



# Thermal Conversion and Waste-to-Energy Process Modeling

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Slides available at  
<http://go.ncsu.edu/swm-lca.resouces>

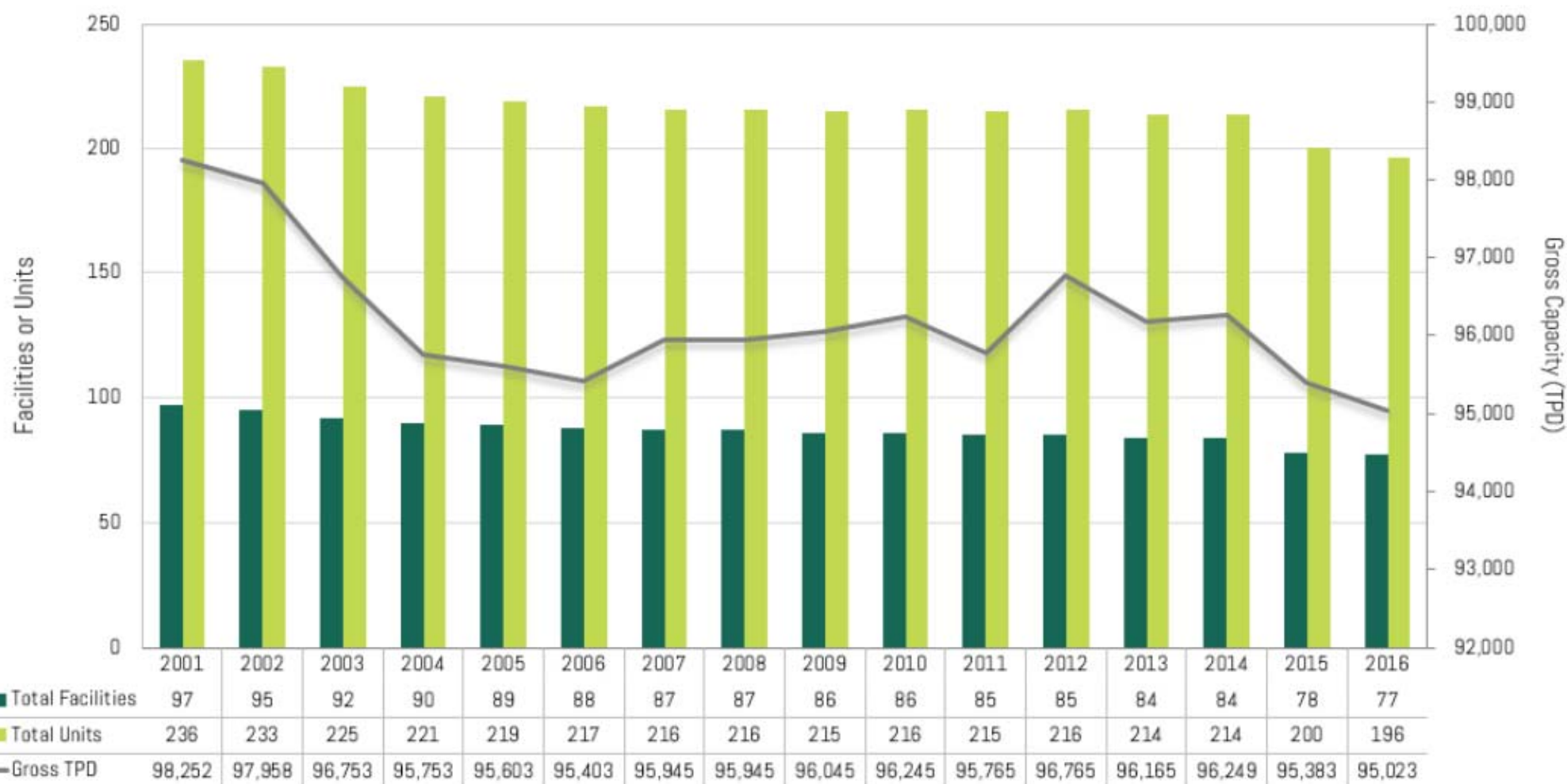
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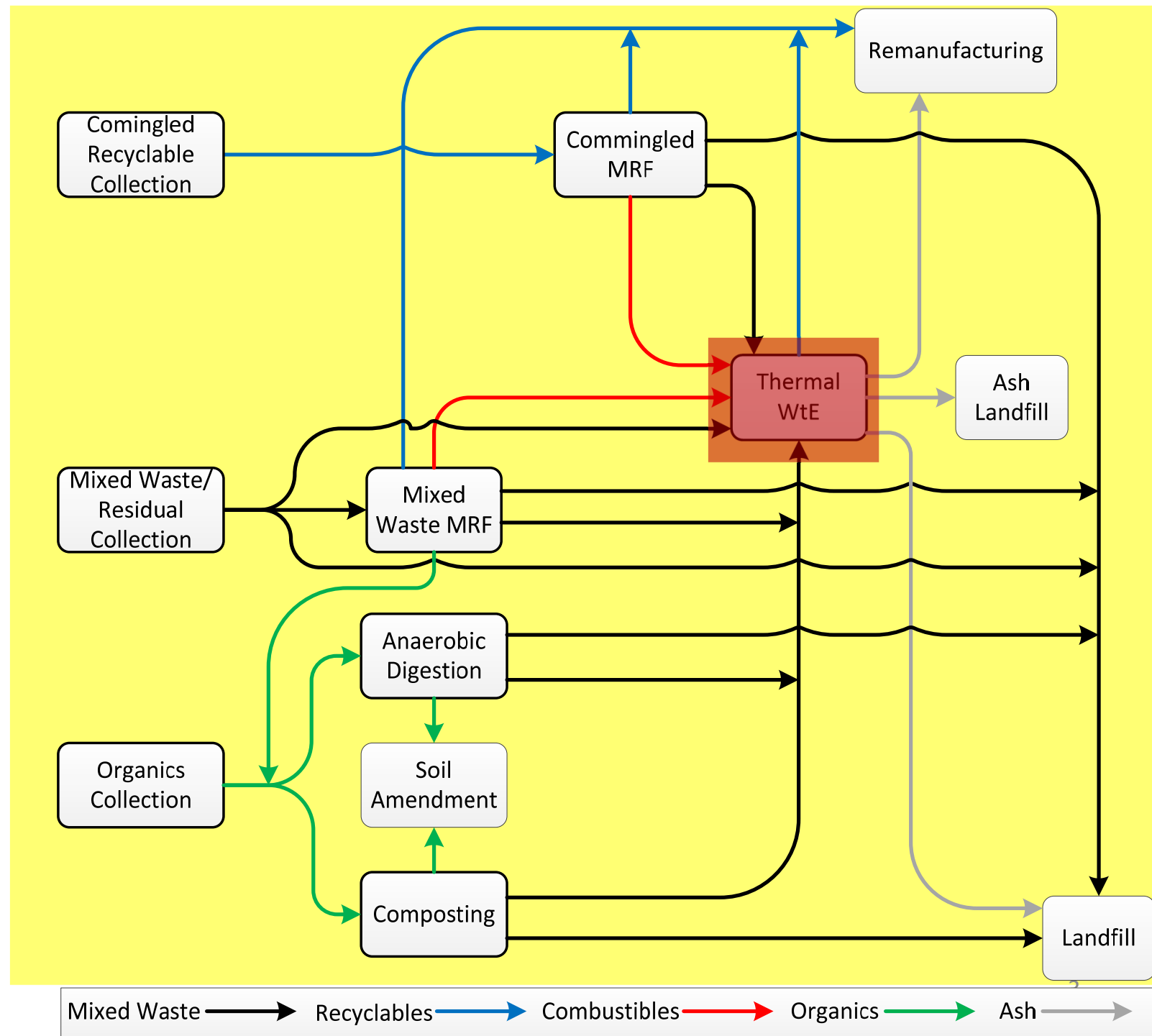
# Waste-to-Energy (WTE) in the U.S.

