

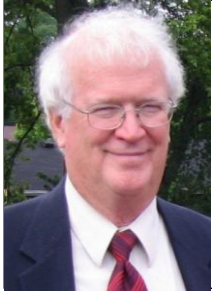
Turning Trash into Renewable Energy Treasure

Steve Goff
Covanta Energy

John Norton
Norton Engineering LLC

Dr. Marco Castaldi
The City University of New York (CUNY)

Today's Presentations



Solid Waste Management Alternatives

John Norton

Owner

Norton Engineering LLC



Gasification of Municipal Solid Waste

Steve Goff

Vice President of Research & Development

Covanta Energy Corporation



Thermal Conversion of Waste to Energy and Products

Dr. Marco Castaldi

Associate Professor, Chemical Engineering Department

The City University of New York (CUNY)

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- Please type all questions in the box at the bottom of your screen.
- We will answer as many questions as possible during the event.
- Speakers will answer as many questions as they can via e-mail.



Solid Waste Management Alternatives

John W. Norton, PE, BCEE



Overview

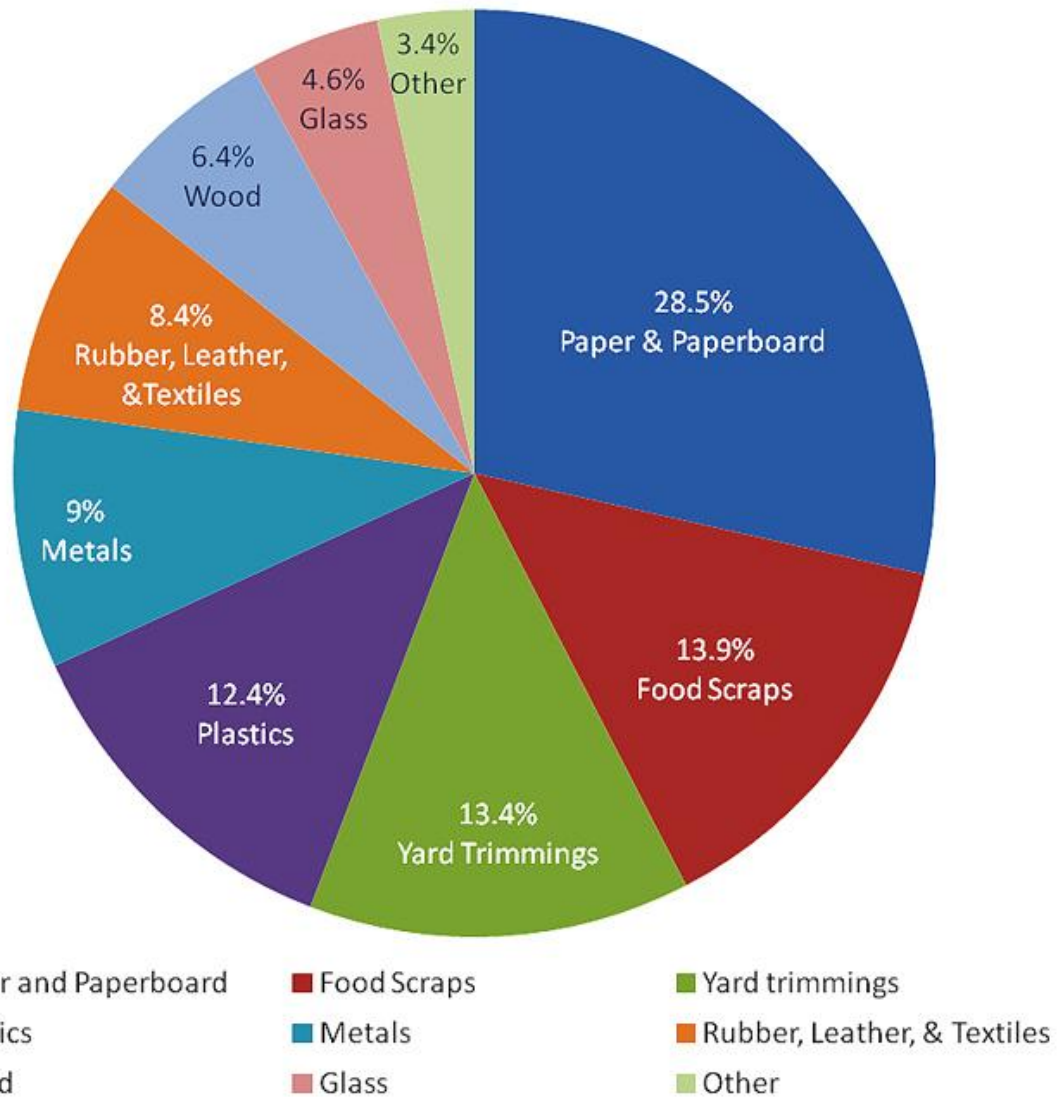
- Definition & Statistics
- Environmental Considerations
- Incinerator Plant Tour
- Ash Recovery/ Management
- Disposal & Trucking
- Challenges with Implementing WTE
- Good News about WTE



Definition

Municipal solid waste (MSW), commonly known as **trash** or **garbage** consisting of everyday items discarded by the public from homes and similar wastes from industries. It includes food wastes, yard wastes, “empty” containers, product packaging, and other similar wastes.

2010 Total MSW Generation (by Material)
250 Million Tons (Before Recycling)



MSW Recycling Rates, 1960-2010

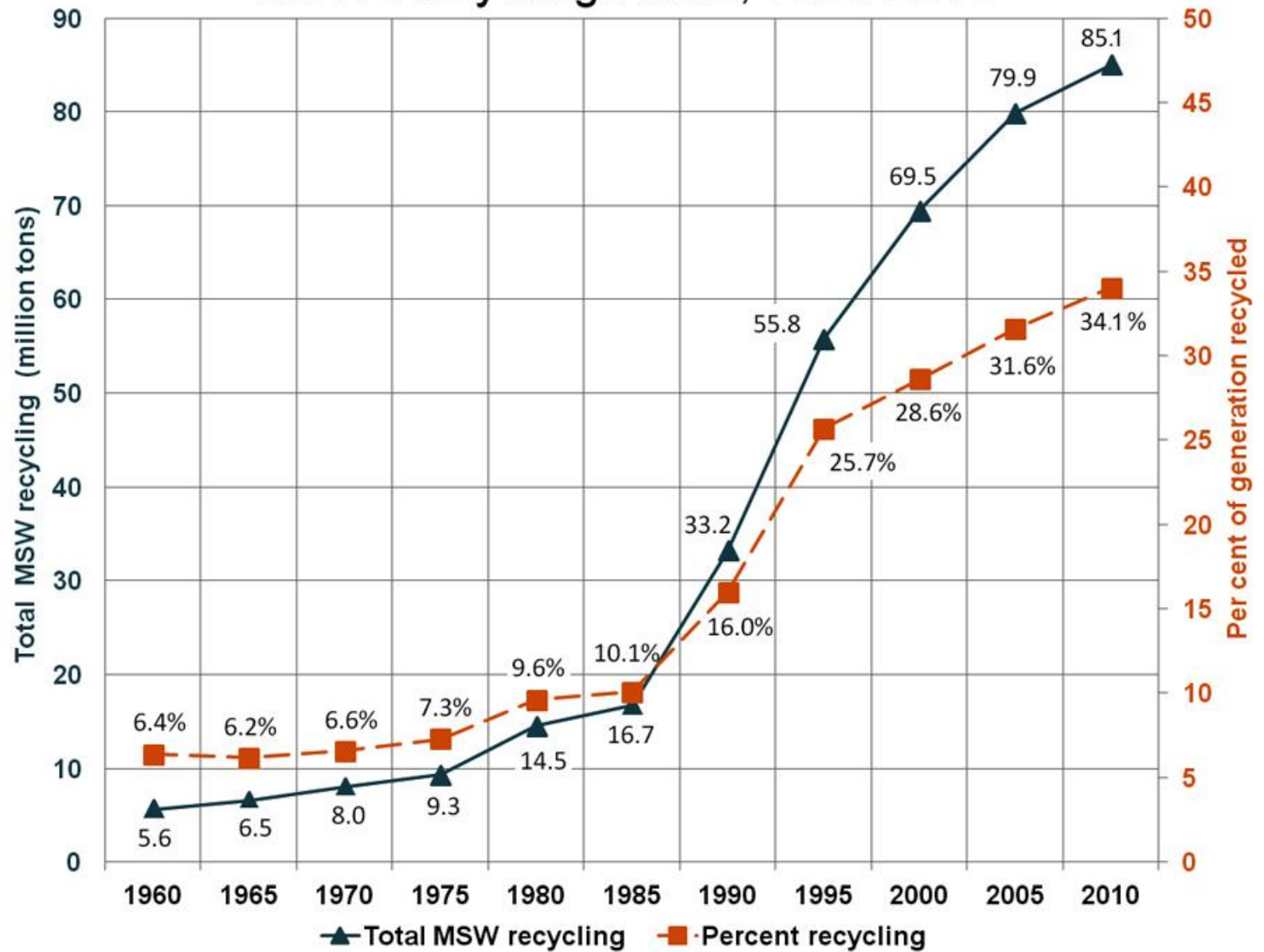
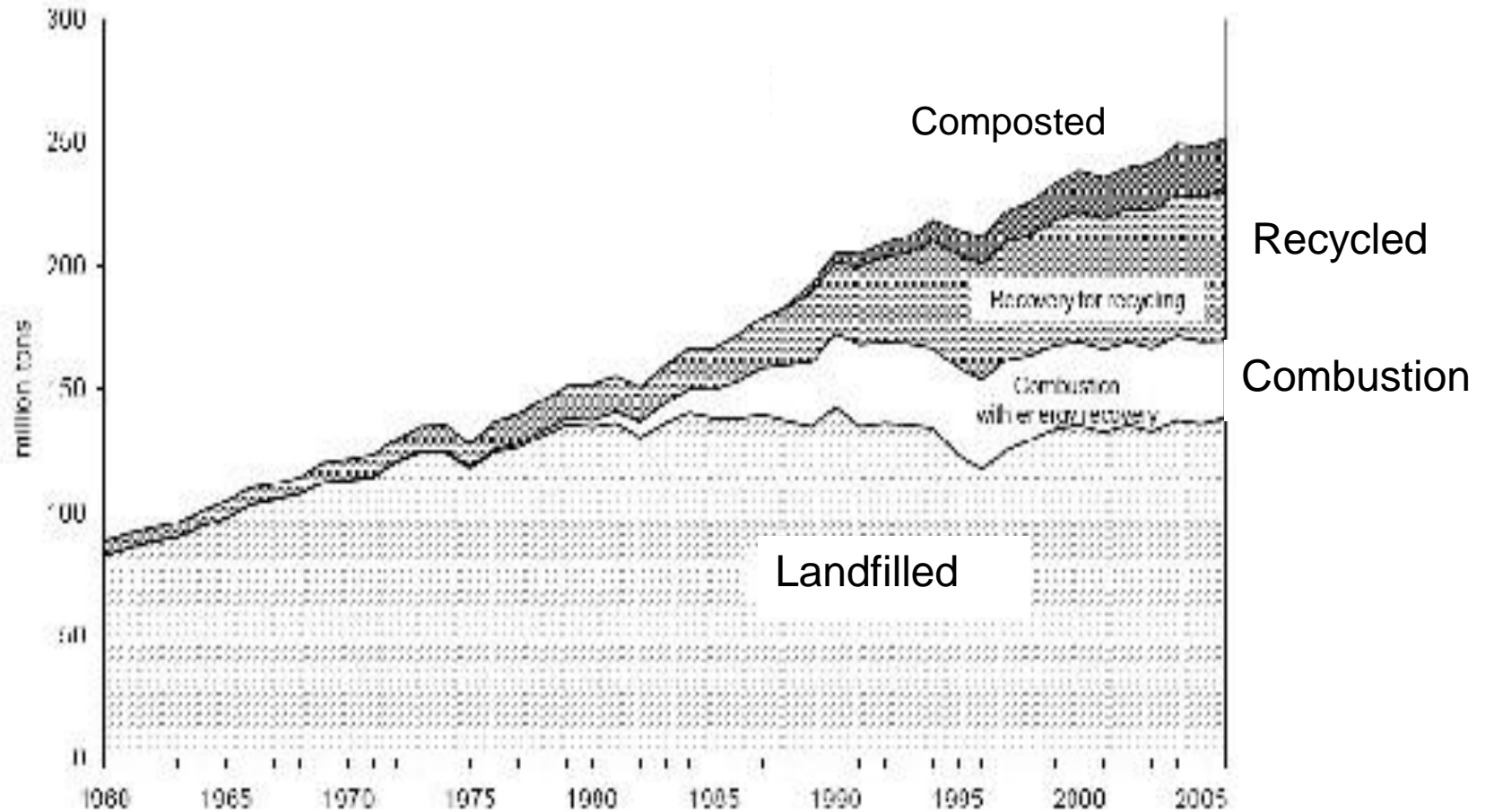


