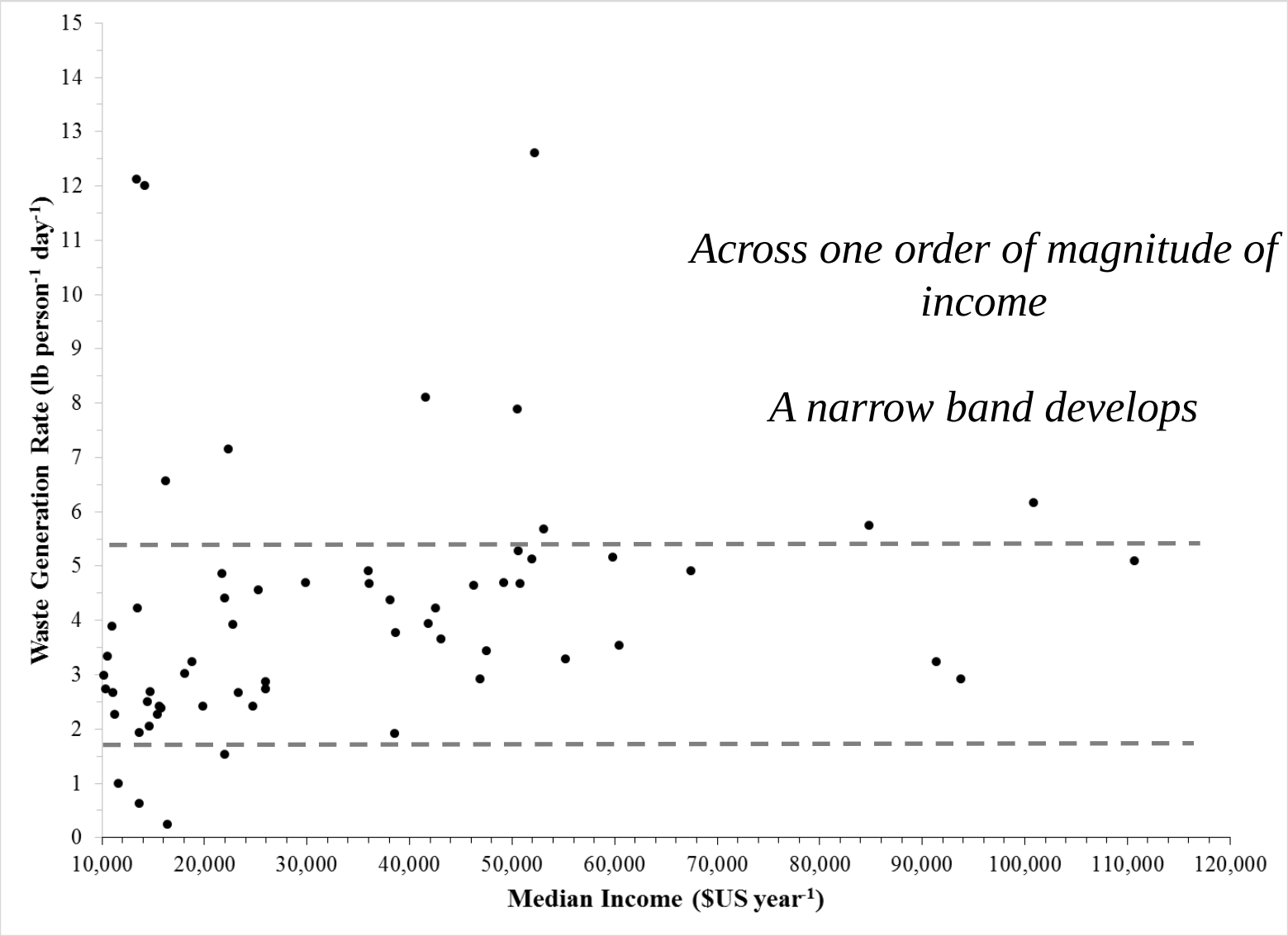
- *No clear correlation with income level when looking at all data*

Waste Generation Rates – Actual Data with Statistics –



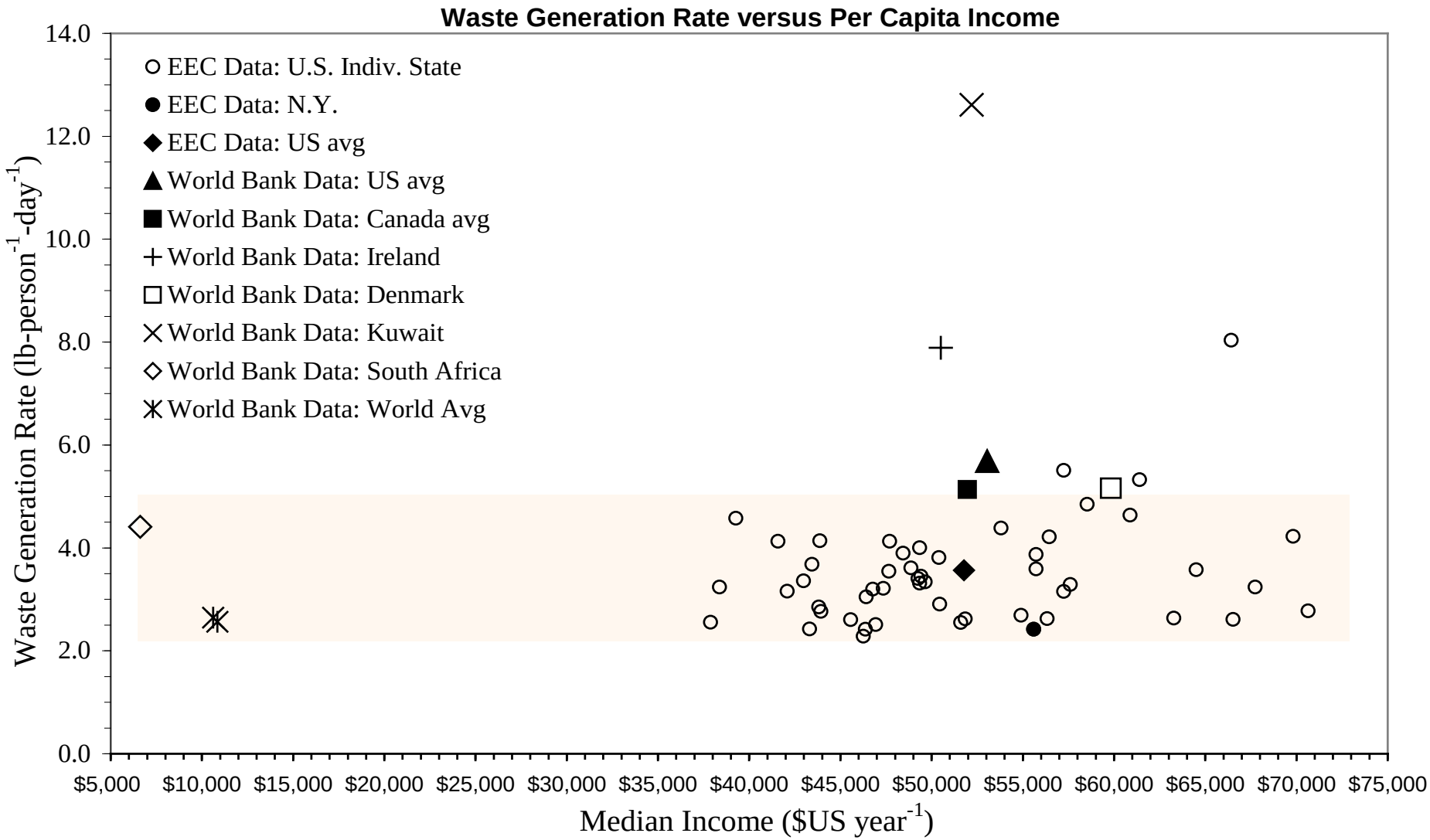
- *Using averages and standard deviation → large overlap*

Is there a minimum amount of waste?



