Review of worldwide gasification applications for the production of electricity and liquid fuels from waste and biomass

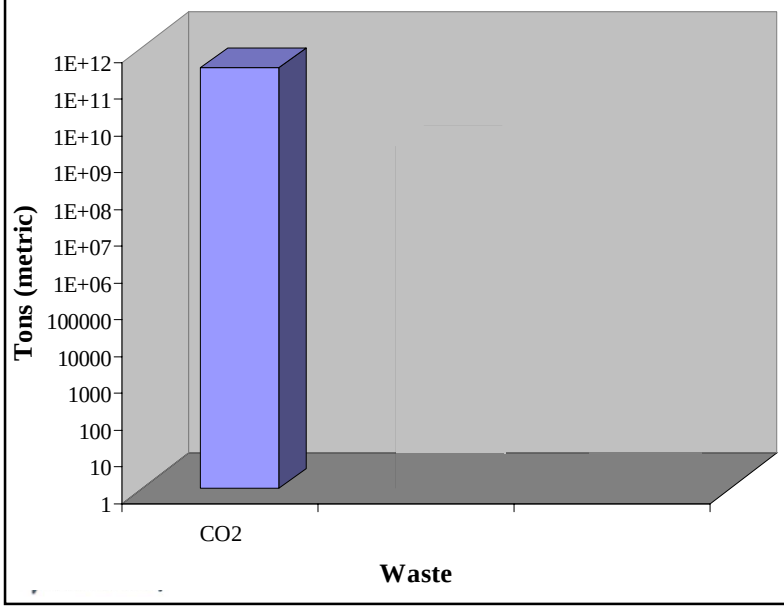
AIR AND WASTE MANAGEMENT ASSOCIATION (A&WMA)
QUEBEC SECTION

Wednesday, May 29, 2013
2:00PM –3:00PM ET,
Montreal, QC, Canada

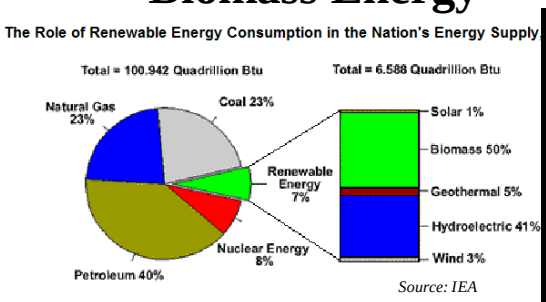
Marco J. Castaldi
Associate Professor
Chemical Engineering Department
The City College of New York
City University of New York

Combustion & Catalysis Laboratory

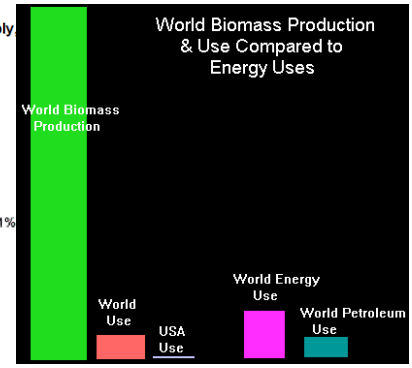
Wastes



Biomass Energy



Source: IEA



Total mass of living matter (including moisture) - 2000 billion ton
Energy stored in terrestrial biomass 25 000 EJ
Net ann. Prod. terrestrial biomass - 400 000 million ton

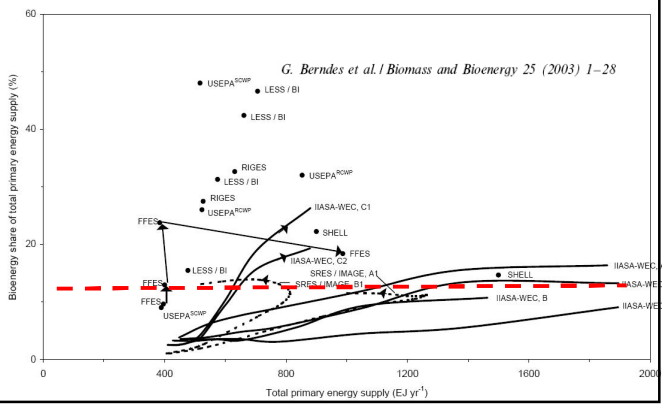
Rate of energy storage by land biomass - 3000 EJ/y (95 TW)
Total consumption of all forms of energy - 400 EJ/y (12 TW)
Biomass energy consumption - 55 EJ/y (1. 7 TW)

Bioenergy

- Sustainable carbon neutral power, heat and chemical feedstocks.
- Potential to provide ~ 15% of energy demand.
- Gasification
  - Lower PM, NO_x, and SO_2, than combustion
  - Steam addition – Increased concentration of H_2
  - CO_2 usage – enhanced char conversion and less residue for landfill.
  - Provides reagents (CO & H_2) for synthetic fuel/chemical production

Estimations vary widely due to land availability and crop yields.

One piece of the alternative energy future technologies



Gasification or Combustion

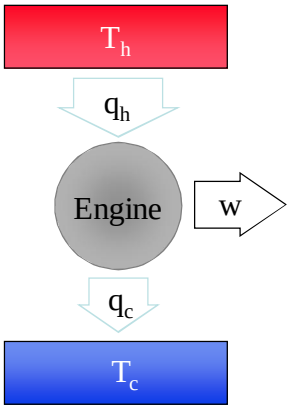
- Sub stoichiometric air
- Lower total volumetric flow
- Lower fly ash carry over
- Pollutants in reduced form (H_2S, COS)
- Char – Low T
- Slag – vitrification – high T
- **Scale: ~ 100 tons/day**

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

Combustion Option

Primarily generate heat

1) $C + O_2 \rightarrow CO_2 + Heat$
2) $C + 1/2O_2 \rightarrow CO + Heat$
3) $H_2 + 1/2O_2 \rightarrow H_2O + Heat$
4) $Char + Heat \rightarrow Slag$
5) $Slag \rightarrow Clinker + Heat$



- A *heat engine* converts heat into work. efficiency is given by $\eta = |w| / q_h$

$\therefore \quad \eta = 1 - |q_c| / q_h$

$\therefore \eta = 1 - |T_c| / T_h$

Combustion Status

(metric tons)