Figure 26. Municipal solid waste management, 1960 to 2006



US Composting, Recycling, Combustion, and Landfilling
(Most recent graph from USEPA website – 1960 to 2006)

US Disposal Practices

90% Trucked to Landfills

San Francisco -
after all possible
recycling has
been done!

And it's 70 miles
to the nearest
landfill....



US Disposal Practices

*Expanded
metal screen
on the back
door...*



Typical trucks get about 3 MPG

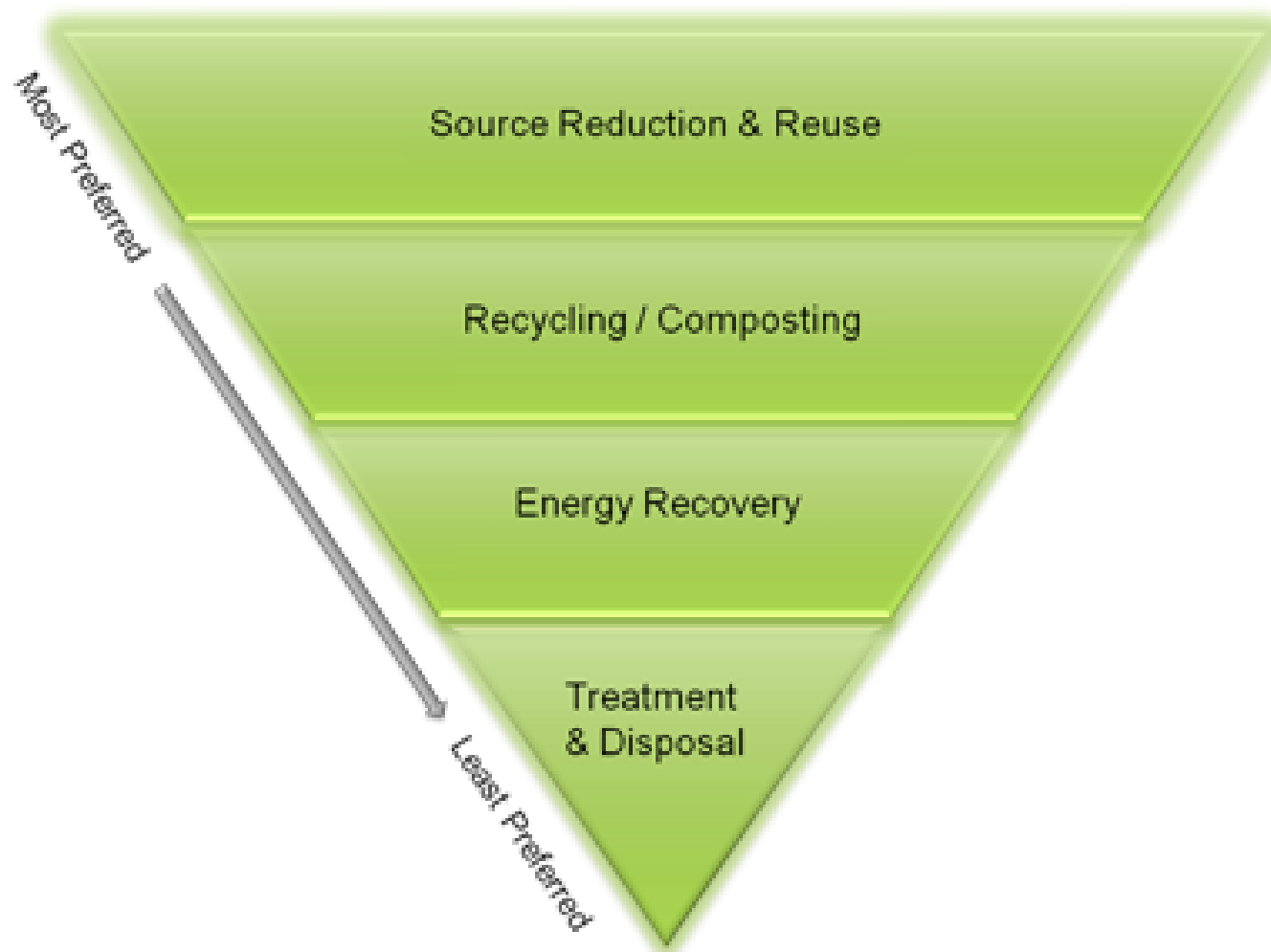


Solid Waste Disposal: Environmental Considerations

- ✓ Air
- ✓ Water
- ✓ Energy
- ✓ Land Use

USEPA Recommended Alternatives

Waste Management Hierarchy





USEPA on Waste-To-Energy (WTE)

- 2002: Best environmental solution for solid waste management
- 2003: Modern Incineration with energy recovery is among the cleanest sources of new electricity (next to wind turbines)

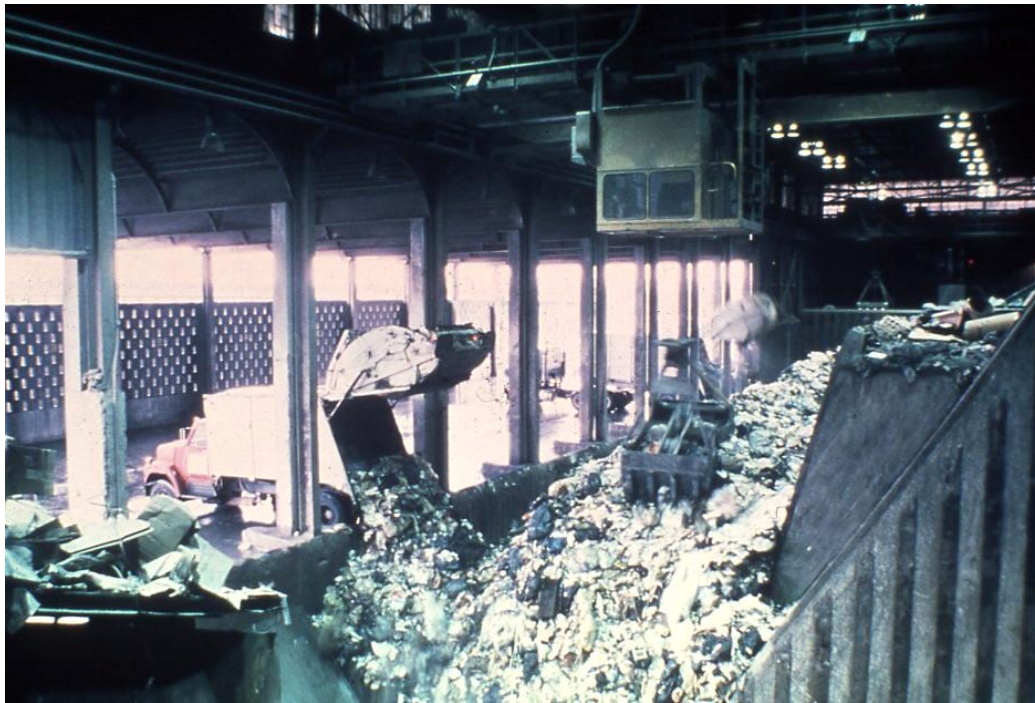
Incinerator Plant Tour!