- ~13% of all MSW is combusted for energy.
- ~80 operating facilities accepting ~95,000 tons per day.

WTE Capacity

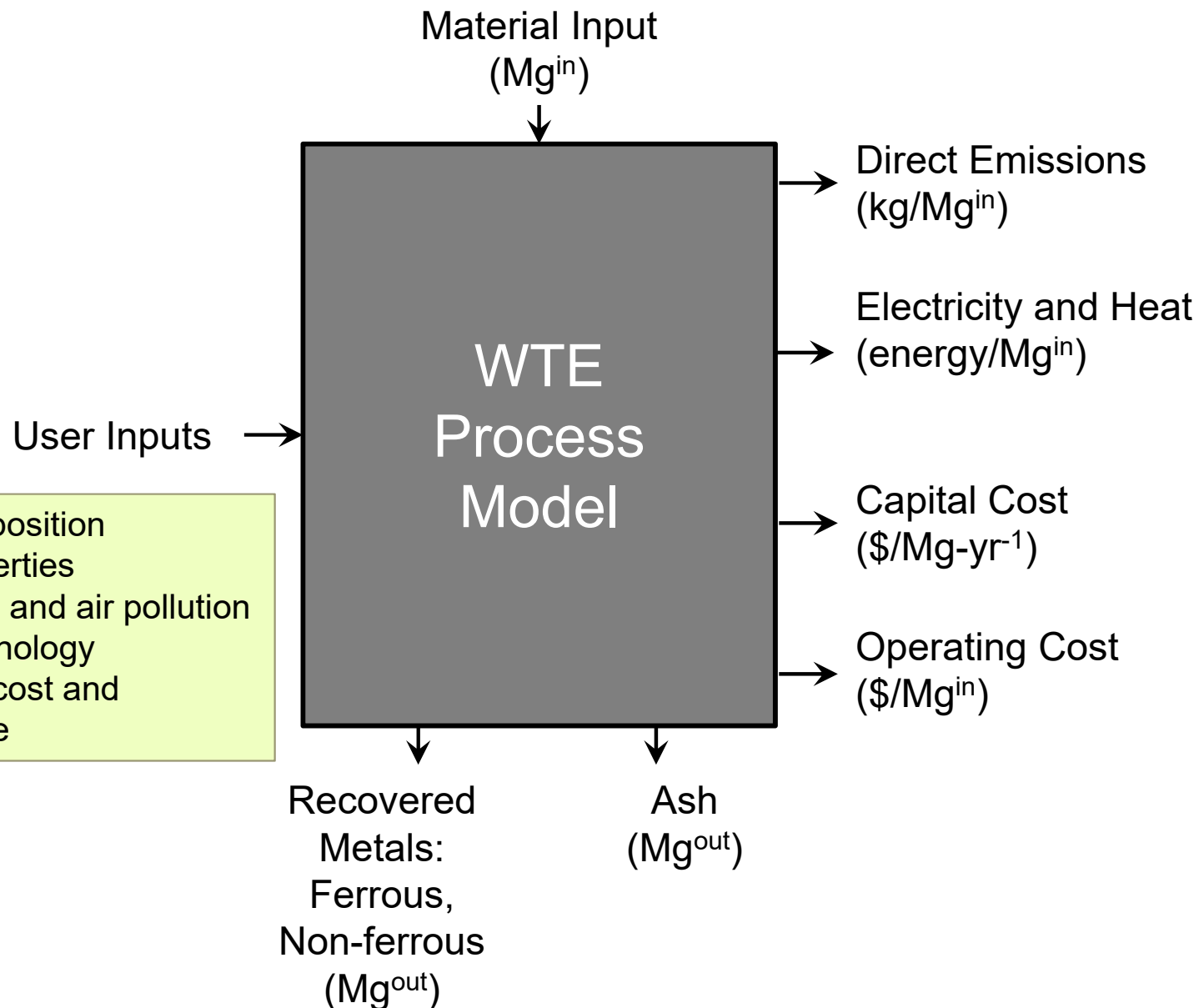


# Solid Waste Systems





# The WTE Process Model





# The Model Allows WTE Performance to Vary with Waste Composition

- Physical and chemical (material) properties differ between waste fractions (e.g., paper, plastic)
- Materials in the waste combusted affect facility electricity generation and stack emissions
- SWOLF allows waste compositions to vary temporally in year 5 year increments



# Model Development

- Waste material properties and facility data are used to calculate electricity and heat generation
  - Energy balance to account for heat loss associated with ash and moisture

$$LHV = \text{Generated Electricity} + \text{Recovered Heat} - \text{Heat Loss}$$

# Data Development

- Much of the data came from Covanta, peer-reviewed literature, and engineering judgment
- Example data types:
  - Waste fraction
    - Elemental composition
    - Heating values
    - Al, Fe recovery efficiency
  - Facility
    - Costs
    - Emissions Data



# Sample Data

## Material Properties

Waste Fraction	Moisture Content (% mass)	Volatile Solids (%TS)	Ash Content (%TS)	Lower Heating Value (MJ/kg VS)	Biogenic Carbon Content (% TS)	Fossil Carbon Content (%TS)	Hydrogen Content (%TS)
Food Waste – Vegetable	77.0	96.4	3.6	18.3	47.7	0.2	6.6
Food Waste - Non-Vegetable	57.1	94.2	5.8	24.6	56.5	1.13	7.9
Newsprint	13.0	92.7	7.3	17.1	44.6	0.2	5.7
Corr. Cardboard	16.5	89	11	15.1	40.7	0.2	5.4

## Facility Economic Data

Facility Lifetime	20	years
Unit WTE Capital Cost	300	\$/design ton per year
Unit WTE O&M Cost	40	(\$/year)/(design ton per year)

## Facility Type Dependent Data

	State of the Art	Average
Electricity Production Efficiency (% LHV)	24	19
Aluminum Recovery Efficiency (%)	65	35
CO Stack gas concentration (ppm <sub>v</sub> at 7% oxygen, dry)	20	30



# Mass Flows

- Model is capable of including beneficial reuse of ash
- Ferrous and non-ferrous are recovered from ash
  - Material properties include aluminum, copper, and iron content of each waste fraction
  - Aluminum, copper, and iron recovery efficiencies are user inputs



# Emission Modeling

Process specific emissions	Emissions are primarily governed by emission control systems rather than the contents of the fuel input itself
Input specific emission	Emissions are primarily governed by the contents of the fuel input, although emission control systems may remove a certain fraction of the components

The LCA modeling approach is critical for the results. If only process specific emissions are applied, no effects from changes in fuel input will be obtained.