- Number of nations using WTE: 35
- Total number of WTE plants > **600**
- Estimated global WTE: **170 million tpy**
- U.S. WTE: 26 million tpy
- Urban global landfilling: 830 million tpy
- U.S. landfilling: 225 million tpy
- Recent expansions of ~800,000 tpy
- New US Facility ~ 1 million tpy (2015)

Gasification Option

Rezaiyan and Cheremisinoff

Gasification (and pyrolysis) have option to make other products, not only heat and work

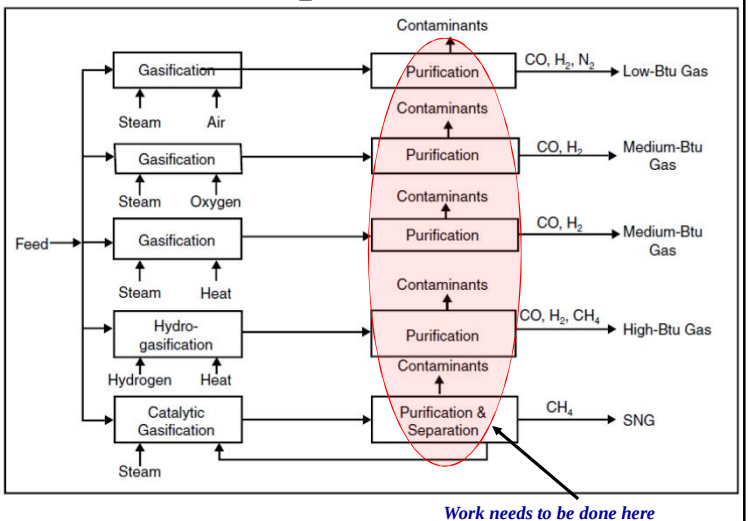


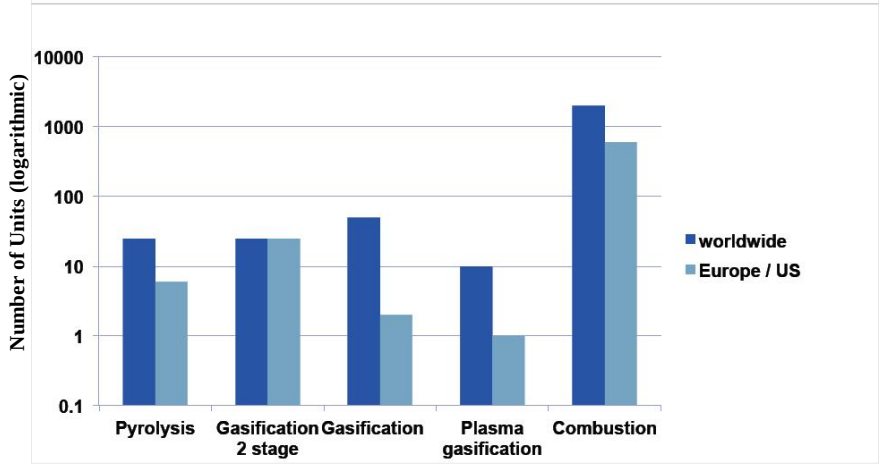
Figure 1.1 Gasification methods.

Gasification status

- 163 commercial gasification projects in development worldwide consisting of a total of 468 gasifiers. *DOE survey*
- ~ 120 plants began operations between 1960 and 2000
  - majority (more than 72 plants) commissioned after 1980. Currently ~34 new plants are at various stages of planning and construction.
- The majority of the existing plants were designed and constructed to produce a synthetic gas, consisting primarily of H_2 and CO
- Ethanol – EnerChem/City of Edmonton – 2008
- Energos (Sweden, UK) building plants @ <150,000 tpy

Totaling ~ **35 million tpy (metric)**

Worldwide Installations of Units (i.e. boiler, gasifier, etc)



Chemicals From Waste

- Military MISER program
  - Trash/Biomass/Solid hydrocarbons to fuels
- American Chemical Society (ACS)
  - Letters to the editor – "chemicals from waste"
    - C&EN April 2006
- Discover Magazine –
  - "DATA" Section : The Ultimate Garbage Disposal
    - How to turn trash into clean energy
- Solena Group Inc – contract with UK for aviation fuels
- EnerChem/City of Edmonton – to make EtOH - 2013

Combustion & Catalysis Laboratory

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**

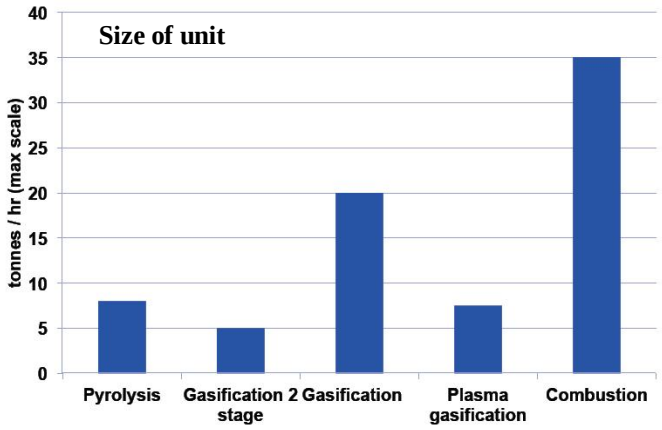
No additional Oxygen (only heat) Unconverted solid will remain!