Dayton's newly built
North Plant back in 1992

Weighing in the
trash





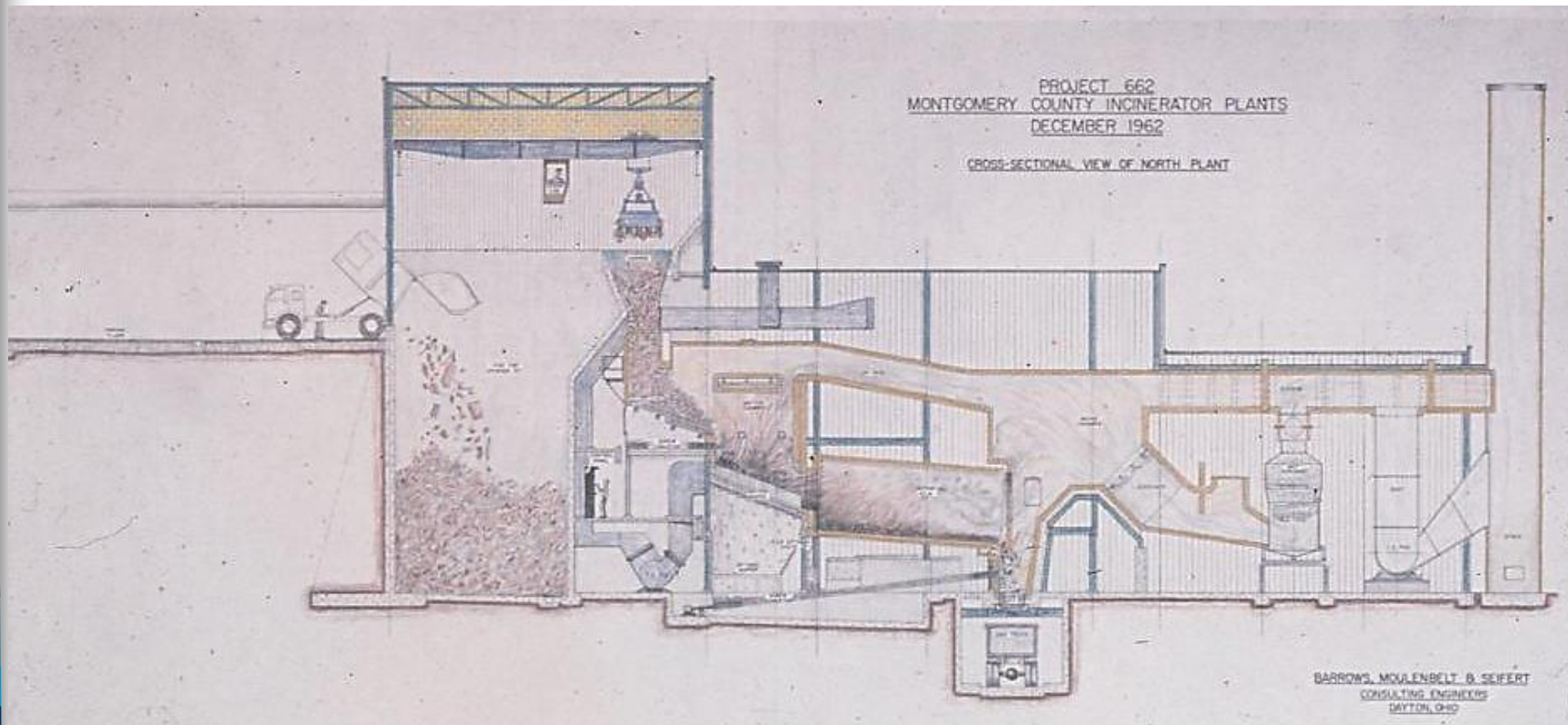
Trucks unload to storage pit

Cranes feed grapples into each of 3 incinerators





Cranes feed grapples into each of 3 incinerators.
Note smoke back on near hopper entrance.



**Typical Cross Section of the
Combustion Box and Kiln**



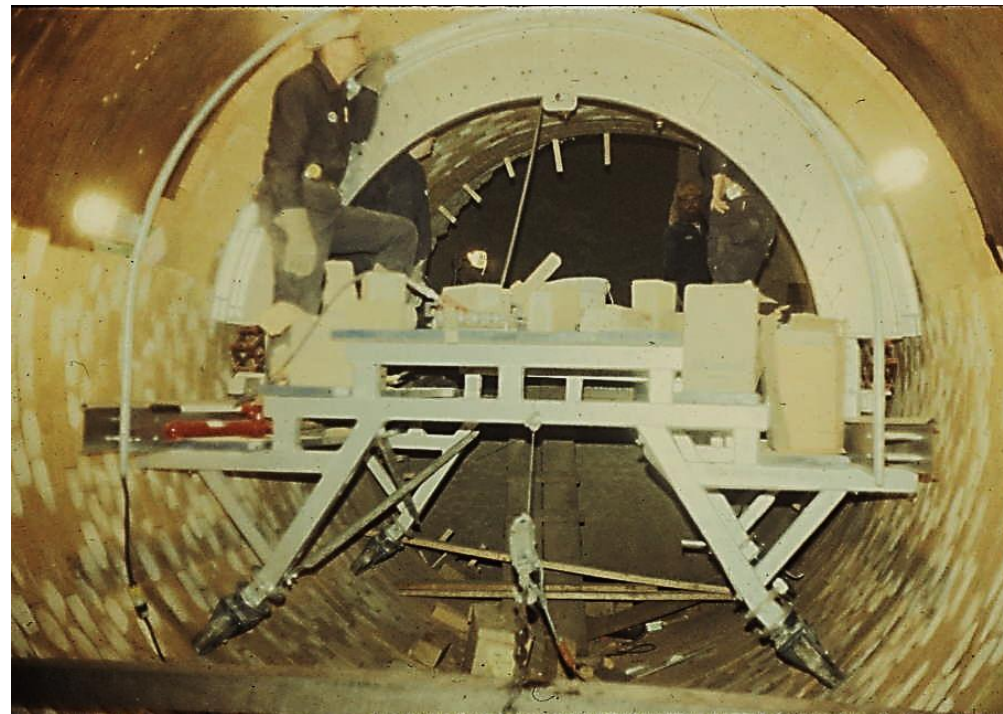
Bottom of the Entrance
Hopper Chute,
Beginning of the
Combustion Box

Looking down on the
Grates. Air comes
from below.





Inspecting the wear
between the
Combustion Box and
Kiln



Repairing the Rotary
Kiln



Note the white hot fire;
this is just the garbage
burning - no auxiliary
fuel !



A smoky view up the kiln

U.S. Garbage

A look into an American Waste Storage Pit



Note the plastics



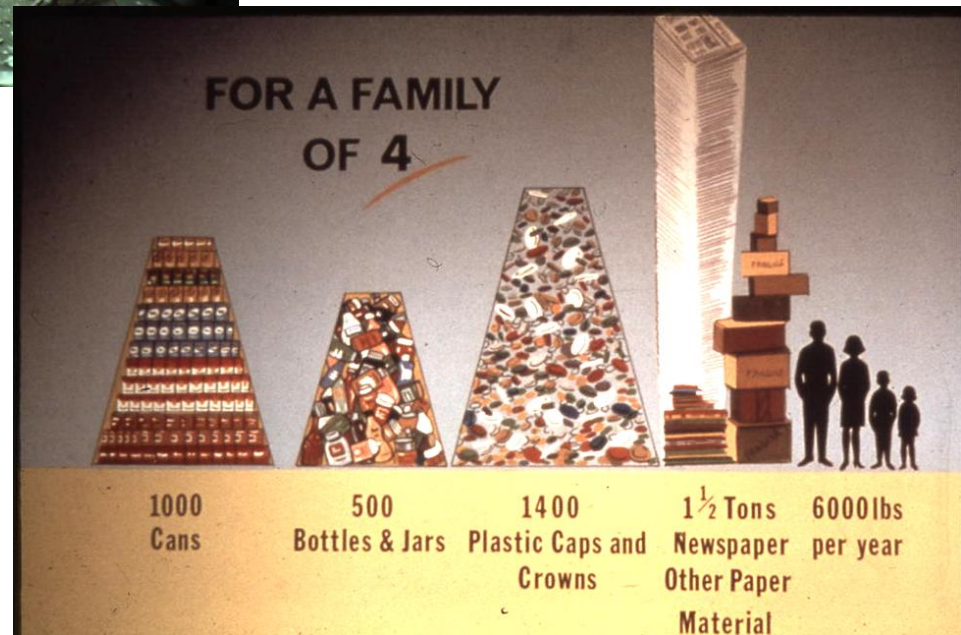
....and the cardboard and wood

U.S. Garbage



Note the small amount of vegetable matter: peels, pits, bad food, etc.