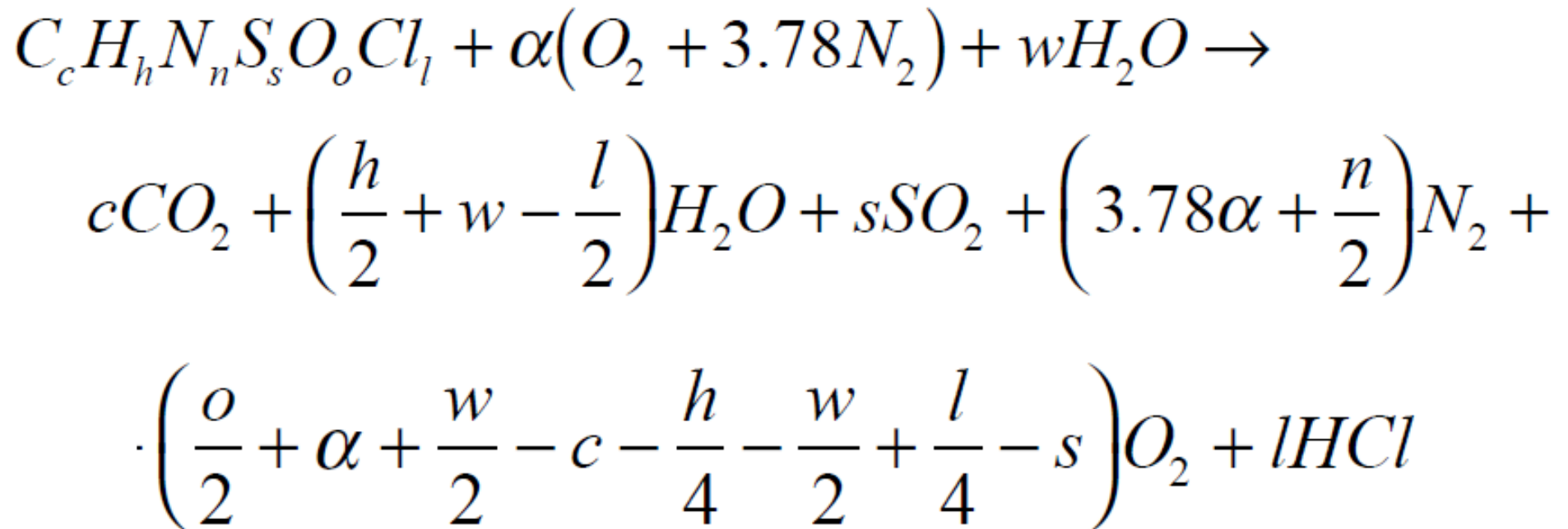
# Input Air Calculation

$$\alpha = -0.699o + 1.50c + 0.35h - 0.244l + 1.50s + 0.053n$$

- All inputs are waste fraction chemical properties
  - Carbon (c), chlorine (l), hydrogen (h), nitrogen (n), oxygen (o), sulfur (s)
- The number of moles of air supplied ( $\alpha$ ) is needed to convert input emissions from per volume to per mass combusted
- $\alpha$  is determined by setting the flue gas to 7% oxygen
  - Regulations in ppm<sub>v</sub> at 7% oxygen



## Carbon Dioxide (CO<sub>2</sub>) Calculation



Uses stoichiometry of combustion to calculate CO<sub>2</sub> emissions for a given waste component (Harrison et. al, 2000)



# Other Non-Metal Stack Emissions

- User inputs include stack emissions in  $\text{ppm}_v$  or mass per volume, which are used to calculate emissions for:
  - Sulfur dioxide (**SO<sub>2</sub>**)
  - Hydrochloric acid (**HCl**)
  - Carbon monoxide (**CO**)
  - Particulate matter (**PM**)
  - Dioxins/Furans
  - Methane (**CH<sub>4</sub>**)
  - Nitrous Oxide (**N<sub>2</sub>O**)
  - Ammonia (**NH<sub>3</sub>**)
  - Hydrocarbons
- Sample calculation for SO<sub>2</sub> (kg SO<sub>2</sub>/Mg input waste)

$$E_{SO_2} = ppmv_{SO_2} \cdot \frac{1 \text{ m}^3}{10^6 \text{ m}^3} \cdot \text{molecular mass}_{SO_2} \cdot \frac{m^3_{\text{flue gas}}}{Mg_{\text{waste dry}}} \cdot \frac{1}{\rho_{\text{air}}}$$