•*Narrow Band: ~2.5 and 4.0 lb/person/day*

Is there a minimum amount of waste?

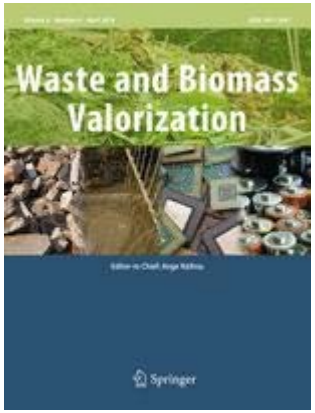


- *No clear correlation with income level*
- *Narrow Band: ~2.5 and 4.0 lb/person/day*
- *Indicates a base level of waste must be generated to live?*

Technical Limits to Recycling

Some areas have great real recovery rates

	Generated (Tons)	waste (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



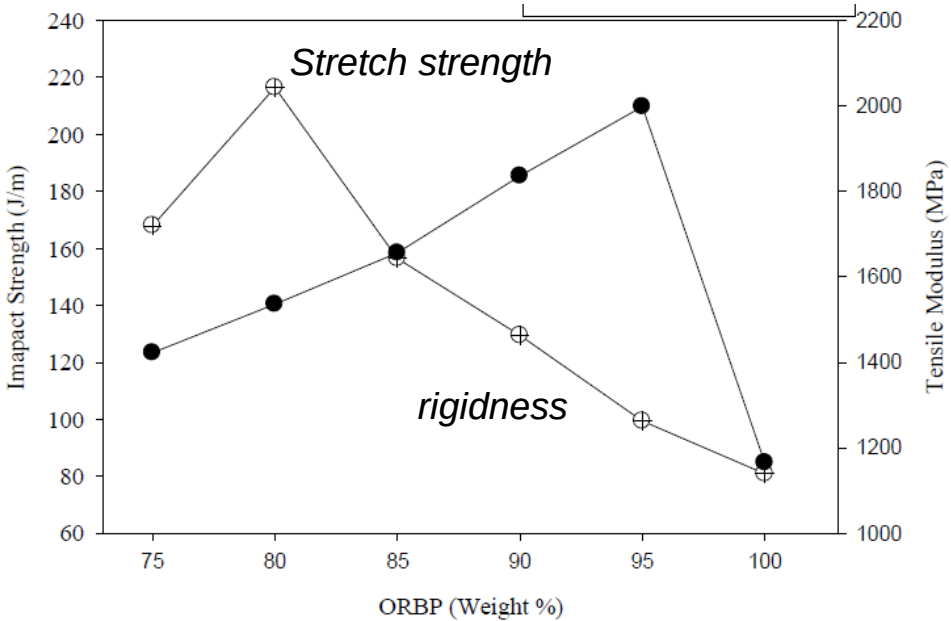
Sharma, D.K., et al. (2017)
https://doi.org/10.1007/s12649-017-0109-5

*Having **ideal** recovery of rates of 85% and 73% for **uncontaminated** 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



Why Thermal Conversion?

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Waste-To-Energy Research and Technology Council

- Four facilities @ 3,000tpd on ~15 acres each
- Processing 11,693 tpd total
- Location Possibilities

If Landfilled, over 30 years
34% of Central Park
0.21×10^{-4} acre/ton @ 25 foot depth

125 Union Avenue, Johnstown, NY | Fulton County
125 Union Avenue — Less Detail -
25 acres
Eric Simonds, CCIM , CBRE Albany, Part of the CBRE affiliate network
24.8 acres of land available for sale in the Johnstown Industrial Park

Route 25, Calverton, NY | Suffolk County
42-Acres-Heavy Industrial Land for Sale-Divisible — Less Detail -
42 acres
Scott Roth , Company Not Provided
Town of Riverhead will consider a variety of industrial & commercial uses for this huge property/ gas, electric & water at the road/ ideal for manufacturing, warehousing, trucking, industrial-park,...

488 Hudson River Road Rear, Mechanicville, NY | Saratoga County
Heavy Industrial Lot-45-Ac-Adj. to Rail — Less Detail -
45 acres
Scott Roth , Company Not Provided
Shovel-ready, Industrial Land for Sale or Lease / 45-acre Lot / Zoning coverage allows for construction of 750,000 SF building / well-suited for manufacturing, R&D, defense-contractor, intermodal,...

WTE in 30 yrs

$1.8 – 0.21 \times 10^{-4}$ acres/ton @ 25' depth

Land preservation/resource recovery

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Incineration vs WTE

- Incineration → designed to thermally destroy a waste material

- WTE → designed to produce electricity and useful steam by thermally converting a waste material.

- Incineration is **<u>not</u>** required to produce energy and many actually consume energy to destroy the waste feedstock.

- WTE facility typically produces an average of 650 kWh of electricity per ton of MSW and approximately 600 kWh of steam per ton of MSW that can be used for heating or cooling operations.

- Only similarity between incineration and WTE is that they both combust the waste with air and strive to achieve a well-established performance metric comprised of temperature, time and turbulence, typically referred to as "the 3 T's". $T \geq 850$ °C; $t_{res} \geq 2$ sec & high turbulence.

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Thermal Conversion

Pyrolysis, Gasification or Combustion

- *Normally no air*
- *Only heat (external or internal)*
- *Want liquid, Gases not desired*
- *Pollutants in reduced form (H_2S, COS)*
- *High Char*
- *Scale: ~ 10 tons/day*

- Sub stoichiometric air
- Lower total volumetric flow
- Lower fly ash carry over
- Pollutants in reduced form (H_2S, COS)
- Char @ Low T
- Vitrified Slag @ high T
- **Scale: ~ 100 tons/day**

- Excess air
- Higher volumetric flowrate
- Fly ash carry over
- Pollutants in oxidized form (SO_x, NO_x, etc)
- Bottom ash
- **Scale: ~ 1500 tons/day**

No additional Oxygen (only heat)
Unconverted solid will remain!

Some additional Oxygen (or air)
Heat added or comes from reactions

Much additional Oxygen (or air)
Heat comes from reactions

In-situ heating

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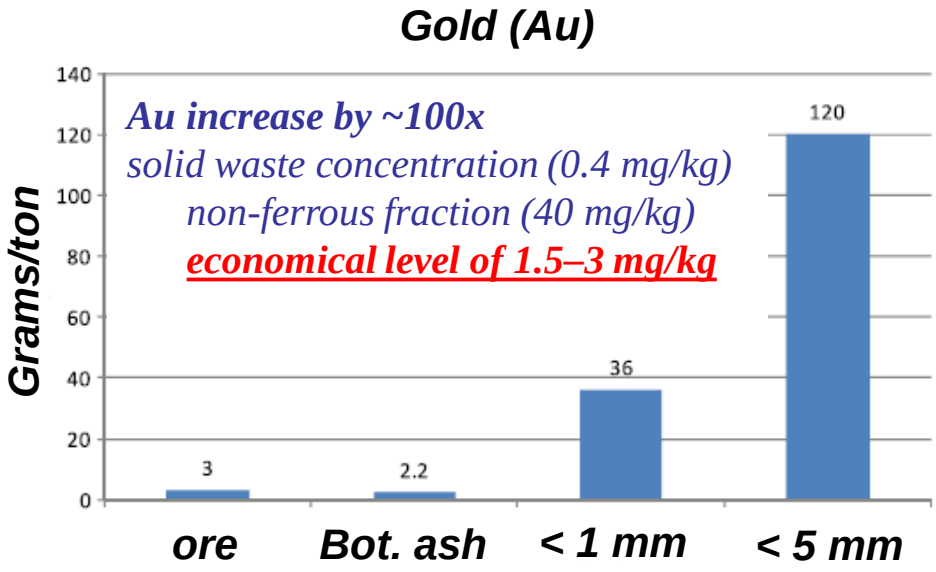
Recovery of materials from ash

Values of one facility in Switzerland

Nearly all facilities recover metals and non-metals from ash residue

Precious metals to critical materials.