Typical percentages of various materials in the American trash.



Back to the Incinerator...



This is where the ash material falls out.

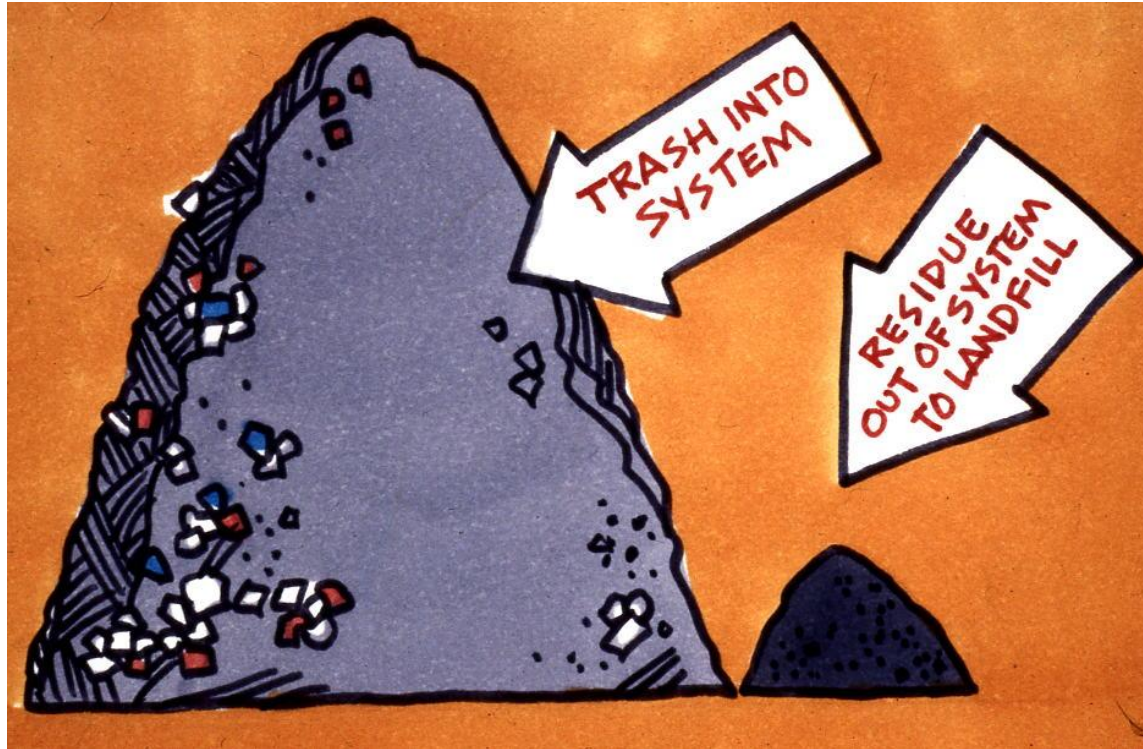
The red bits are molten glass and steel bits like nails, screws, nuts, bolts, etc.

This is the drag conveyor that pulls it out of the water.

Note the acetylene bottle, these units are tough!



Incinerator Ash Management



In the U.S, the primary benefit from incineration is reduced volume.

But the ash material can be recovered too!

Ash Recovery - Steel first, then all the other metals

After the steel has been removed, all the Brass, Aluminum, Copper, and Tin can all be removed by passing the relatively uniform ash residue across a spinning magnet which causes any metal in its magnetic field to jump off the conveyor.



Reclaiming Steel...



This is where the metal had first been removed; we allowed people to come in and just pick it out for sale. They paid us about \$1 per ton just so we could keep track of how much there was.

Unfortunately these men missed a lot of it and they would occasionally get into fights about whose pile belonged to who.



Reclaiming Steel...



Eventually we selected a big metal firm to set up their own equipment and recover almost all of the metal. Iron first...



Mostly is it removed by size selection and magnetics.

Several passes, perhaps.



Reclaiming Steel...



Here is a view of the recovered iron and steel material.

An even closer view.

On closer inspection, you can find not only paper clips, but staples from the paper documents as well, essentially 100%



Ash Recovery: Building Blocks



With all the metals removed the remaining material (glass cullet, crockery particles, rocks and sand) can be used to make Building Blocks.



Ash Blocks used to build these buildings in Dayton...



Building used for tractor maintenance



US Disposal Practices

- 90% Trucked to Landfills
- 10% Incinerated via WTE

EU Disposal Practices

- EU policy: nothing to be buried with more than 2% combustible content.
- Results in a higher % of combustion and energy recovery



Challenges Implementing WTE

- ☐ Costly
- ☐ Financing is impossible without "Flow Control"



“Flow Control”

- Supreme Court ruling in 1994 appeared to eliminate “flow control” [for the waste to be directed into the new large, expensive plants to burn]
- Supreme Court ruling in 2007 now clarifies that flow control for this purpose is legal.
- Very tight air pollution control restriction in the 1999 CAAA: MACT vs BACT
 - Maximum vs Best Available Air Control technology; MACT includes not pricing consideration



Good News about WTE

- 86 large operating WTE incinerator plants in this country.
 - Non compliance measured in minutes over a 15 year period of intense scrutiny.
- Roughly 10 WTE incinerators are undergoing popular expansions at this point.
- Some new plants under consideration
- WTE lowers the Carbon Footprint



Gasification of Municipal Solid Waste

Steve Goff
Covanta Energy Corporation
May 2013



Agenda

1. Gasification Basics
2. Challenges with MSW
3. Commercial Demonstration
4. Covanta CLEERGAS[®] System



Gasification

Gasification is the partial oxidation of the organic content of a feedstock to produce a H₂ / CO containing syngas

PYROLYSIS	GASIFICATION	COMBUSTION
H _C s, Tars, Char	H ₂ / CO	CO ₂ , H ₂ O
(No air)	(Partial air)	(Excess air)
Very Endothermic	Exothermic / Endothermic Balance	Very Exothermic

- Market perception that gasification is a superior process
- Potential benefits of reduced air requirement and lower emissions

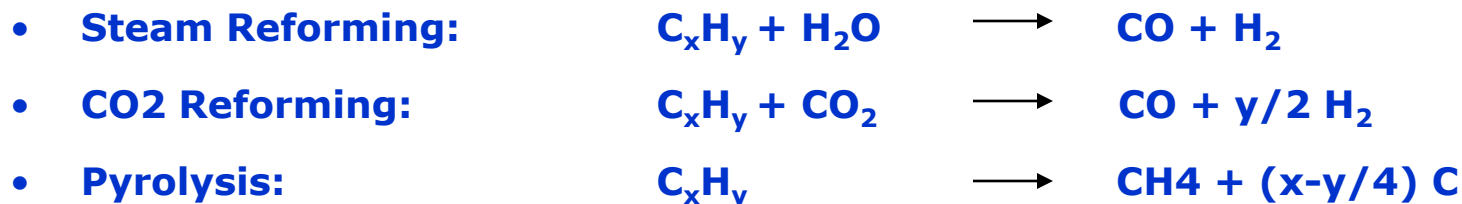


Gasification Reactions

➤ OXIDATION REACTION:



➤ GASIFICATION REACTIONS:



➤ EQUILIBRIUM REACTIONS:





Challenges With MSW

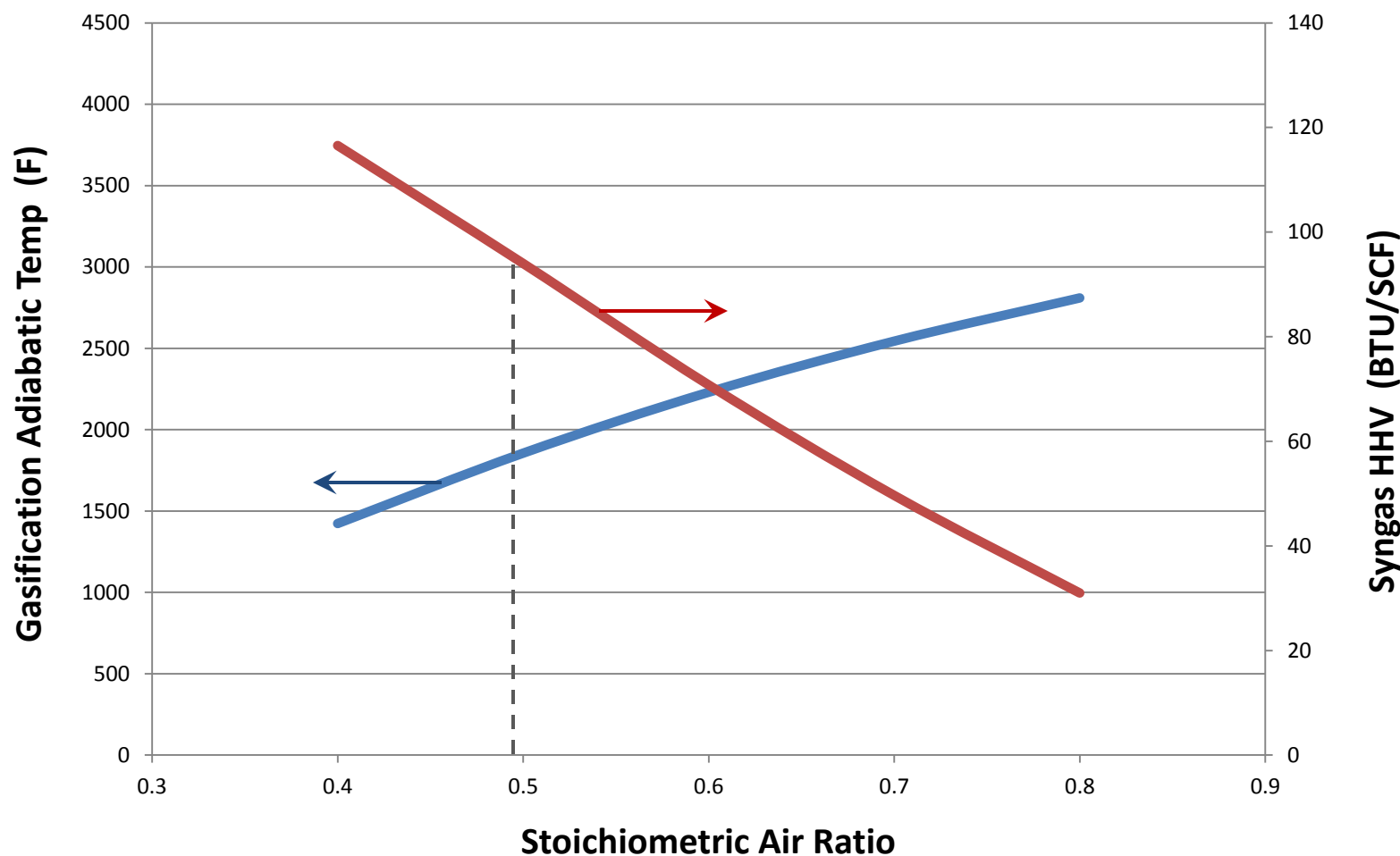
Gasification of MSW is technically and economically challenging