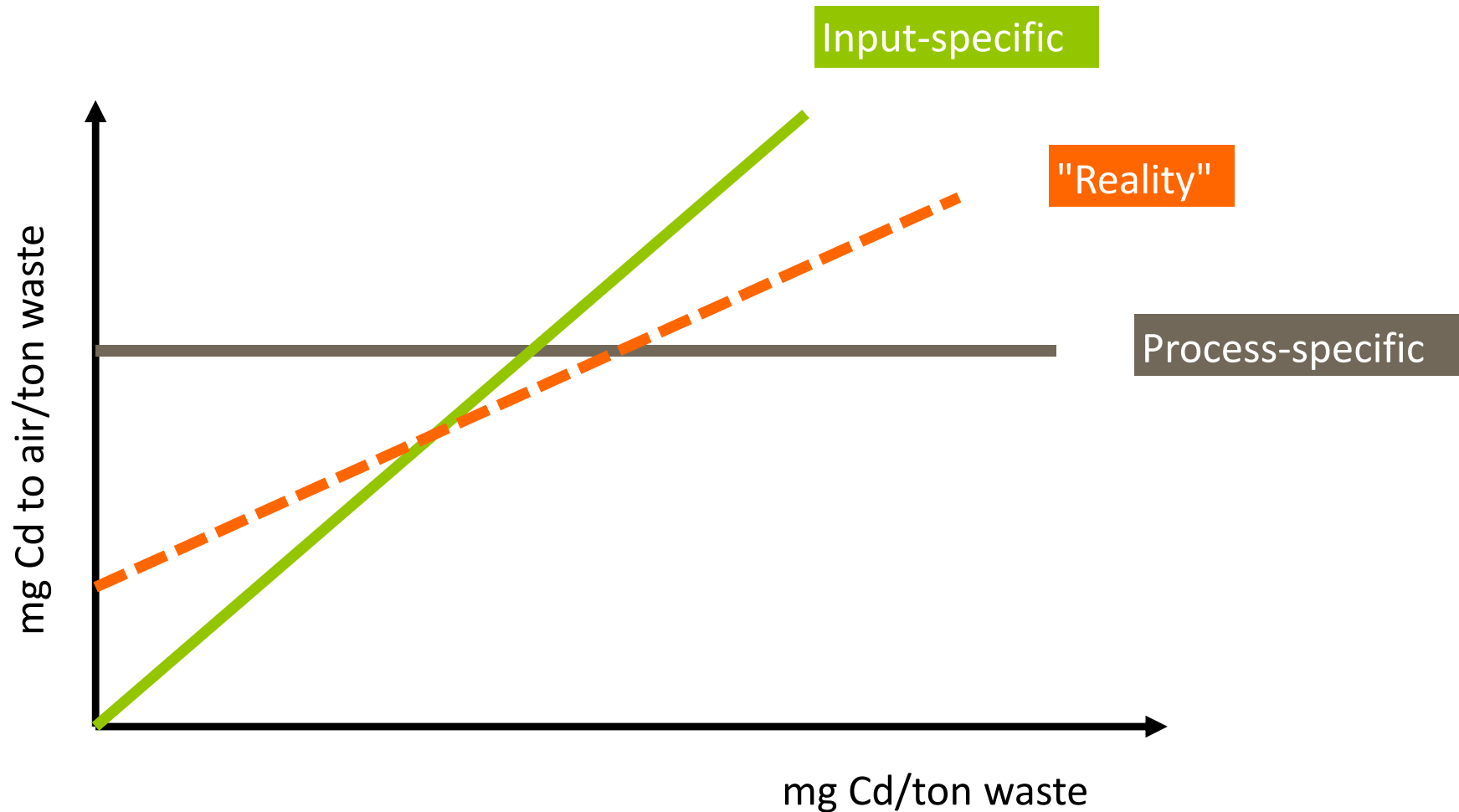
Calculated using input air ( $\alpha$ )

# Metal Stack Emissions

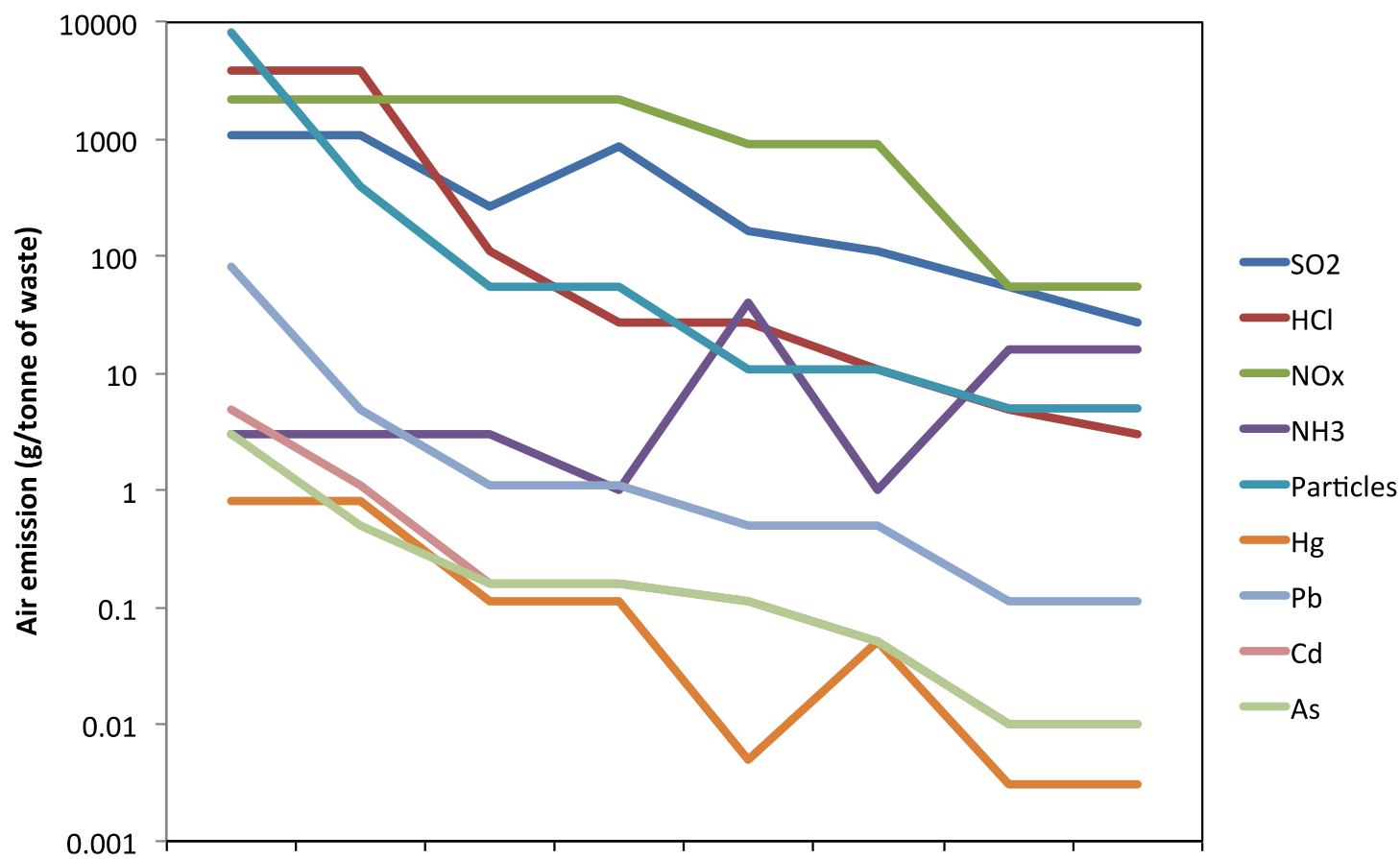
- Chemical composition of each waste fraction used to calculate the input amount of:
  - Arsenic (**As**)
  - Cadmium (**Cd**)
  - Chromium (**Cr**)
  - Copper (**Cu**)
  - Mercury (**Hg**)
  - Nickel (**Ni**)
  - Lead(**Pb**)
  - Antimony (**Sb**)
  - Zinc (**Zn**)
  - Capability for Others
- E-waste components are significant source of metal emissions, which are not modeled here in detail
- If metals emissions are a focal point, we recommend pursuing other methods to estimate them.