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

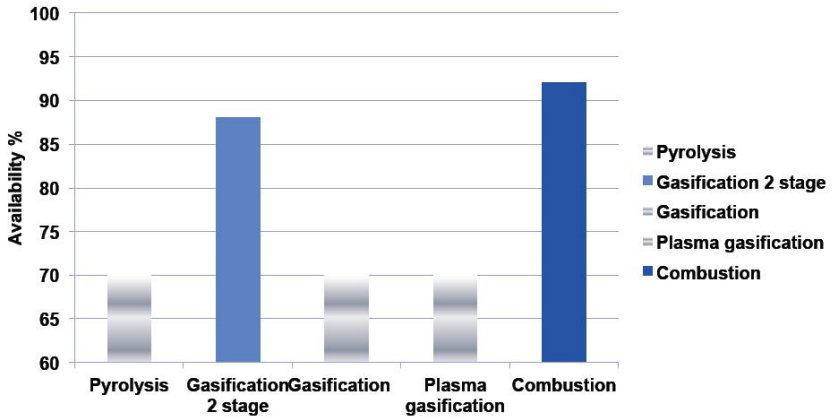
Much additional Oxygen (or air) Heat comes from reactions

Combustion & Catalysis Laboratory

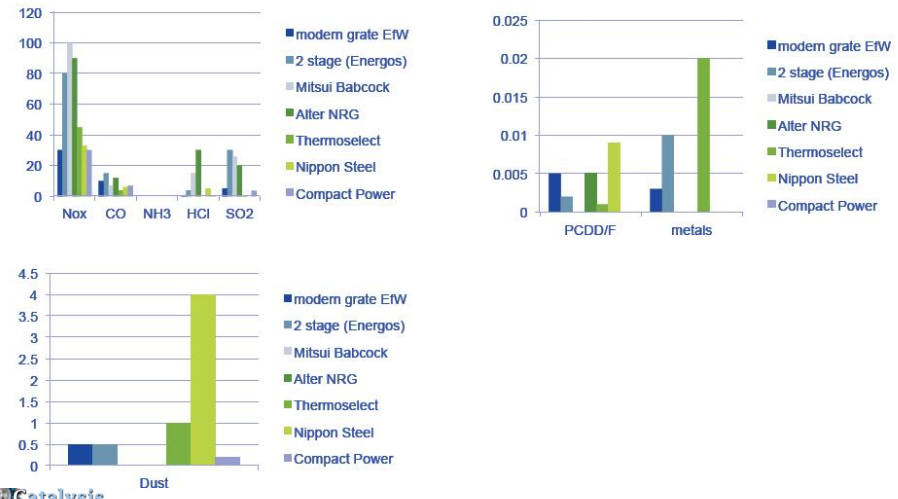
Scale of operation



Availability (known or unknown) %

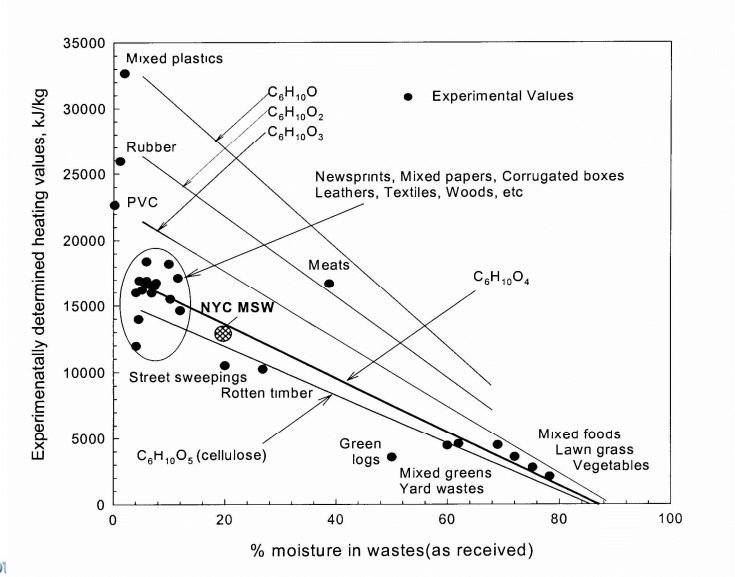


Emission Comparison of Thermal Treatment Technologies

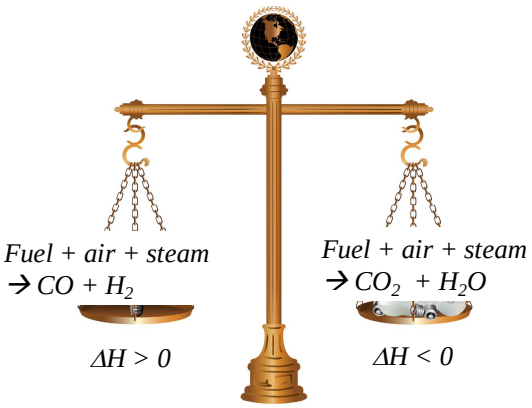


Effect of constituents and moisture on heat value of MSW

(Themelis, Kim, Brady 2002)



Water is good for gasification but increases endothermicity

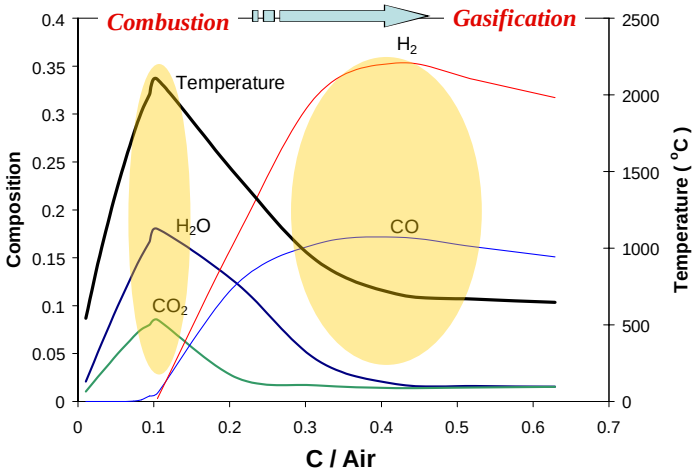


If perfectly balanced – reaction should occur at T = 298K (25°C)

$$R = Ae^{\frac{-E_{act}}{RT}} \prod_i C_i^{\alpha}$$

Combustion to Gasification

$C + O_2 \xrightarrow{\text{Combustion}} CO_2 + 2H_2O$ $\qquad$ $C + O_2 \xrightarrow{\text{Gasification}} 2H_2 + CO$



Net effect: Moderate Temp rise; rearrangement of molecules (CO, H_2)
Water addition → $CO + H_2O = CO_2 + H_2$

Ref: STANJAN calculations

- *Most HC fuels ($C_xH_yO_zN_aS_b$) exist above lines*
- *Need oxygen source or hydrogen to get below (CO_2, O_2, air H_2O, H_2)*