- **Heterogeneous nature of MSW complicates equipment design, process design and process control**
 - Broad range of physical and chemical properties
 - Heating value variability
- **Gasification processes developed for coal or biomass require significant pre-processing of MSW – high cost**
 - Moving bed, fluidized bed, entrained flow reactor types
- **Syngas quality and heating value dependent on many parameters**
 - Gasification temperature, air vs. oxygen, other reactants (steam, CO₂), other energy inputs (plasma), gasifier design, control system



MSW Gasification

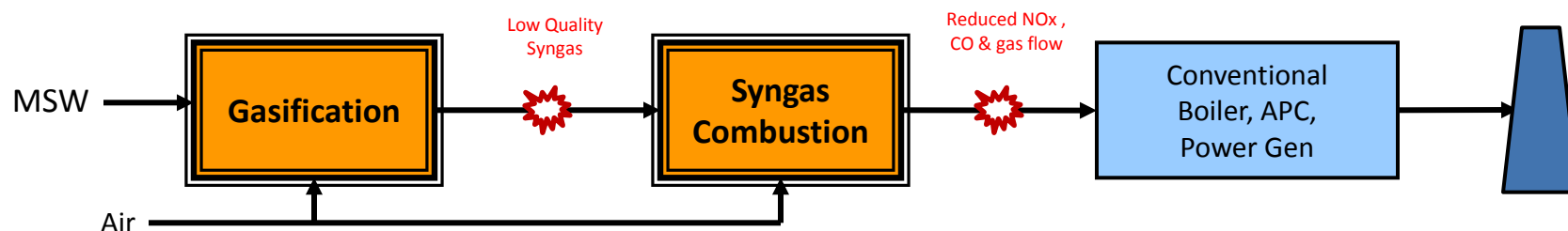
Energy Balance Considerations



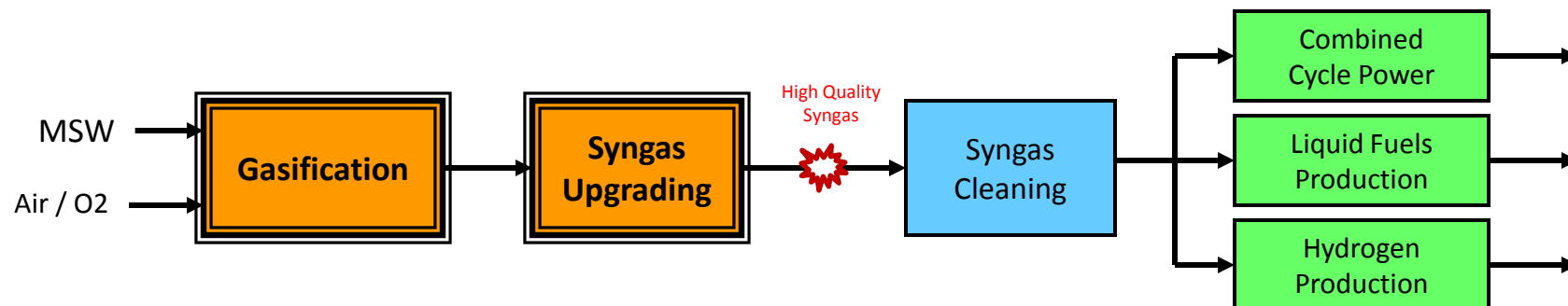


Types of MSW Gasification Processes

GASIFICATION / SYNGAS COMBUSTION - Goal of improved emissions & energy efficiency



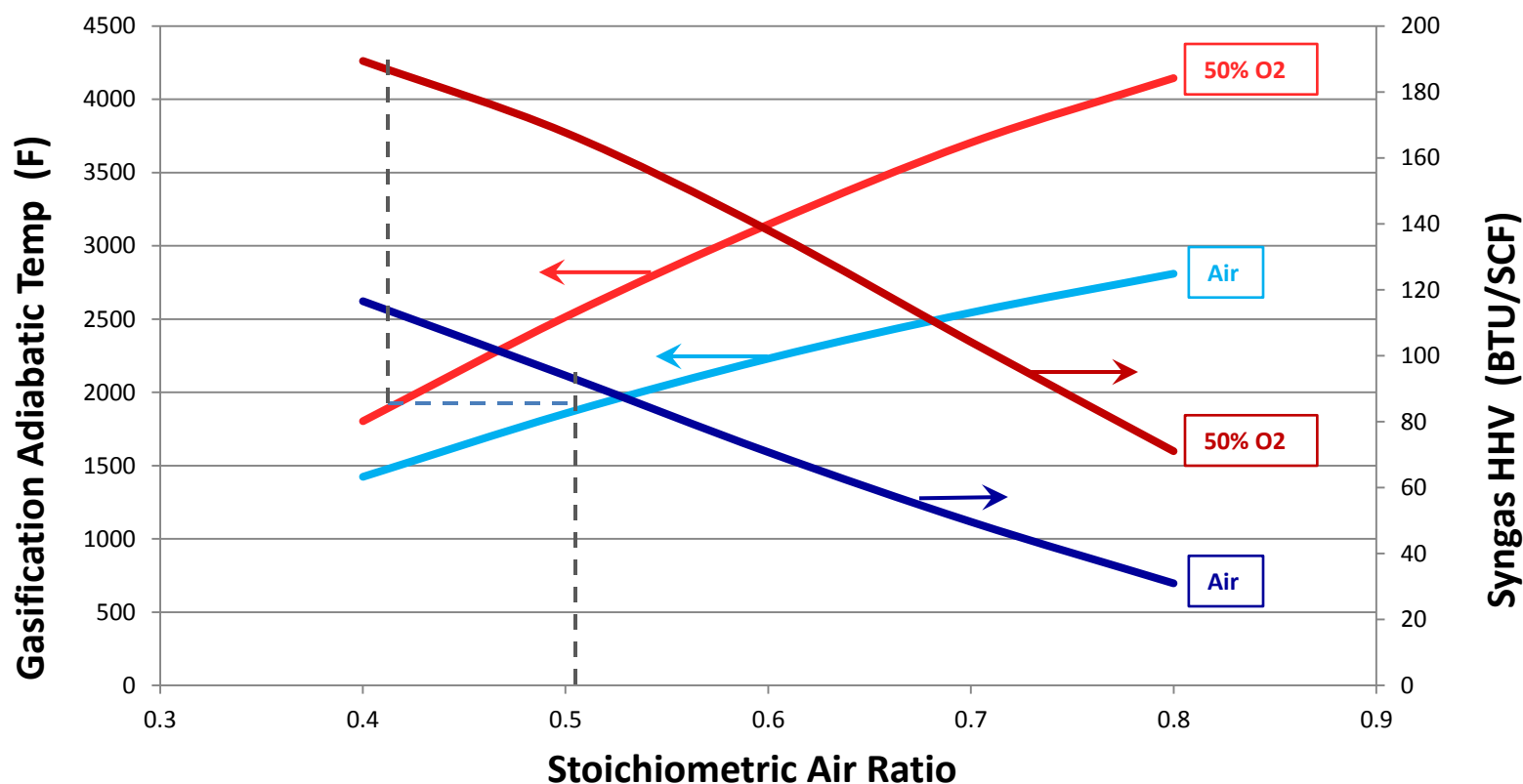
GASIFICATION / SYNGAS RECOVERY - Goal of combined cycle power or high value products





MSW Gasification

Impact of Oxygen Enrichment



Cost of O₂ enrichment determined to not justified for power generation processes



Covanta Research & Development

Ongoing Investment in Development of MSW Gasification

- | | |
|--|--------|
| • Comprehensive study on hundreds of advanced thermal technologies | — 2006 |
| • 5 TPD gasification / syngas combustion pilot program | — 2009 |
| • 5 TPD gasification / syngas recovery pilot program | — 2010 |
| • 350 TPD commercial gasification / syngas combustion unit | — 2011 |
| • Engineered commercial 300 TPD modular system | — 2012 |
| • Continuing R&D on gasification / syngas recovery | — 2013 |