# Air-emission modeling



# Air Emissions and Control Systems



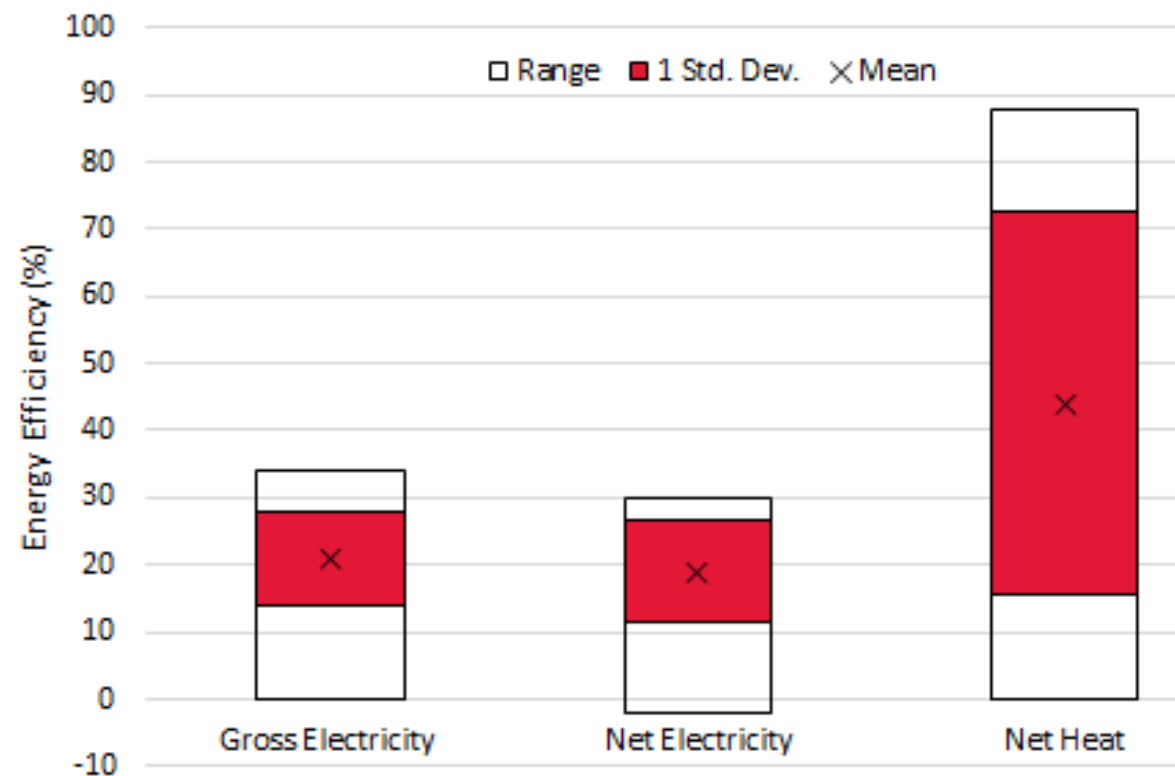
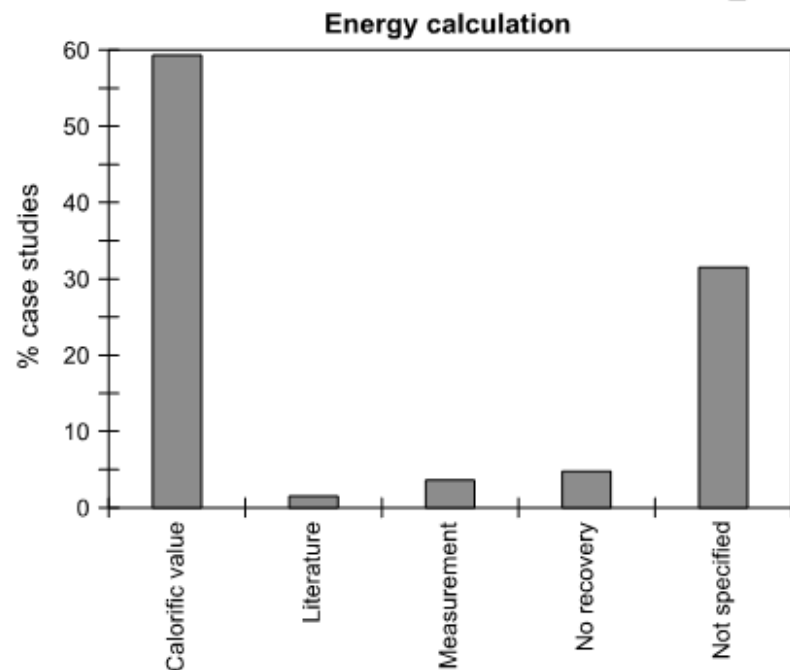
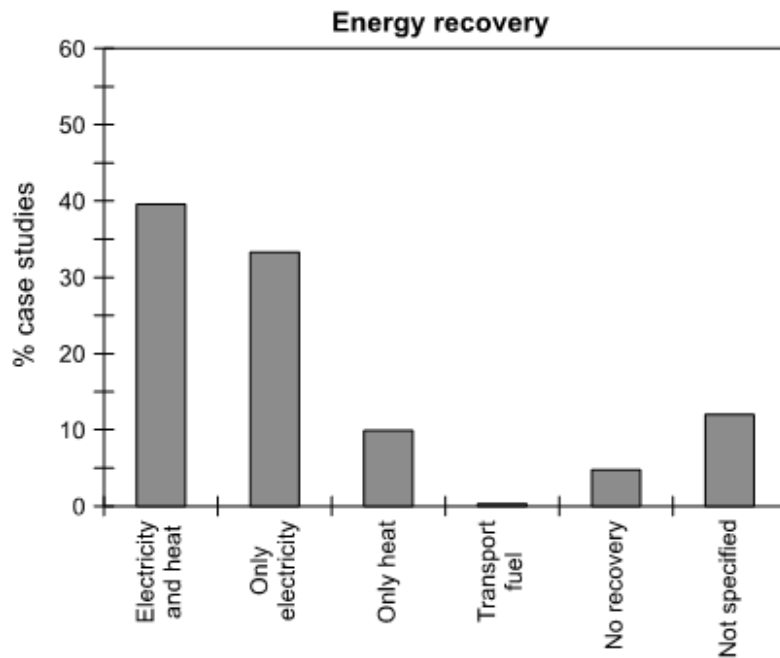
APC-technology	APC 1	APC 2	APC 3	APC 4	APC 5	APC 6	APC 7	APC 8
Particle removal	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Scrubbing	No	No	Dry	Wet	Dry	Wet	Dry	Wet
Dioxin filter	No	No	No	No	Yes	Yes	Yes	Yes
Flue gas condensation	No	No	No	No	No	No	Yes	Yes