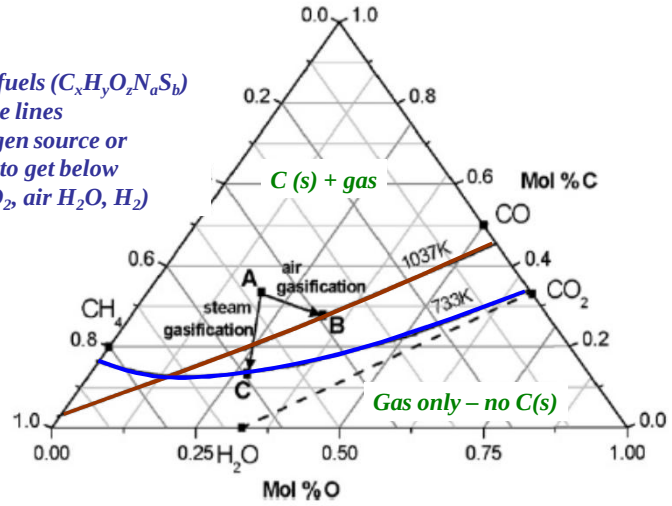


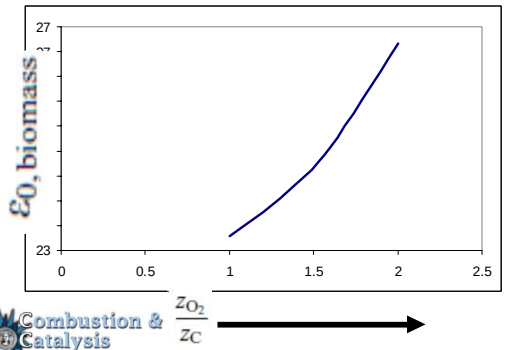
Fig. 1. Molar triangular diagram indicating (A) biomass feed, (B) biomass in equilibrium with air at carbon boundary, (C) biomass in equilibrium with steam of 500 K at carbon boundary.

M. J. Prins et al. / Chemical Engineering Science 58 (2003) 1003 – 1011

Exergy (Entropy) Analysis

$$\beta = \frac{1.0412 + 0.2160\frac{z_{H_2}}{z_C} - 0.2499\frac{z_{O_2}}{z_C}\left[1 + 0.7884\frac{z_{H_2}}{z_C}\right] + 0.0450\frac{z_{N_2}}{z_C}}{1 - 0.3035 z_{O_2}/z_C} \quad \text{valid for } \frac{z_{O_2}}{z_C} \leqslant 2.67,$$

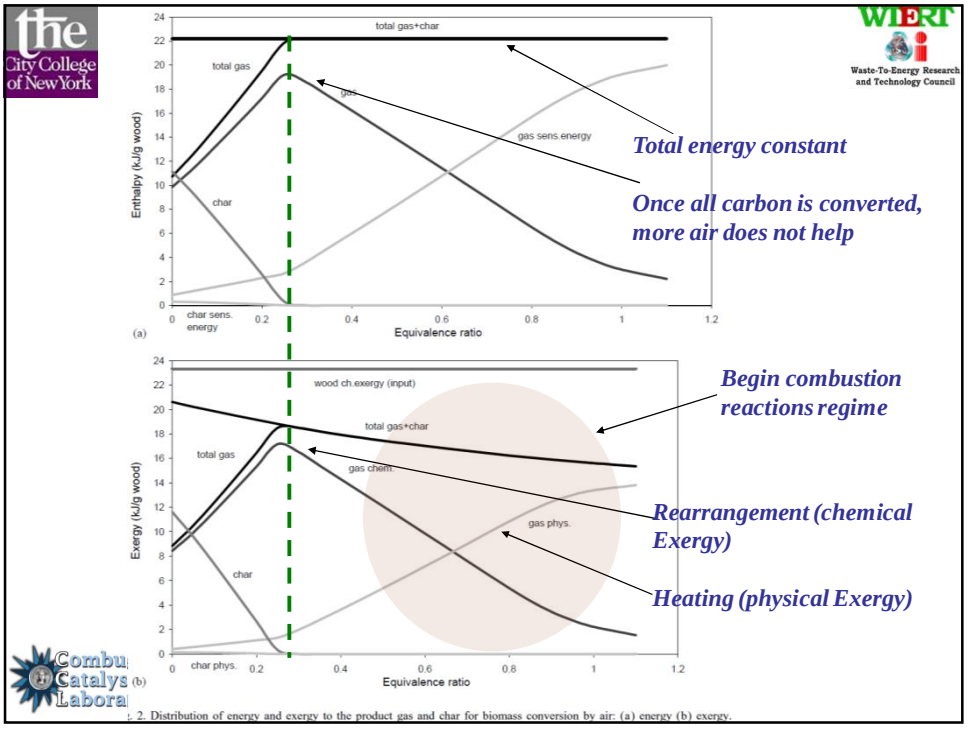
$$\varepsilon_{0,\text{biomass}} = \beta \cdot \text{LHV}_{\text{biomass}},$$



- More oxygen in fuel, more exergy
- Higher heating value – more exergy

Related to arrangement of molecules and heat generation or capture as chemical energy