MSW Gasification

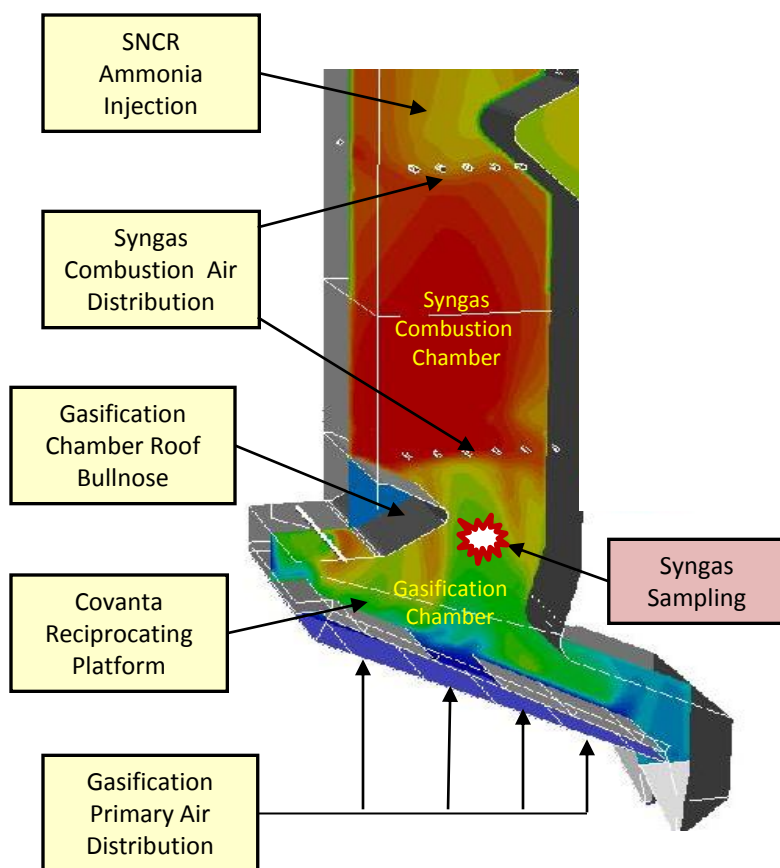
Key Components for Commercial Viability

- System designed for unprocessed, post-recycling MSW
 - Handling, shredding, processing, storing waste = high costs
- Employ reliable solid handling equipment for feed system, gasifier, and ash removal
 - Analogous to conventional EfW
- No additional sources of energy input to the process
 - No electric power, plasma, coal or coke
- Air based – no oxygen enrichment
 - Oxygen aids process, but cost is not recovered in product value

Commercial success very dependent on the process and equipment.



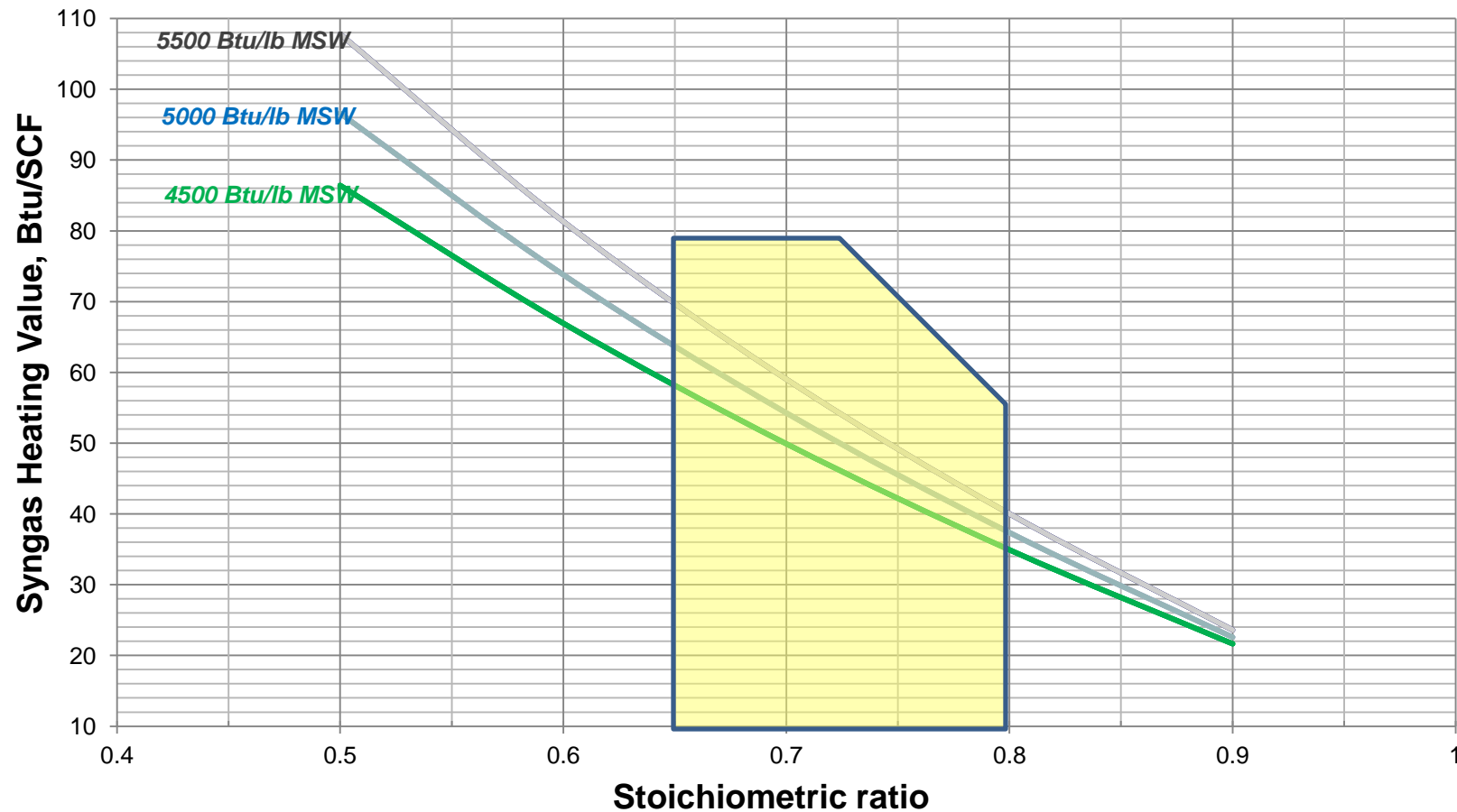
Commercial Demonstration MSW Gasification with Syngas Combustion



- Refurbishment of existing 350 TPD EfW waterwall boiler – Tulsa, OK
- No preprocessing of MSW
- Covanta designed reciprocating platform
- Extensive air distribution system
- Covanta designed control system
 - Superior system stability
- Operating reliably since July 2011
 - 94% availability
- Low emissions: NO_x at 40 – 60 ppm
- Reduced particulate resulting in less boiler fouling and corrosion



Syngas Sampling and Analysis

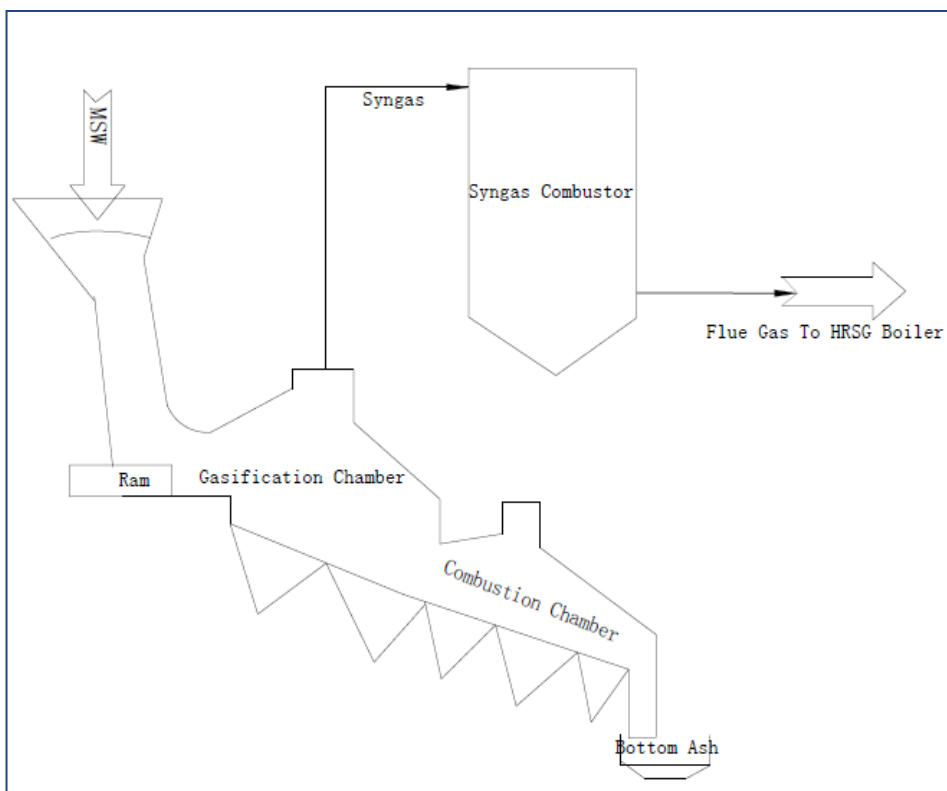


Syngas heating value from Tulsa demonstration limited by retrofit of waterwall furnace