Source: Morf, L.S., et al. Waste Management (2012), http://dx.doi.org/10.1016/j.wasman.2012.09.010

Table 4

Estimated annual flow of selected precious metals, REE and other metals in the waste input of the SWI in Hinwil, Switzerland (kilograms/year) including uncertainty (standard deviation).

	Annual flow (kg/a) ± uncertainty (sd)
Iron	6,300,000 ± 309,000
Aluminum	3,400,000 ± 191,000
Copper	440,000 ± 44,000
Zinc	320,000 ± 60,000
Barium	150,000 ± 12,000
Lead	110,000 ± 9800
Chromium	36,000 ± 2800
Strontium	26,000 ± 1800
Nickel	24,000 ± 2300
Zirconium	23,000 ± 8400
Tin	15,000 ± 1400
Wolfram	11,000 ± 9600
Vanadium	2200 ± 150
Cobalt	2100 ± 160
Lithium	1800 ± 120
Cadmium	1800 ± 110
Molybdenum	1700 ± 180
Rubidium	1700 ± 90
Yttrium	1600 ± 710
Neodymium	1500 ± 590
Silver	1100 ± 140
Bismuth	570 ± 31
Hafnium	530 ± 187
Niobium	500 ± 19
Gallium	440 ± 27
Praseodymium	380 ± 170
Tantalum	250 ± 110
Scandium	190 ± 16
Gadolinium	150 ± 35
Selenium	89 ± 4.1
Gold	81 ± 40
Indium	58 ± 4.4
Beryllium	56 ± 6.2
Germanium	41 ± 2.8
Tellurium	17 ± 2.2
Thallium	16 ± 4.1
Platinum	12 ± 4.4
Ruthenium	0.10 ± 0.033

3,400 tons

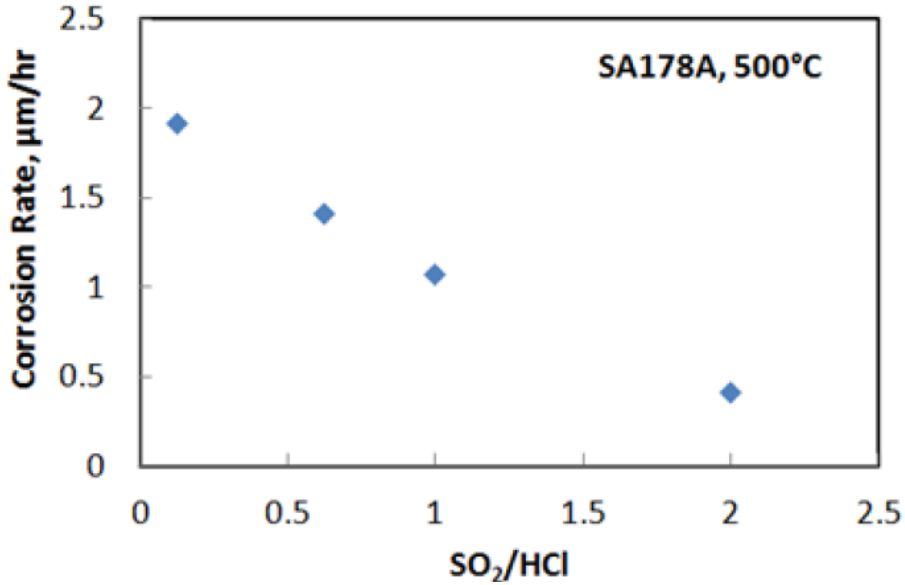
440 tons

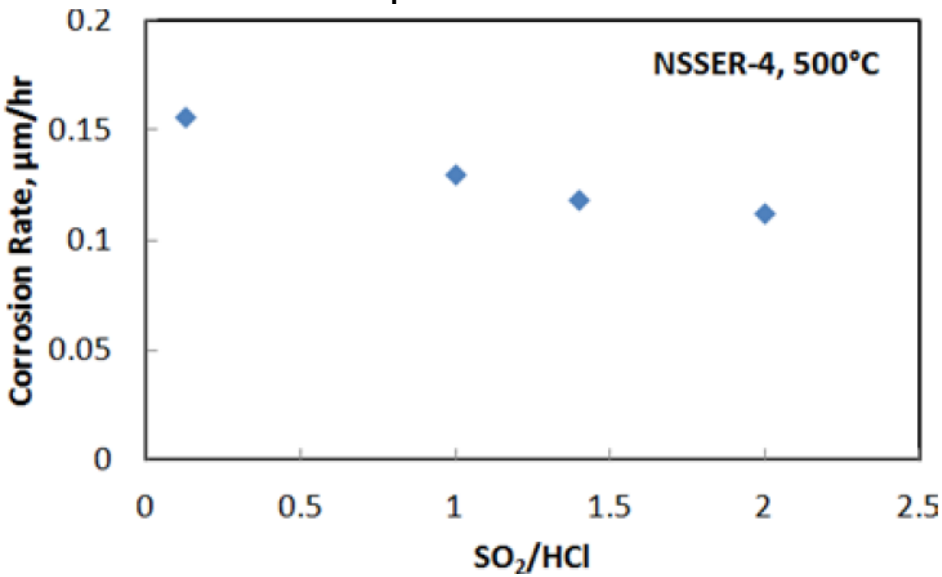
1.5 tons

1.1 tons

Addition of Sulfur in Boiler Sequesters Cl

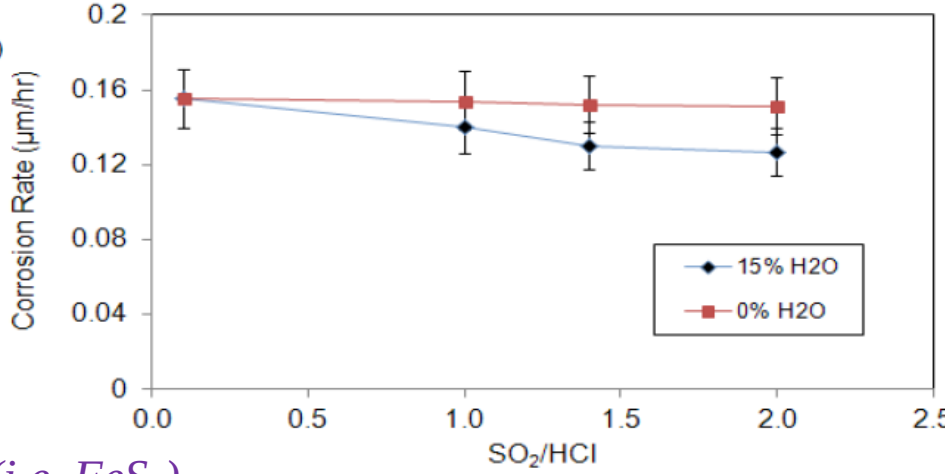
corrosion used as measure of capture





$$2NaCl_{(s,g)} + SO_{2\,(g)} + 0.5\,O_{2\,(g)} + H_2O_{(g)} \rightarrow Na_2SO_{4\,(s)} + HCl_{(g)}$$

$$2NaCl_{(s,g)} + SO_{2\,(g)} + O_{2\,(g)} + \rightarrow Na_2SO_{4\,(s)} + Cl_{2(g)}$$



NaCl comes in with waste

Sulfur comes with waste but can be easily added (i.e. FeS_2)

Water plays a key role – prevents the formation of chlorine gas

Sharobem, T. T. (2017). *Mitigation of High Temperature Corrosion in Waste-to-Energy Power Plants* (Doctoral dissertation, Columbia University).