Source: M. J. Prins et al. / Chemical Engineering Science 58 (2003) 1003 – 1011



Total energy constant

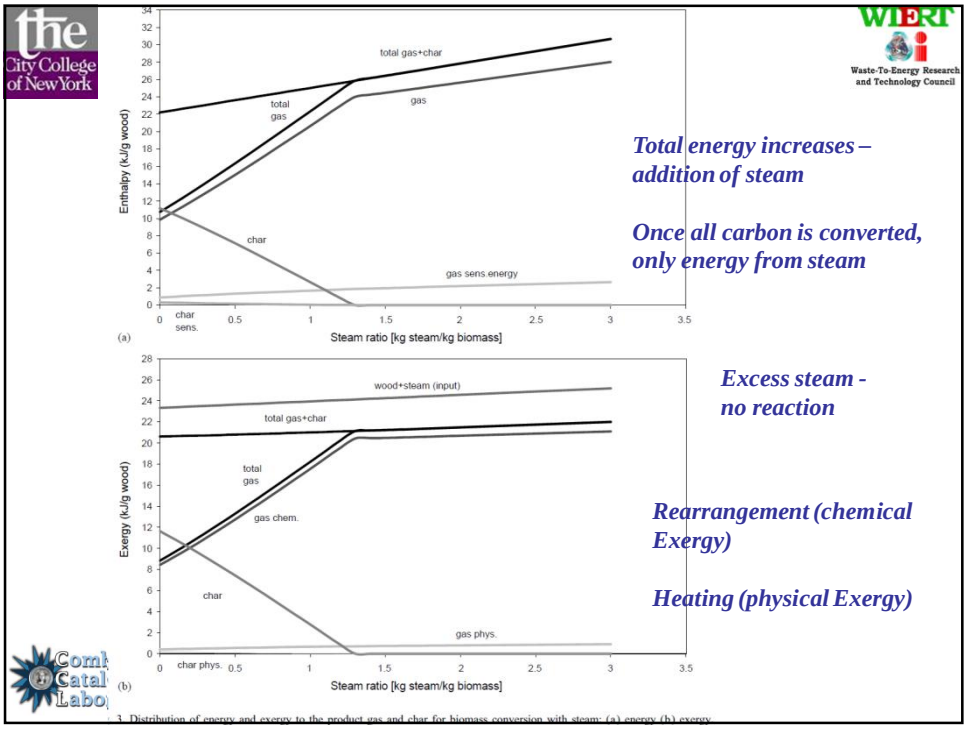
Once all carbon is converted, more air does not help

Begin combustion reactions regime

Rearrangement (chemical Exergy)

Heating (physical Exergy)

2. Distribution of energy and exergy to the product gas and char for biomass conversion by air: (a) energy (b) exergy.



Total energy increases – addition of steam

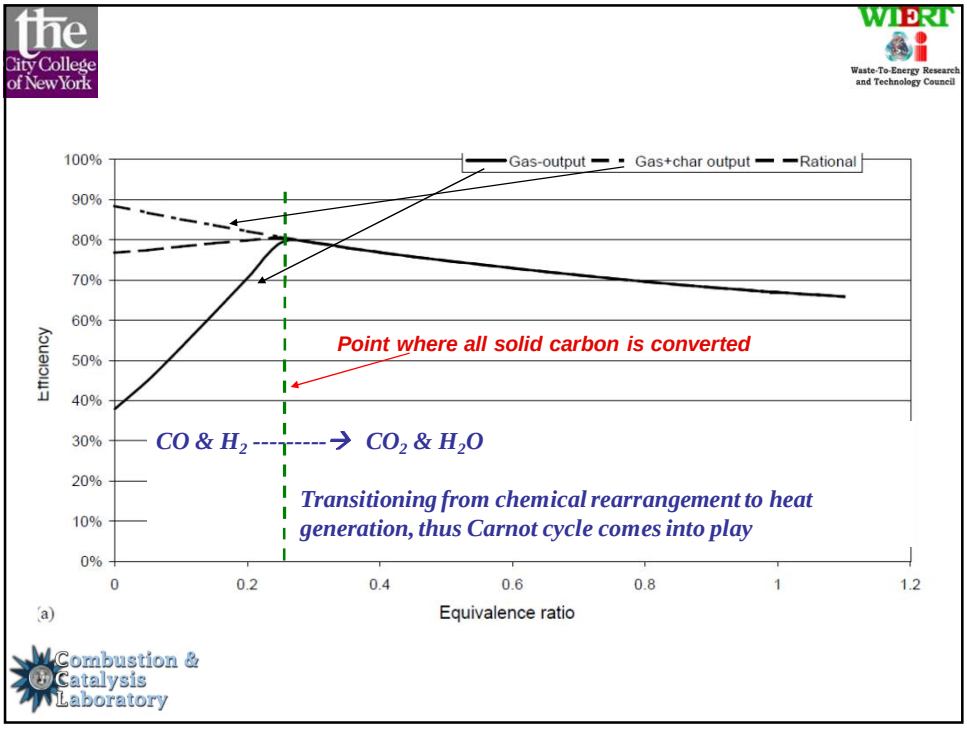
Once all carbon is converted, only energy from steam

Excess steam - no reaction

Rearrangement (chemical Exergy)

Heating (physical Exergy)

3. Distribution of energy and exergy to the product gas and char for biomass conversion with steam: (a) energy (b) exergy.