Covanta CLEERGAS® Gasifier

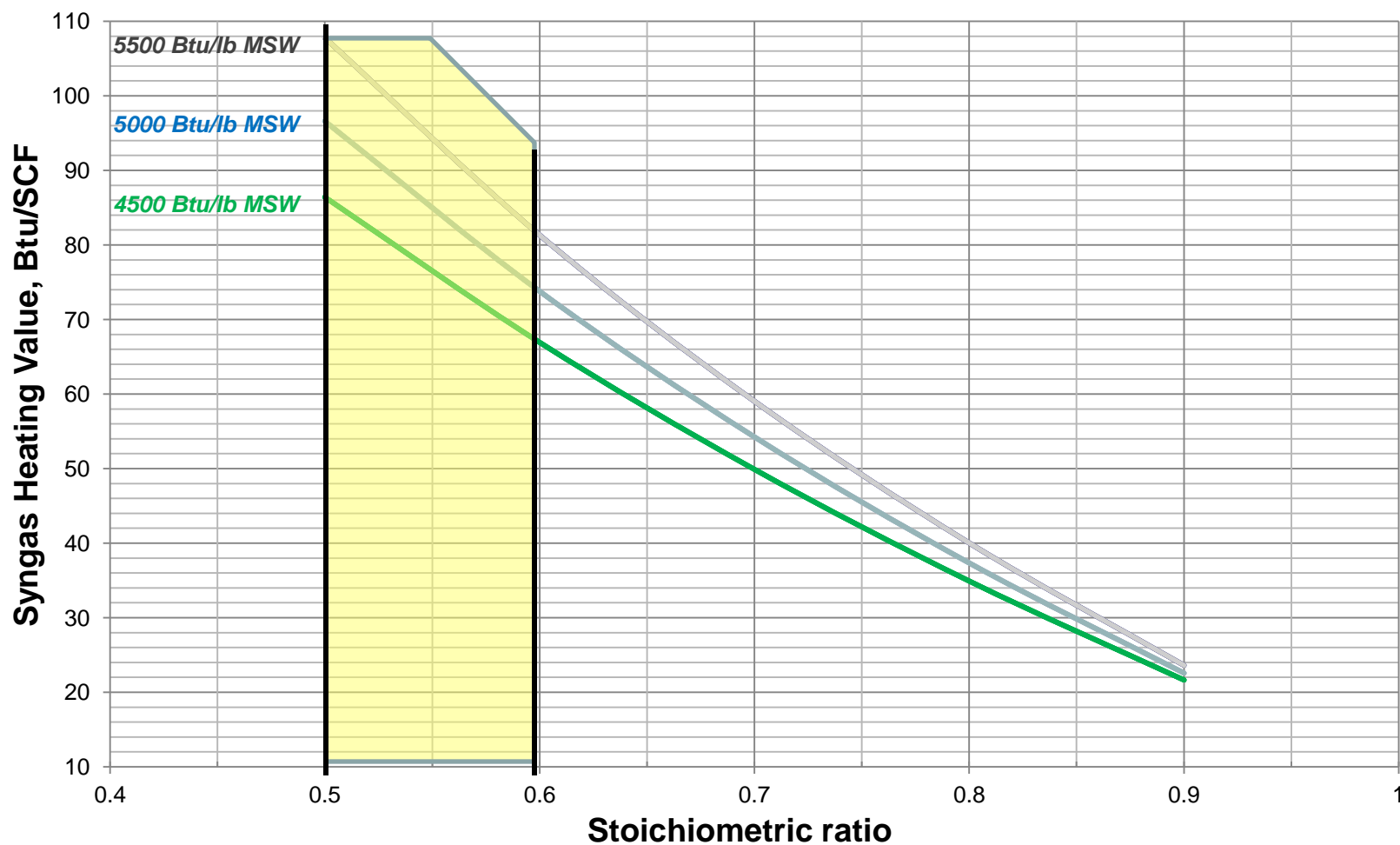
Process Improvements from Tulsa Refurbishment



- Separation of gasification zone from carbon burnout zone in gasifier reactor
- Burnout zone energy recovered to drive gasification process – reduces stoichiometric ratio and increases syngas heating value
- Refractory-lined gasifier to minimize energy loss – simpler design than waterwall furnace
- Cylindrical waterwall syngas combustor with staged air injection – reduces air requirement and NO_x formation
- Optimal SNCR performance in turbulent syngas combustor
- Advanced control system developed from Tulsa demonstration



CLEERGAS® – Higher Syngas Quality





Covanta CLEERGAS®

- **Commercialization of MSW gasification with syngas combustion**
 - Lower emissions
 - Higher boiler efficiency
 - Reduced boiler fouling and corrosion
 - Lower capital cost – modularization
 - Developing projects around the world
- **Ongoing development of gasification with syngas recovery**
 - Syngas tars conversion and clean-up difficult
 - Main driver remains reduced emissions potential
 - Minimal energy efficiency benefit potential with gas engines & turbines
 - Conversion to liquids challenged by syngas quality and economics



COVANTA
ENERGY
for a cleaner world

Thank You

Thermal Conversion of Waste to Energy and Products

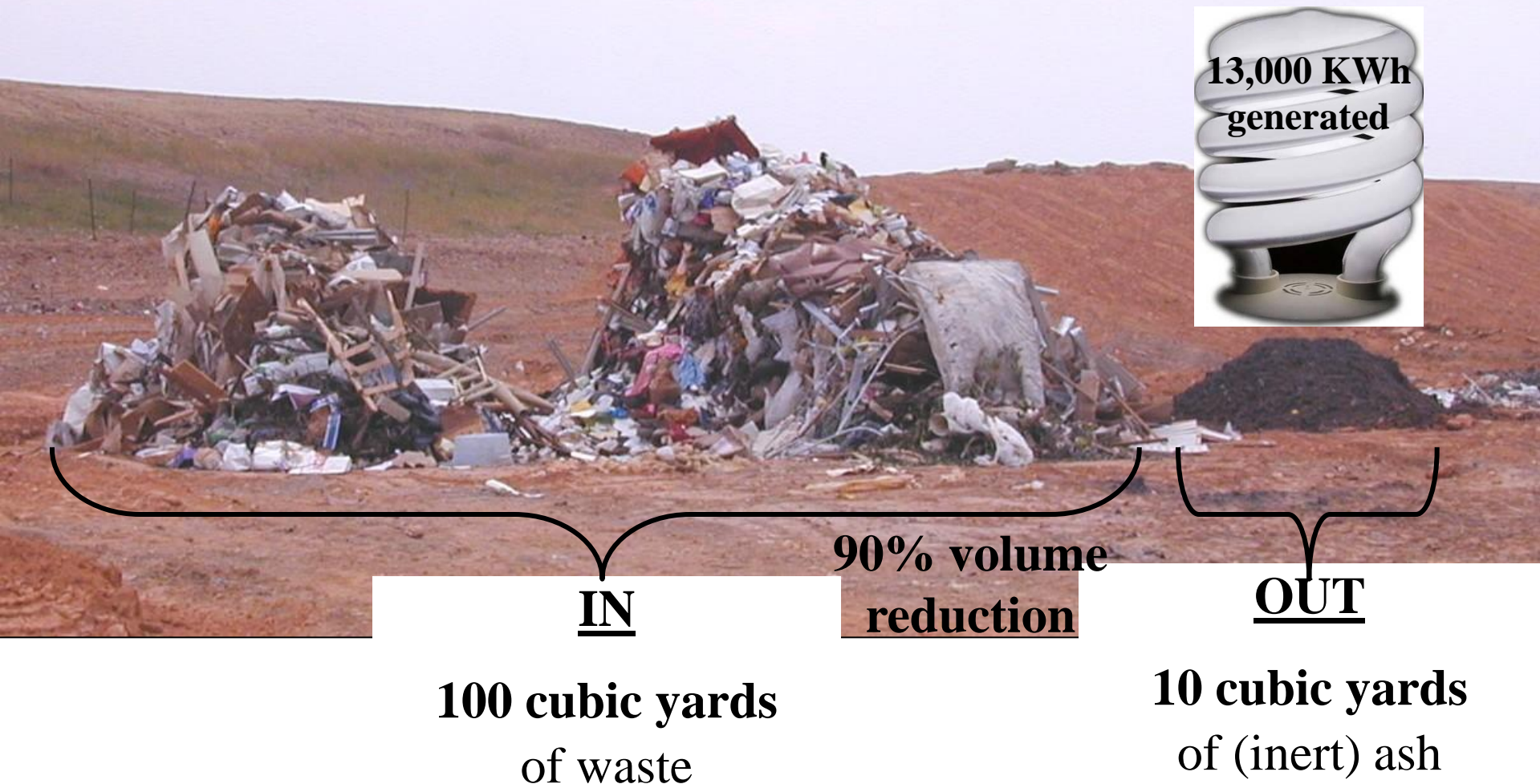
American Society of Mechanical Engineers (ASME)
Webinar: Turning Trash Into Renewable Energy Treasure

Thursday, May 30, 2013
2:00PM – 3:00PM ET,
New York U.S.