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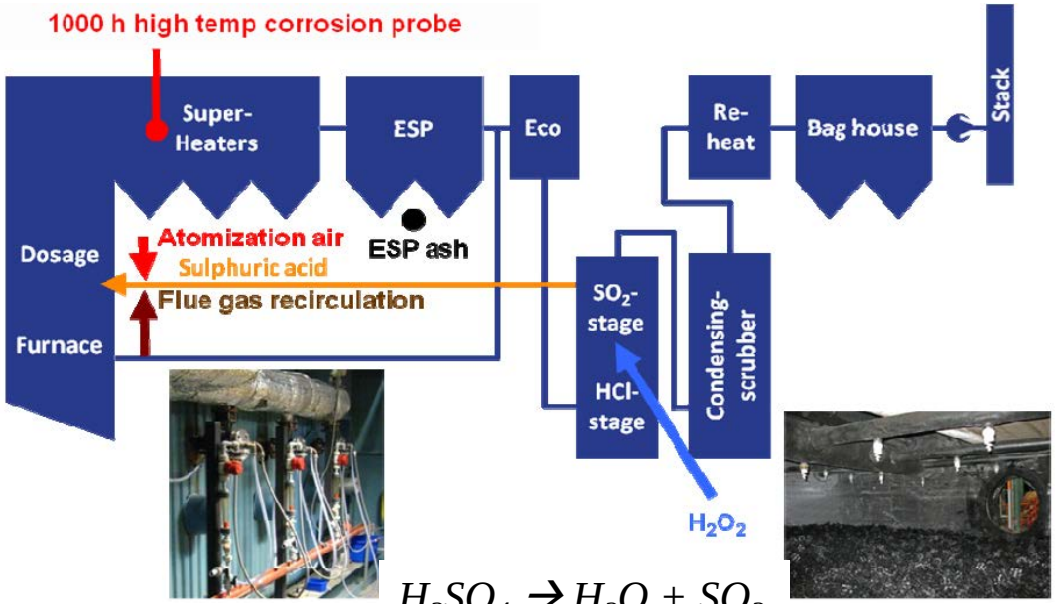
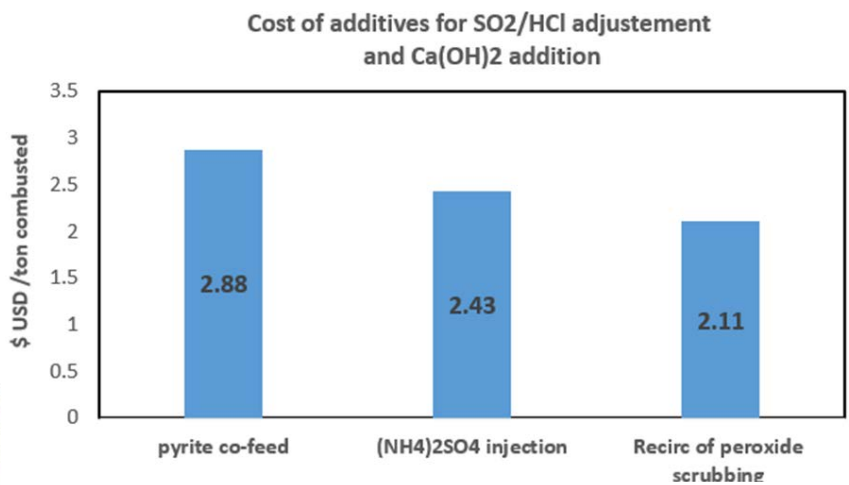
Field Test: Flue gas recycle & S recycle

corrosion reduction for increased availability





$$H_2SO_4 \rightarrow H_2O + SO_3$$
$$SO_3 \rightarrow SO_2 + ½\ O_2$$

- ***Added costs***
  offset from Fe sales?
- ***No change in emissions***

Table 3 - Mean values of emissions during the 1000 hour reference run and 1000 hour sulphur recirculation run together with the 24-h emission limits. *Guideline value.

	HCl	*SO_2*	*NH_3*	*NOx*	*CO*	*TOC*	*CO_2*	*O_2*
	mg/Nm^3 dg,11%O_2	mg/Nm^3 dg,11%O_2	mg/Nm^3 dg,11%O_2	mg/Nm^3 dg,11%O_2	mg/Nm^3 dg,11%O_2	mg/Nm^3 dg,11%O_2	vol% dg	vol% dg
Emiss. Lim	10	50	10*	200	50	10		
Reference	3.8	1.0	1.3	49.0	15	0.23	10.5	8.6
Recirculation	3.7	1.5	0.18	53.5	4.7	0.24	10.5	8.7

Hunsinger et. al. (2007) Environ. Eng. Sci., 24, 1145-1159 Andersson S., et. al. Project report WR-07, WasteRefinery, SP, Borås, Sweden.

Emissions Improvements Continue

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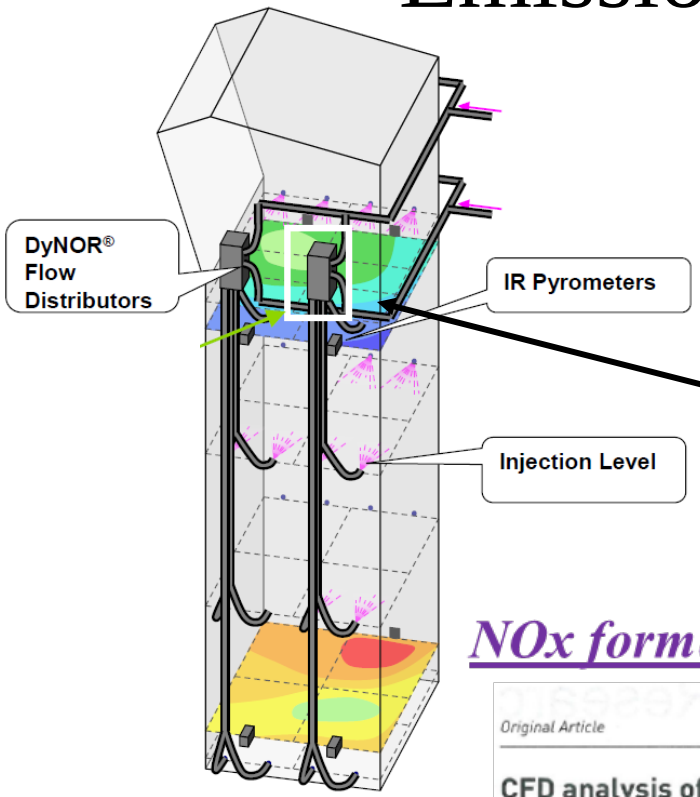