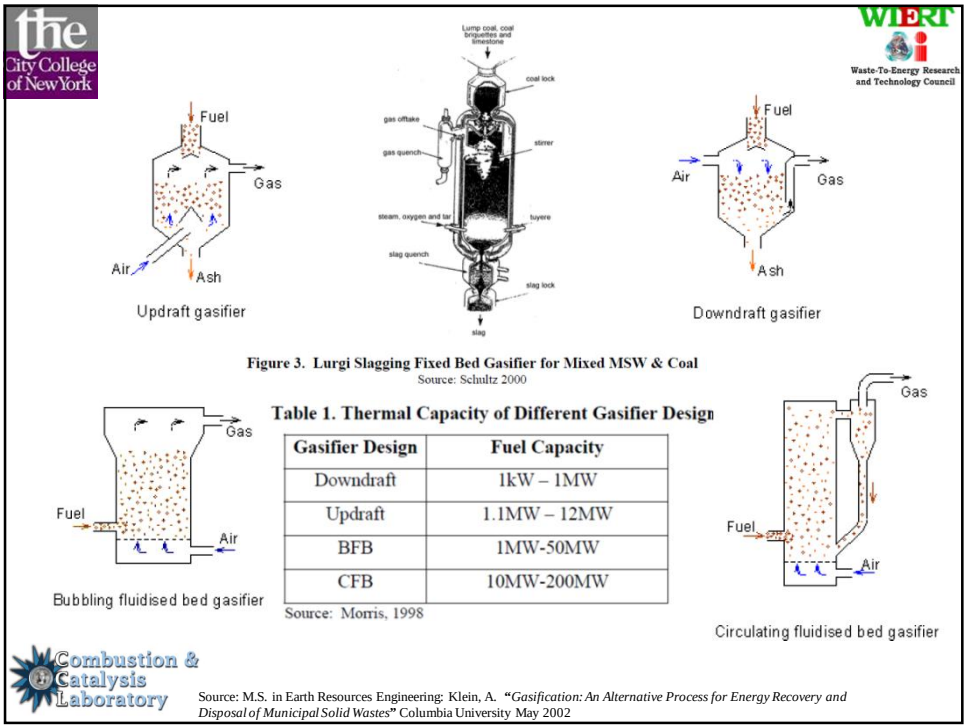


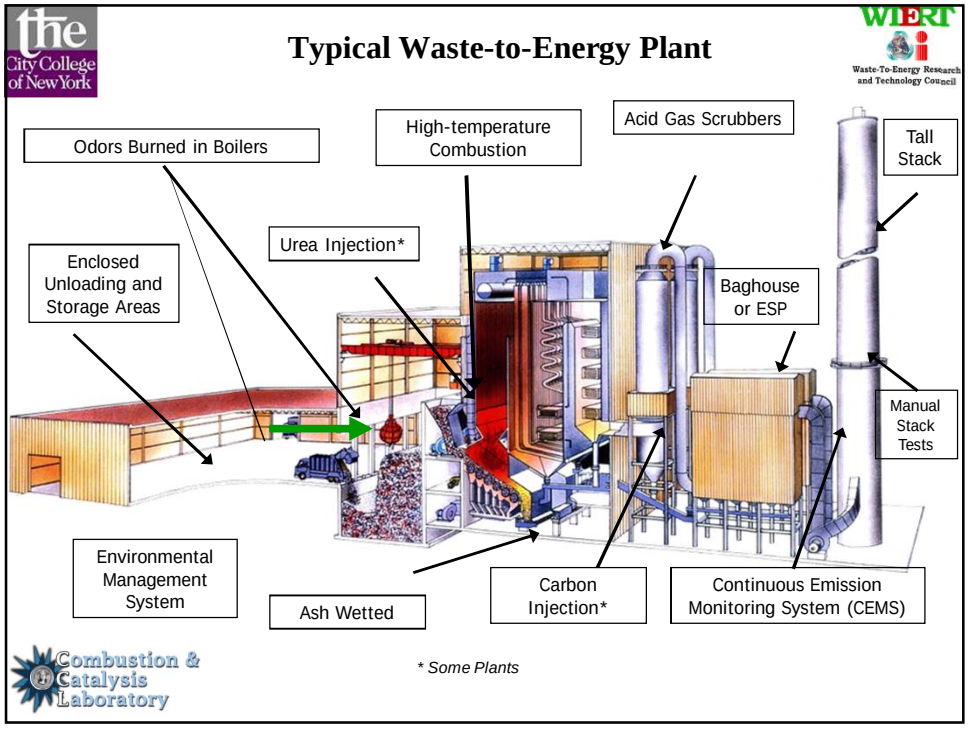
Figure 3. Lurgi Slagging Fixed Bed Gasifier for Mixed MSW & Coal
Source: Schultz 2000

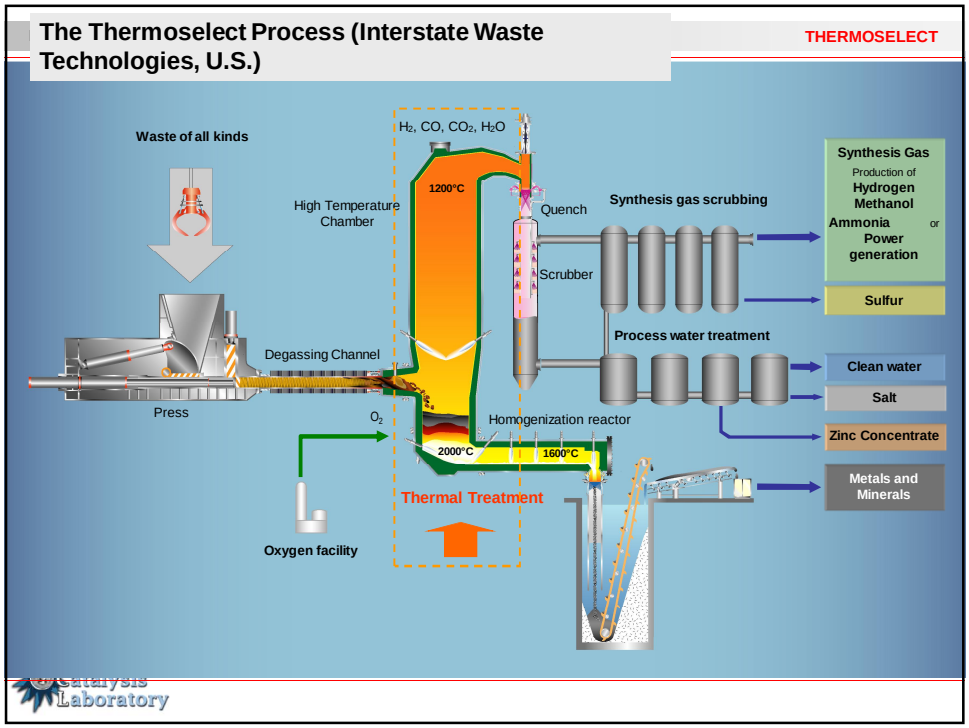
Table 1. Thermal Capacity of Different Gasifier Design

Gasifier Design	Fuel Capacity
Downdraft	1kW – 1MW
Updraft	1.1MW – 12MW
BFB	1MW-50MW
CFB	10MW-200MW