Damgaard et al. (2010): Life-cycle-assessment of the historical development of air pollution control and energy recovery in waste incineration. *Waste Management*, 30, 1244-1250





# Energy Recovery

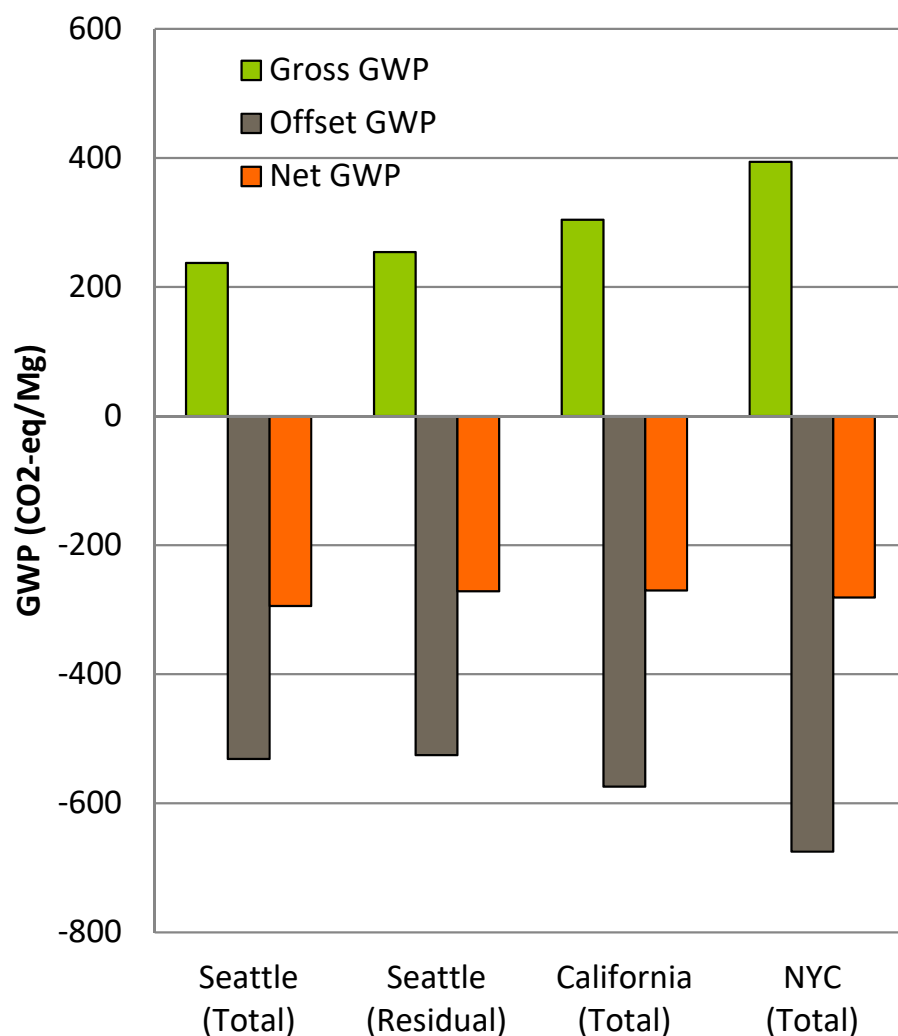


# Illustrative Results: Stack Emissions

Compound	kg/wet kg combusted
SO <sub>2</sub>	2.9E-03
HCl	1.6E-03
NO <sub>x</sub>	3.6E-02
Carbon Monoxide (CO)	1.3E-02
PM	7.6E-04
Dioxins/Furans	7.6E-10
Methane (CH <sub>4</sub> )	4.0E-04
Nitrous Oxide (N <sub>2</sub> O)	1.3E-03
Ammonia (NH <sub>3</sub> )	7.7E-04
Hydrocarbons	1.9E-03

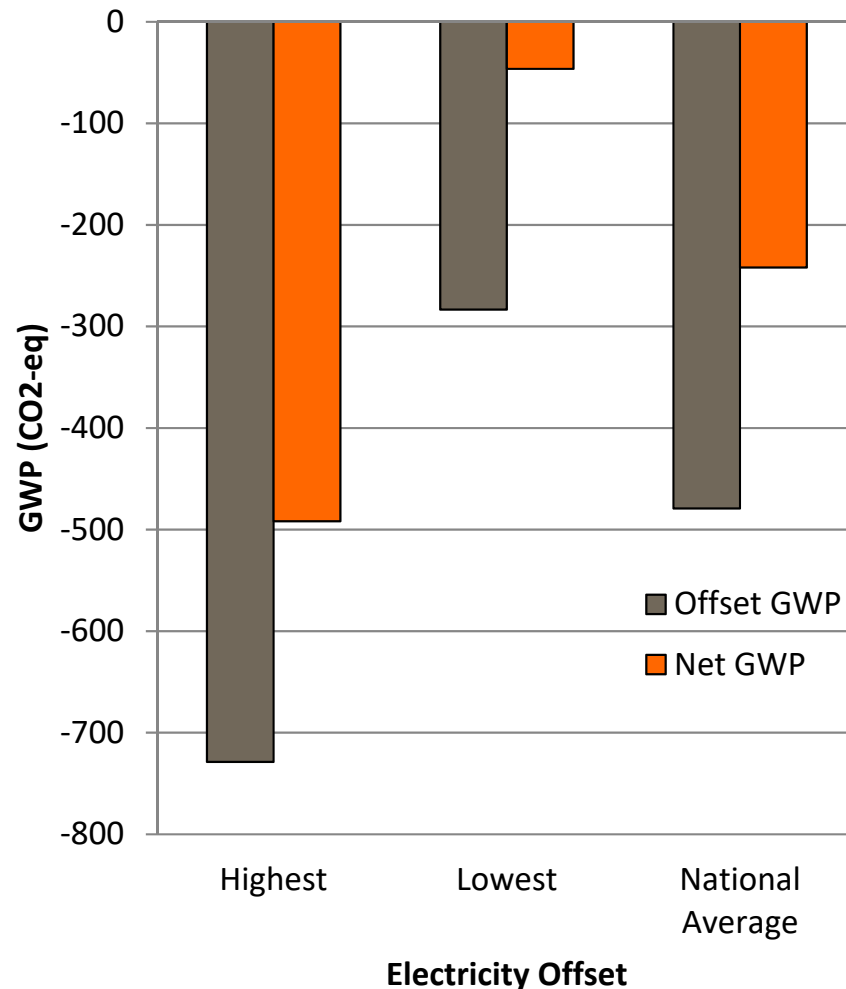
- As-generated waste composition for Seattle, WA
- State of the art facility

# Global Warming Potential (GWP)



- Waste composition affects GWP
- Model estimates for electricity generation range from 670 kWh to 830 kWh per Mg for a state of the art facility
- Greater electricity production indicates greater offset GWP
- Metal recovery contributes to offset

# Impact of LCI Data Selection on Offset GWP



Analysis Based on Seattle (Total) Composition

- GWP for 1 kWh of electricity ranges from 0.42 to 1.08 kg CO<sub>2</sub>-e between NERC regions
- National average 0.71 kg CO<sub>2</sub>-e per kWh
- NERC region selection can determine whether facility has net GWP costs or savings
- Geographic location of facility may influence choice
- Careful documentation of offset selection is required to ensure fair comparison between systems
- Sensitivity analysis is critical



# Questions?



[go.ncsu.edu/swolf](http://go.ncsu.edu/swolf)

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## References

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- Brogaard, L. K., Riber, C., & Christensen, T. H. (2013). Quantifying capital goods for waste incineration. *Waste Management (New York, N. Y.)*, 33(6), 1390–6.  
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