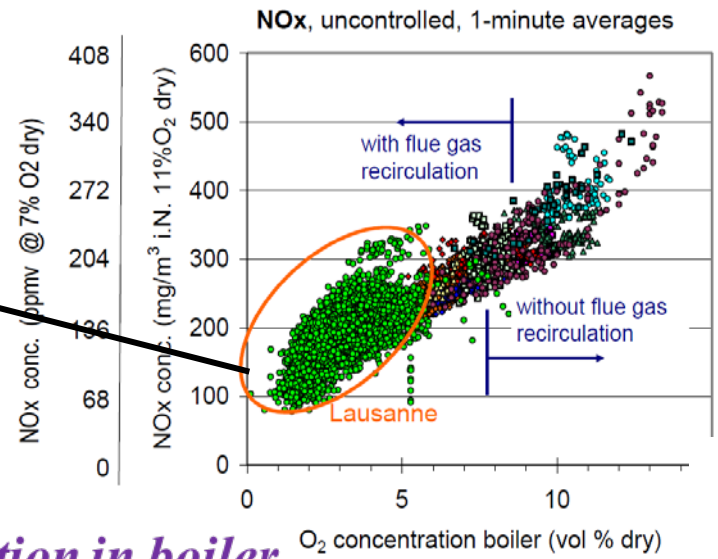

NOx formation in boiler

Original Article

WM&R

CFD analysis of municipal solid waste combustion using detailed chemical kinetic modelling

Waste Management & Research
2014, Vol. 32(8) 745–754
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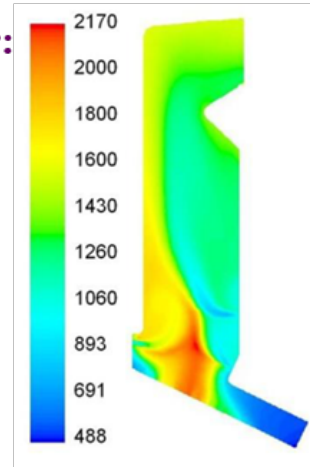
DOI: 10.1177/0734242X14538395
www.sagepub.com
SAGE

- **Fuel-N to HCN or NH_3 precursor: NOx formation at 2° air inlet**
- **Fuel-N to NO precursor: little change in boiler**
- **Fuel-N to NO direct conversion is ~50%**



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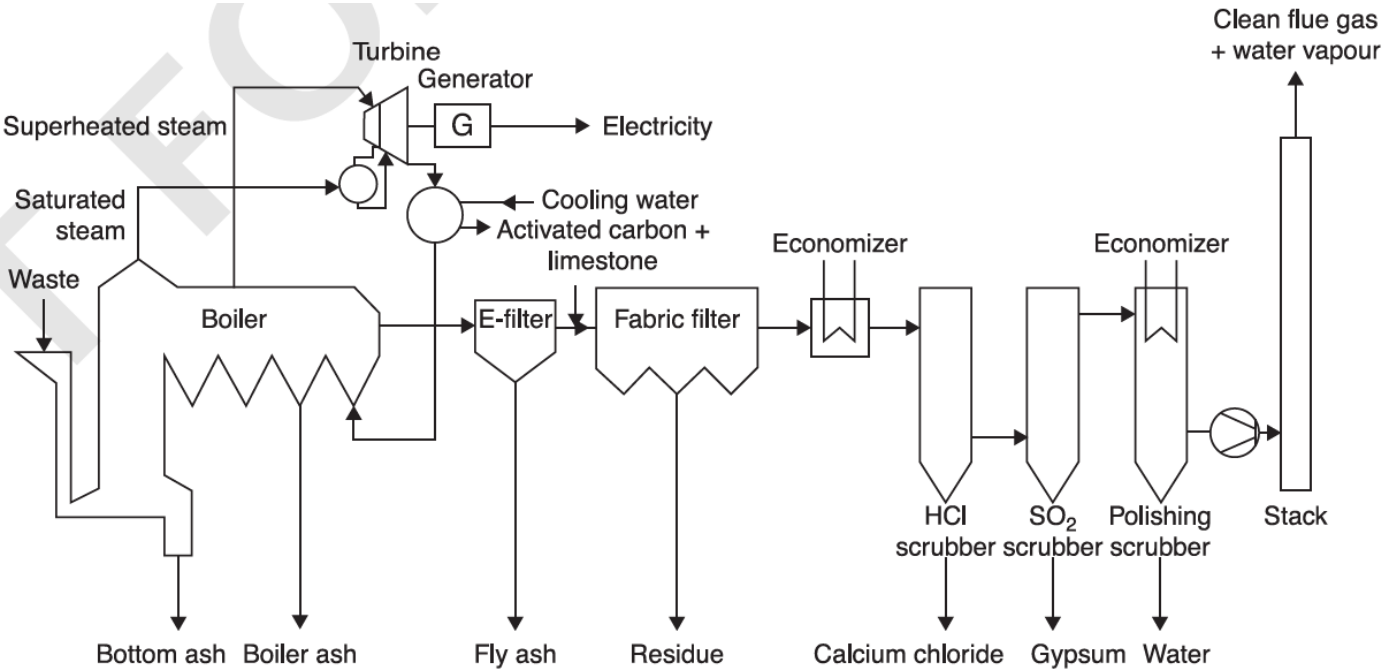
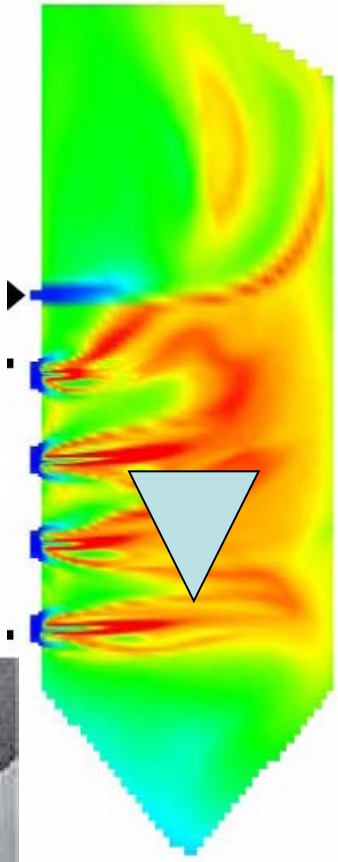
Field Operations: Emissions Reductions

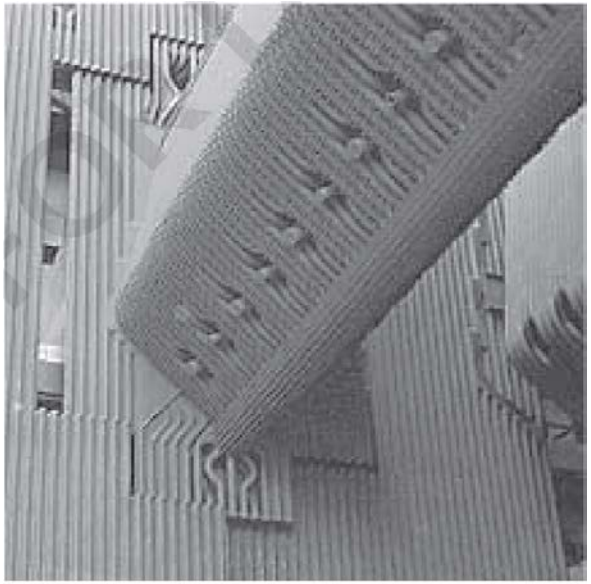


11.10 Amsterdam's waste-fired power plant.



Research & Development Continue

- *OFA Strategies*
  - *Seagers Prism – induces recirculation*
  - *Sludge injection – carbon and water*



Fly Ash Treatment Research

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Objective: Washing and thermal treatment experiments were carried out to determine a feasible pacification method for fly ash.