Source: Morris, 1998

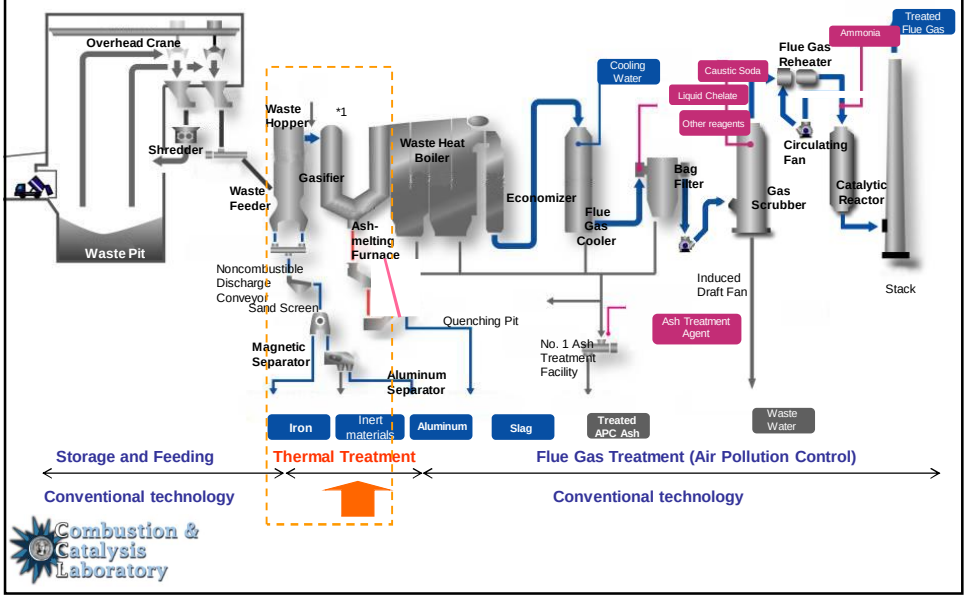
Source: M.S. in Earth Resources Engineering: Klein, A. **"***Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes***"** Columbia University May 2002


Typical Waste-to-Energy Plant
the City College of New York
WTERT
Waste-To-Energy Research and Technology Council
Odors Burned in Boilers
High-temperature Combustion
Acid Gas Scrubbers
Tall Stack
Enclosed Unloading and Storage Areas
Urea Injection*
Baghouse or ESP
Manual Stack Tests
Environmental Management System
Ash Wetted
Carbon Injection*
Continuous Emission Monitoring System (CEMS)
Combustion & Catalysis Laboratory
* Some Plants


The Thermoselect Process (Interstate Waste Technologies, U.S.)
THERMOSELECT
Waste of all kinds
H2, CO, CO2, H2O
High Temperature Chamber
1200°C
Quench
Synthesis gas scrubbing
Synthesis Gas
Production of
Hydrogen
Methanol
Ammonia
or
Power generation
Scrubber
Sulfur
Process water treatment
Degassing Channel
Clean water
Salt
Press
O2
Homogenization reactor
Zinc Concentrate
2000°C
1600°C
Metals and Minerals
Thermal Treatment
Oxygen facility
Catalysis Laboratory

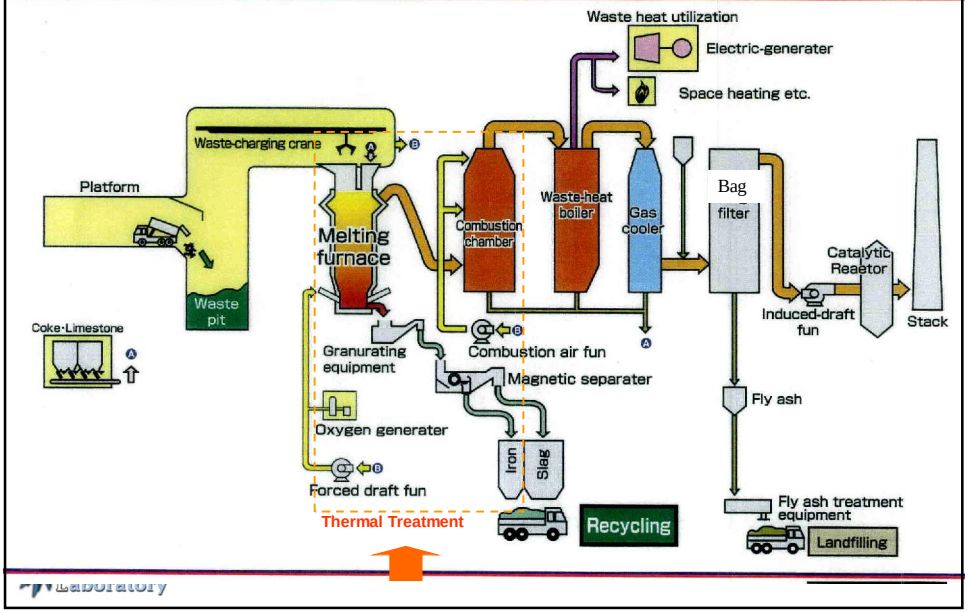
Ebara Fluidized-bed TwinRec/TIFG Technology

Process Flowsheet

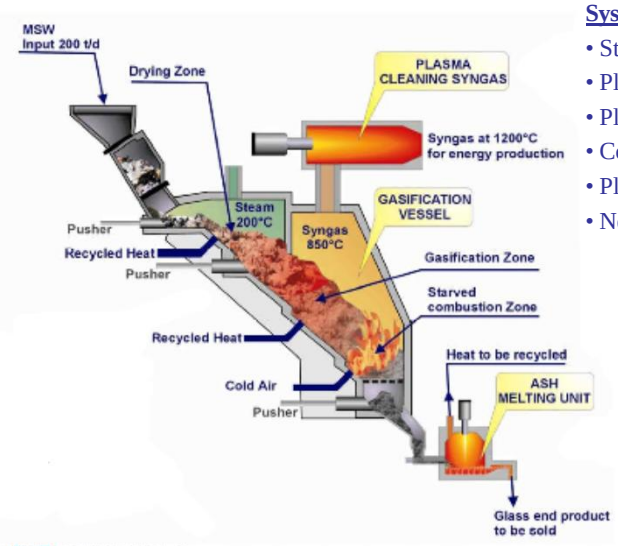


The Nippon Steel WTE Process

Basic Flow Chart of Direct Melting System



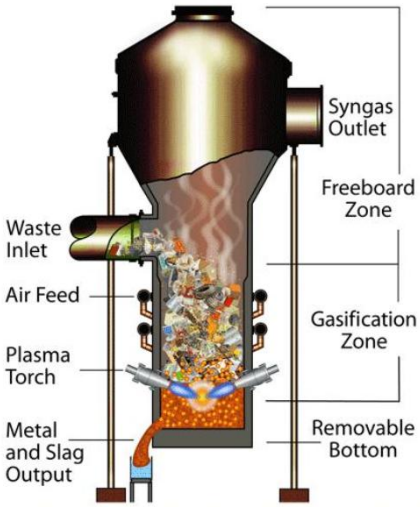
Europlasma



System:

- Stoker Grate Gasifier
- Plasma Unit for Syngas Cleaning
- Plasma Unit for Ash Vitrification
- Commercial Startup → April 2011.
- Plant capacity will be 50,000 tons/y
- Net electrical output → 12 MW

Alter NRG (Westinghouse)

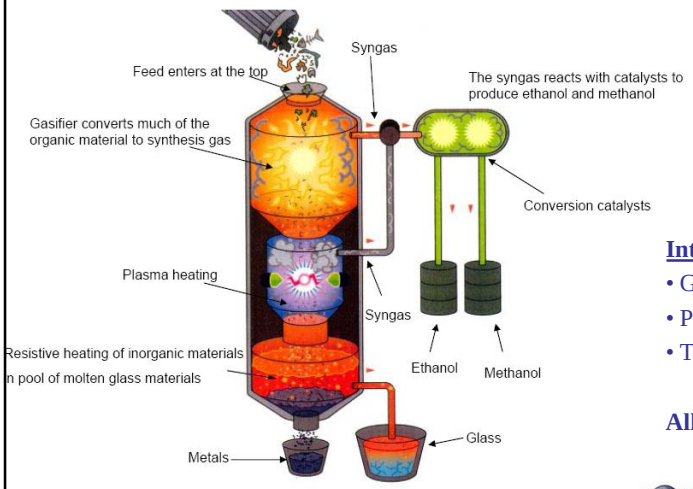


System:

- Metallurgical coke (met coke) injected
  - retain the heat energy from the plasma torches
  - Provide a "skeleton" to support MSW in the gasifier
- Similar to the phenomena occurring in an iron cupola or blast furnace.
- Process can handle any moisture in MSW
- Main commercial plant in Utashinai
  - Originally; 80% ASR / 20% MSW @ 180 tpd
  - Plant operating on 100% MSW @ 150 tpd

INENTEC Plasma Unit

Liquid Fuels from Municipal/Commercial Waste



Leading Plasma Gasification Solutions

Integration:

- Gasifier
- Plasma Unit
- Thermal Residence Unit

All operated in "sweet spot"

WasteManagement & InEnTec

S4 Energy Solutions

- Joint Venture Formed to Commercially Deploy Gasification of Waste
- 50/50 Joint Venture Between WM and InEnTec
- Venture Officially Launched in February 2009
- JV to Operate in Collaboration with, but Independent of JV Partners

Recognition of inherent value in waste for energy

Plasma Gasification Field System Summary

Technology	Energy (kWh/ton)	Capital Costs ($/ton)
InEnTec	530	~77 (est)
Alter NRG	617	81
Europlasma	605	86
Plasco	530	86
Newer WTE	650	74
Grate WTE (US avg)	550	60

Combustion & Catalysis Laboratory

Other Examples

Energos, Sarpsborg 2 stage

Alter NRG Utashinai plasma

cBOS$_{TM}$, Dumfries 2 stage

Nippon steel, Kita Kyushu gasification

Mitsui recycling Toyoashi city (Ex Siemens) pyrolysis

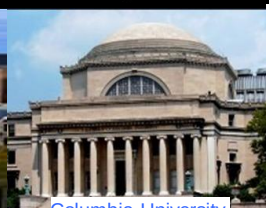
CHO Power Morcenx Gasification + plasma

Combustion & Catalysis Laboratory

WTERT Waste-to-Energy Research and Technology Council

Advancing the Goals of Sustainable Waste Management

City College of New York (CCNY)



Columbia University

What is WTERT

The Waste-to-Energy Research and Technology Council (WTERT) is a top-tier-technical group that brings together engineers, scientists, and managers from industry, universities, and government with the objective of advancing the goals of sustainable waste management globally.

A truly international organization: Sister organizations in many nations

- WTERT, U.S. (2002) www.wtert.org
- SYNERGIA, Greece (2007) www.wtert.gr
- WTERT, China (2008) www.wtert.cn
- *CEFWC, Canada (2008)* *www.wtert.ca*
- WERT, Germany (2009) www.wtert.eu
- WTERT, Japan (2010) www.wtert.jp
- WTERT-Brasil, Brazil (2010) www.wtert.com.br

- Under formation: France, U.K., India, Argentina, Mexico, Thailand, Italy, Czech Republic

Combustion & Catalysis Laboratory

State University of New York, Marine Sciences Research Center (U.S.)

Delft University of Technology, Dept. of Applied Earth Sciences (The Netherlands)

Sheffield University Waste Incineration Centre (United Kingdom)

National Tech. University of Athens (Greece)

University of Patras (Greece)

Institute for Thermal Power Engineering of Zhejiang University (China)

College of Mechanical and Energy Engineering Zhejiang University (China)

Chongqing Waste to Energy Technology Research Institute (China)

the City College of New York

IT3 HWC

32ND INTERNATIONAL CONFERENCE ON THERMAL TREATMENT TECHNOLOGIES & HAZARDOUS WASTE COMBUSTORS

October 21-23, 2013 • San Antonio, TX

Conference Supported by ASME-MER and WTERT

Welcome | Conference Information | Registration | Conference Location | Exhibition & Sponsorship

WTERT Waste-To-Energy Research and Technology Council

Beginning in 2013, the IT3/HWC conference will be organized in odd years in partnership with the Waste-to-Energy Research and Technology Council (WTERT) and the Materials and Energy Recovery Division (MER) of the American Society of Mechanical Engineers (ASME). These groups will be involved in the conference planning and development of technical sessions

WTERT

The City College of New York CUNY

Chemical Engineering Department

Earth Engineering Center
Columbia University and City College of New York

Combustion & Catalysis Laboratory

Acknowledgements

Earth Engineering Center
Columbia University and City College of New York

ISWA International Solid Waste Association

WIERT Waste-To-Energy Research and Technology Council

Chemical Engineering Department

CUNY The City College of New York

ENERGY RECOVERY COUNCIL

Combustion & Catalysis Laboratory

Sustainability in Urban Environment

- Capstone project (Engineering, Science & Architecture)
  - *"An Integrated Waste-to-Energy Plan for New York City"*

You, The Audience for Attention