Testing : Fly ash from current operating facilities were tested.

- **Washing**: Fly ash was washed with water and acid to obtain pH 7.
- **Thermal**: Heating fly ash to high temperature (200, 300, 400,500, 550^0 C) in inert and ambient conditions.

Results:

Washing : **Fly ash washing testing concluded washing to be expensive (85 $/ton ash).**

Thermal Treatment: Treatment resulted in sintering of fly ash at 500°C.

- **The compounds effecting the sintering of ash → $CaCO_3$, $Ca(OH)_2$, $CaSO_4$ and CaCl(OH).**
  - vitrified product was unstable yet became fryable after one week exposed to ambient conditions.

Addition of $CaCO_3$ and $CaSO_4$ in fly ash increases the stability of the fly ash.

Degree of vitrification

Temp	550^0 C				500^0 C				450^0 C			
Time	15 min	30 min	60 min	120 min	15 min	30 min	60 min	120 min	15 min	30 min	60 min	120 min
Sample A	N	N	N	N	N	N	N	N	N	N	N	N
Sample B	N	P	P	P	N	N	P	P	N	N	N	N
Sample C	P	V	V	V	P	P	V	V	N	P	P	P

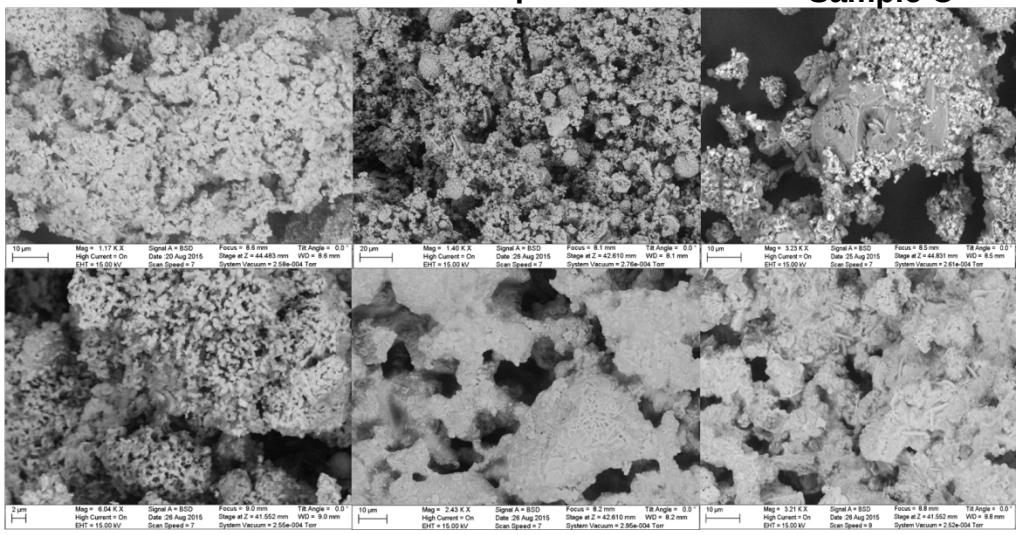
N = not vitrified
P = partially vitrified
V = vitrified

Vitrification occurs in the temperature range of 450^0 and 550^0 C

Sample A | Sample B | Sample C

450^0 C

550^0 C



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Bottom Ash Investigations

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Correlation between Pb oxidation and leaching

WTE plant	Lead compound type	TCLP Pb data
Plant 1	Pb3O4	0.132/3.62
Plant 2	PbO	1.57
Plant 3	Lead silicate	4.61
Plant 2a	-	1.57
Plant 3a	PbO	4.61
Plant 4	PbO2	0.311
Plant 4a	PbO	3.928

FAIL
PASS

Stability high to low
PbO_2 >Pb_3O_4>Lead Silicate>PbO

Low stability Pb compounds leach easily.

PbO_2 forms at the lower temperature, as the temperature increases this converts into PbO.

More precise temperature control in the boiler will impact quality of ash

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Bottom Ash Investigations

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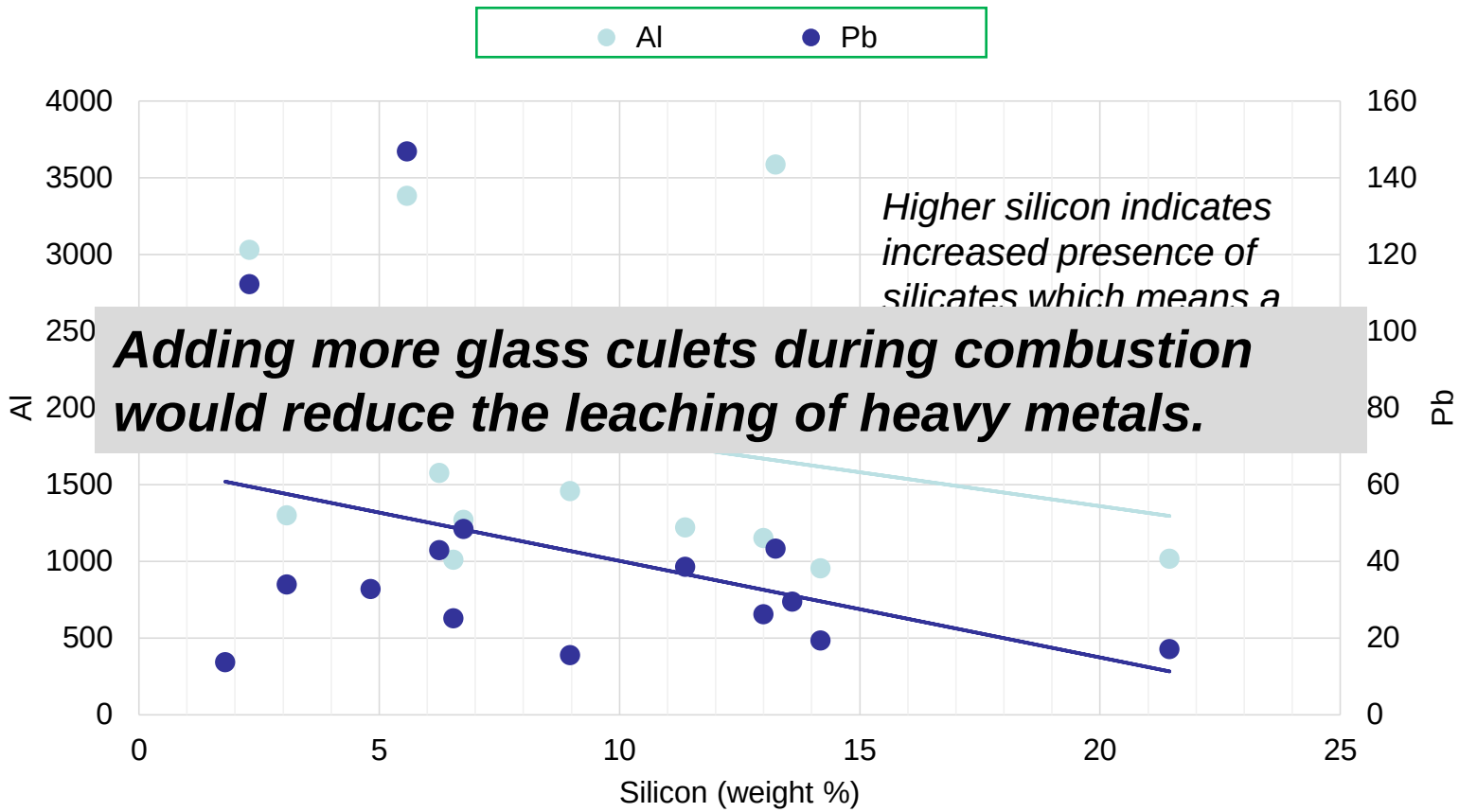
Silicon vs Lead/ Aluminum



Adding more glass culets during combustion would reduce the leaching of heavy metals.

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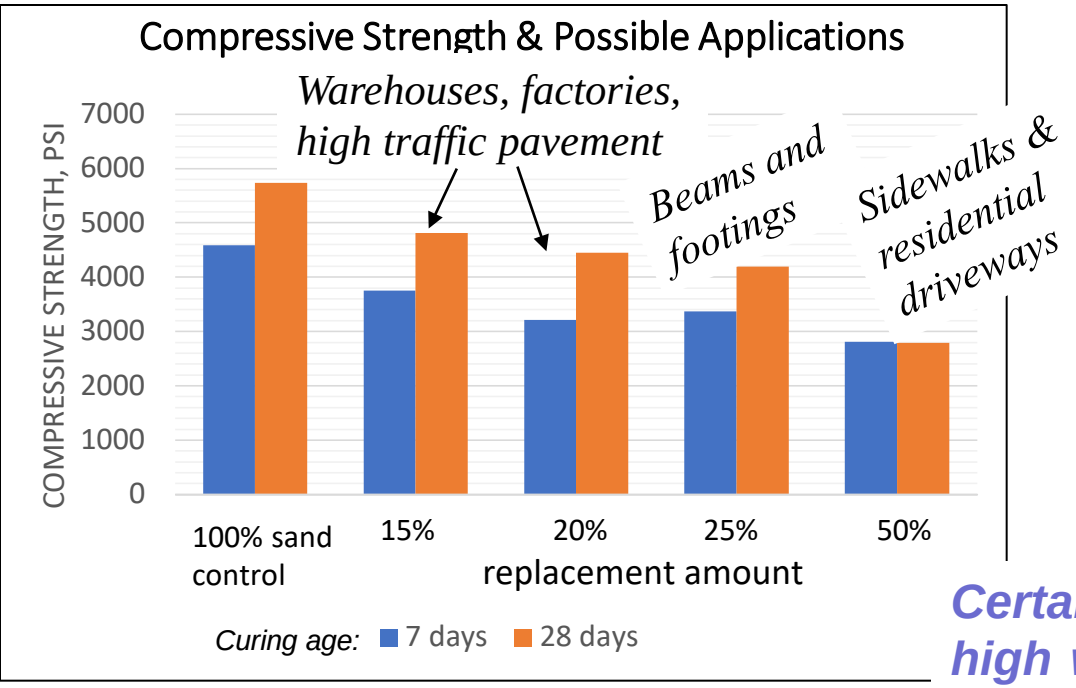
Beneficial Use of Waste-to-Energy Residual

- *Aggregate from WTE facilities can be diverted from landfill and repurposed into a construction aggregate*
- *Tests demonstrate that up to 50% of the natural sand in a concrete mix can be efficiently replaced.*



Aggregate material from WTE successfully pass ASTM cement and concrete standards:

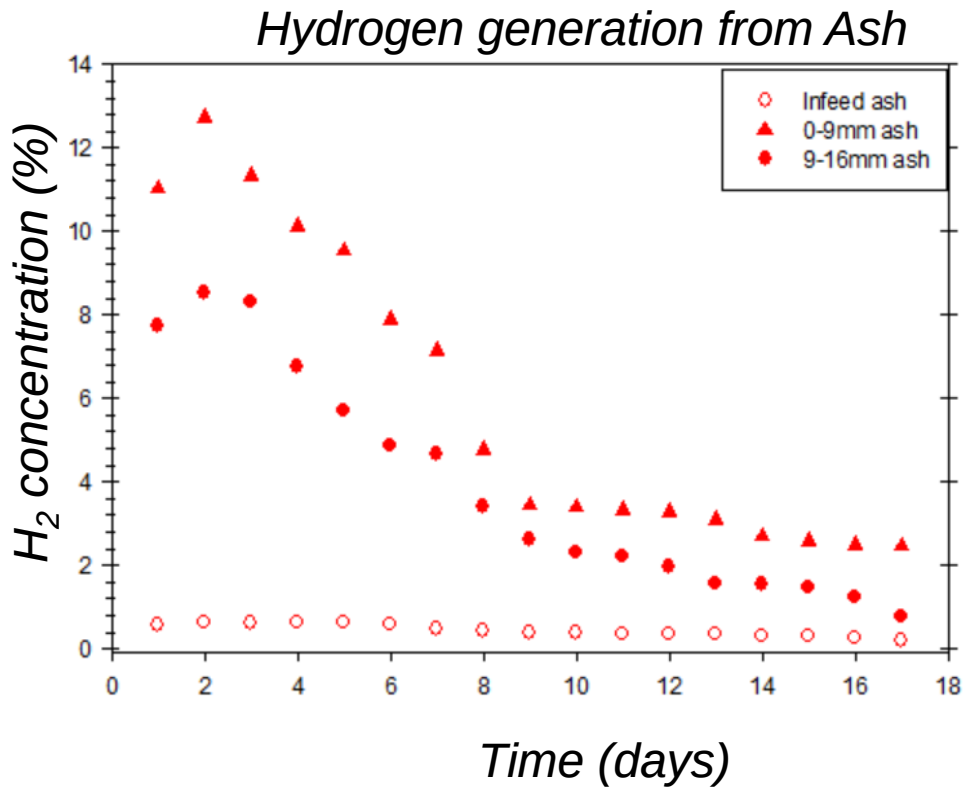
C39/C39M-18 (Compressive strength)
C128-15 (Specific gravity)
C289-07, C1260 (Alkali-Silica Reactivity)
D2419-14 (Sand Equivalent Value)
C138 (Density, Air content)
C1252 (Aggregate Angularity)
D2434 (Permeability)

Certain fractions of the aggregate have high water uptake. Possibility for use in applications requiring long cure times

Hydrogen generation from WtE ash

Issues

- H_2 production rate varies:
  - 2 L/kg to 12 L/kg of ash
  - Particle Size dependent.
- Problems during transport and storage



Opportunity?

Wet extraction of bottom ash can enhance hydrogen generation

A Few Words About Plastics

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New York City Situation

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

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

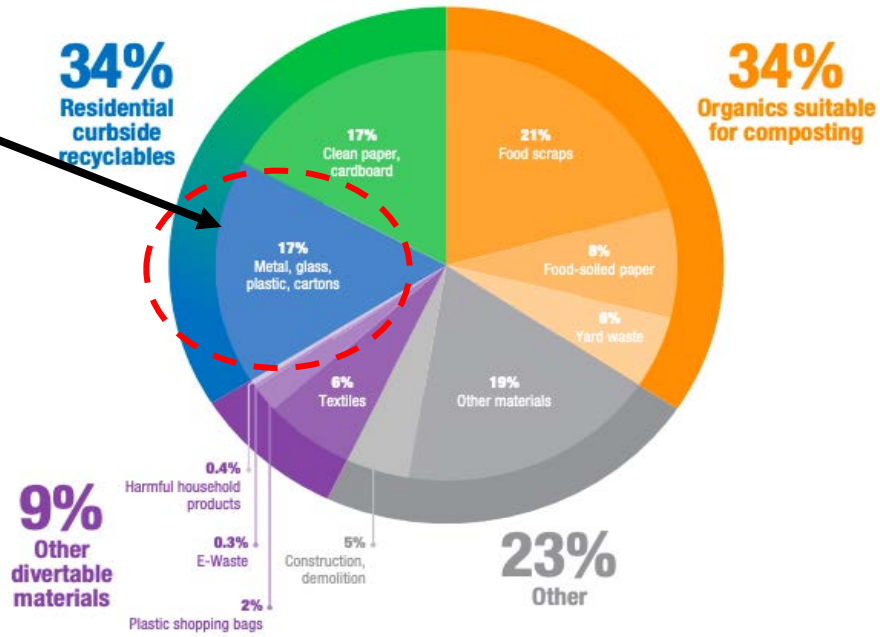
Blue bin plastics collected = 81,679 tons (18%)

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

If all recovered plastics are recycled = 8.8%

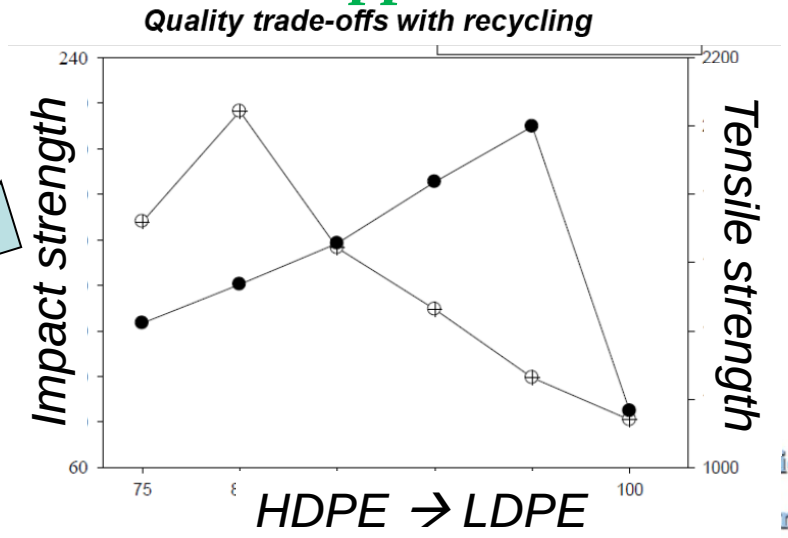
U.S. EPA states = 9.1%

biocycle states = 7.5%



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

Remember the trade-off



Plastics recycling: ~8% → 73%

Remember: Recovery is not recycling

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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

Possible "Big Idea"

Asphalt Use in Road Construction

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.

Asphalt

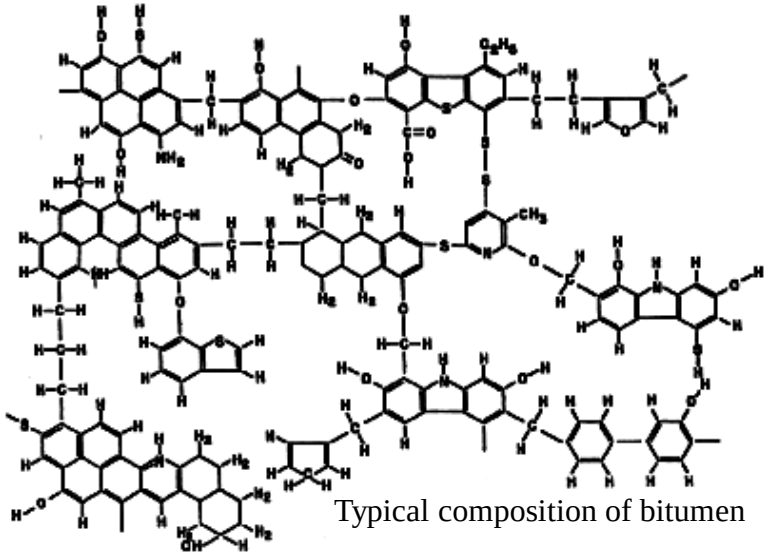
Indirectly

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

Start-up Company

evizero®
the ecological, transparent binder

"The product is sold in PE bags which can be introduced into the **production process without even having to be opened."**



Typical composition of bitumen

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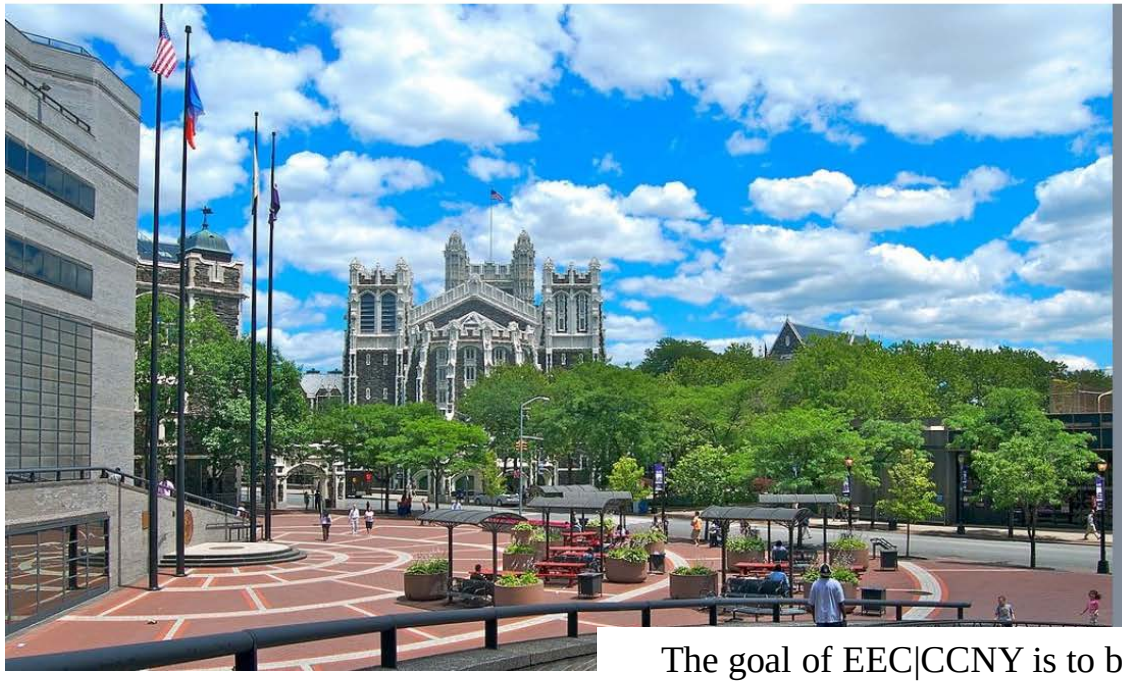

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Engineering of Earth's energy and material resources for responsible utilization and preservation

Much of this work is developed by students and research associates of the Earth Engineering Center

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