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

Waste-to-Energy (WTE) Facility

Reducing the Volume of Waste & Generating Energy

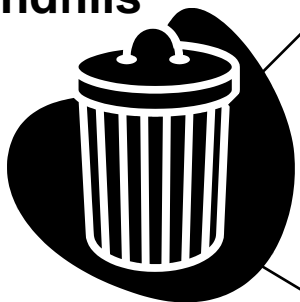


$$E = M \times C^2$$

*Energy is mass times a constant
(from the mass recover energy)*

Waste Management Options

249 Million tons
of trash (MSW)
goes to
landfills



Landfills



Renewable Energy Generated
from Landfills - 5 billion kWh

Up to **100** kilowatt hours of
electricity **per ton** of waste

Waste to Energy



Renewable energy generated from
WTE Facilities - 15 billion kWh

Up to **700** kilowatt hours of
electricity **per ton** of waste

29 Million tons
of trash goes to
EfW

These two options must co-exist for the foreseeable future

WTE is Increasing

- In 2011 the world MSW generated ± 2 billion tons
- Currently ~ 800 thermal WTE plants
 - Operating in nearly 40 countries
 - This is 11% vs. 70% landfilled
- WTE expected to increase
 - From 221 terawatt hours in 2010 to 283 tW-hrs by 2022
 - Global market for WTE technologies \$6.2 billion in 2012 and expected to grow to \$29.2 billion by 2022.

Source: Pike Research

WTE cuts across many sustainable fronts

- ***WTE conserves fossil fuels by generating electricity. (Energy)***
 - 1 ton of waste combusted = 45 gallons of oil or 0.28 tons of coal
 - Most WTE facilities in U.S. process between 500 and 3,000 tons of waste per day
 - Electricity for 2.8 million homes
- ***WTE facilities process 14% of the MSW in the United States. (Health)***
 - Trash-disposal needs about than 37 million people
- ***WTE facilities meet some of the world's most stringent standards. (Environmental, local)***
 - Achieved compliance with new Clean Air Act pollution control standards in 2000
 - EPA data :dioxin emissions now account for less than 0.5% of dioxin emissions
- ***WTE facilities reduce greenhouse gas emissions. (Climate, global)***
 - EPA estimates: WTE facilities prevent 33 million metric tons of CO₂ per year avoided
- ***WTE facilities save real estate. (Land)***
 - They reduce the space required for landfills by about 90%
- ***WTE is compatible with recycling. (Resource Minimization)***
 - WTE Communities recycle 35% of their trash, compared to 30% for the general population.
 - Annually removes more than 700,000 tons of ferrous materials
 - 3 million tons of WTE ash reused as landfill cover, roadbed, or building material.
- ***WTE facilities provide economic benefits. (Economic)***
 - WTE is a \$10 billion industry employs ~ 6,000 American workers annual wages ~ \$400 million

A Renewable Resource

Proportions Biobased vs. Fossil Based
indicated by ^{14}C content

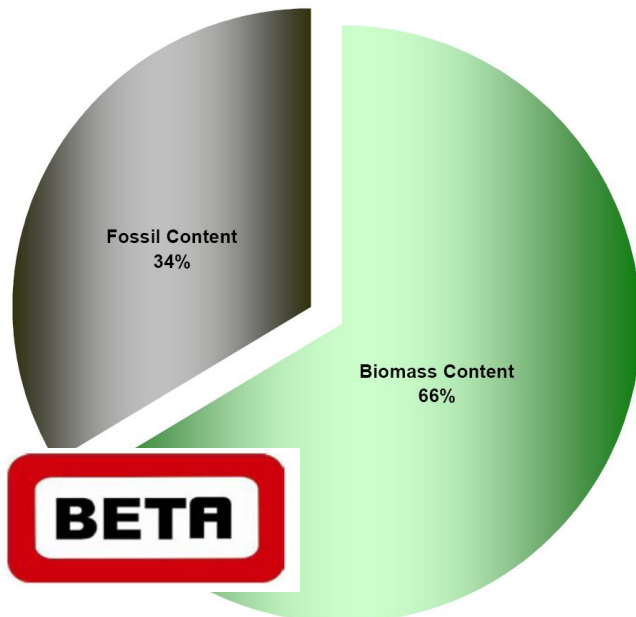


Table 3. Characterization of U.S. MSW by USEPA [7]

Biomass components	%	Petrochemical components	%
Paper/board	36.2	Plastics	11.3
Wood	5.8	Rubber, nylon, other textiles.*	3.7
Yard trimmings	12.1		
Food scraps	11.7		
Textiles (cotton, wool, leather)*	3.7		
Total biomass	69.5%	Total fossil-based	15.0%

**Rubber, leather and textiles category of USEPA 7.4%) were assumed to be divided equally between natural and man-made products*

- ASTM D8666 testing standard using ^{14}C
- Biomass content; 3 WTE flue gas samples
- 66%, 68% and 66%
- 10% - 36% reduction of CO_2 emissions compared to landfill

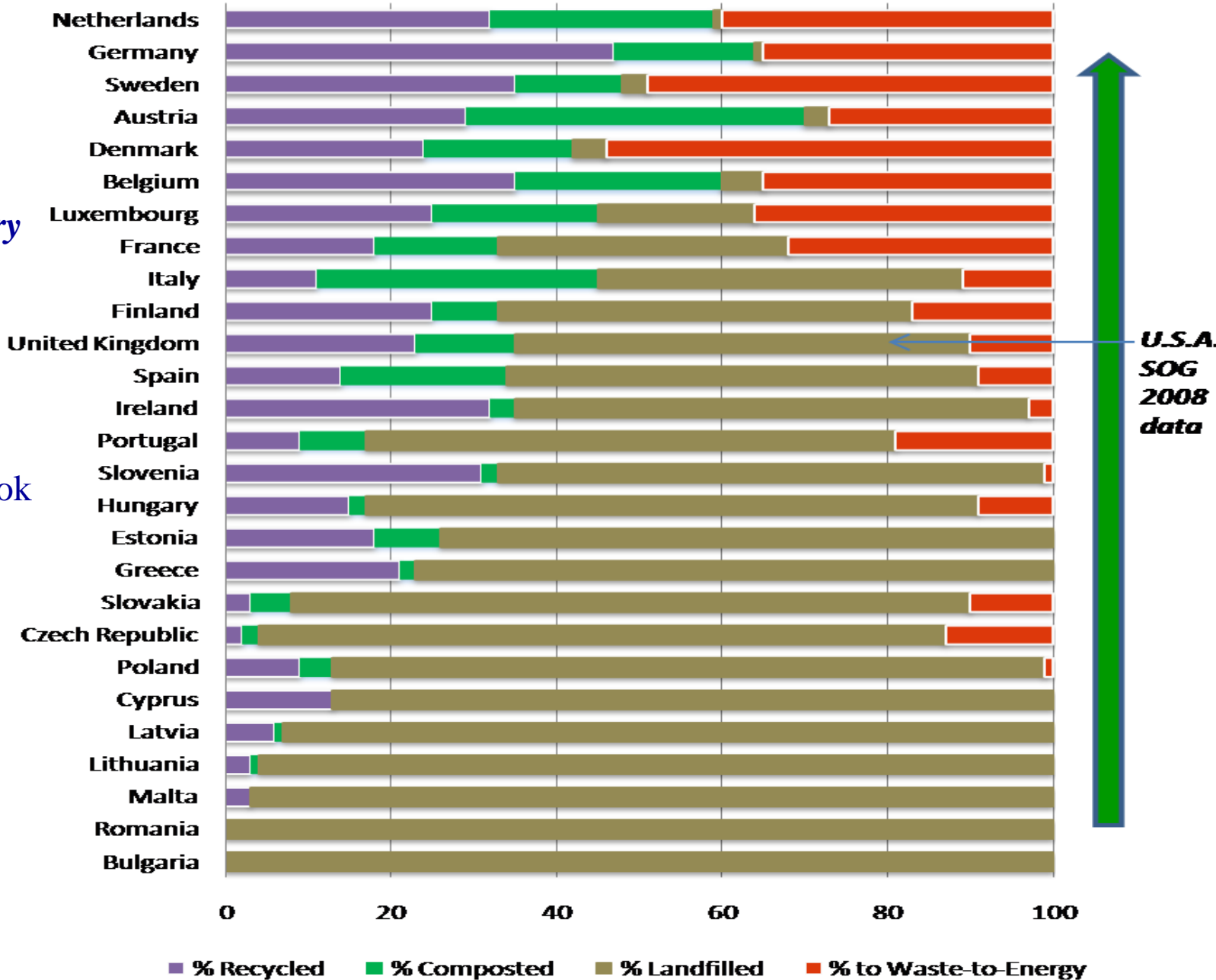
The Sustainable Waste Management Ladder

Earth Engineering Center, Columbia University (based on Eurostat 2008 data)

*WTE and
recycling are
complementary*

Why?

*A complete look
at waste
management
includes ALL
options*

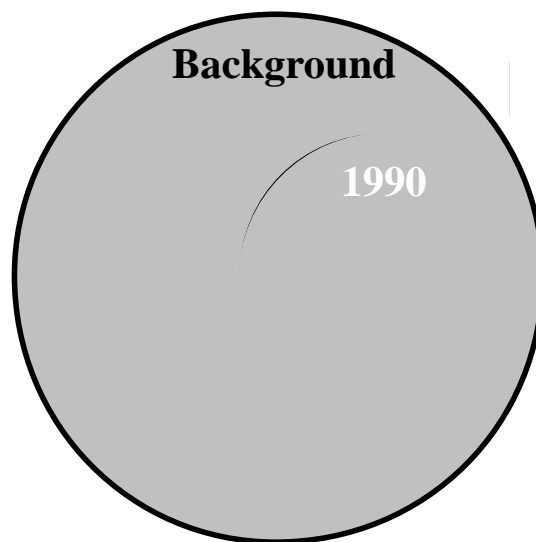
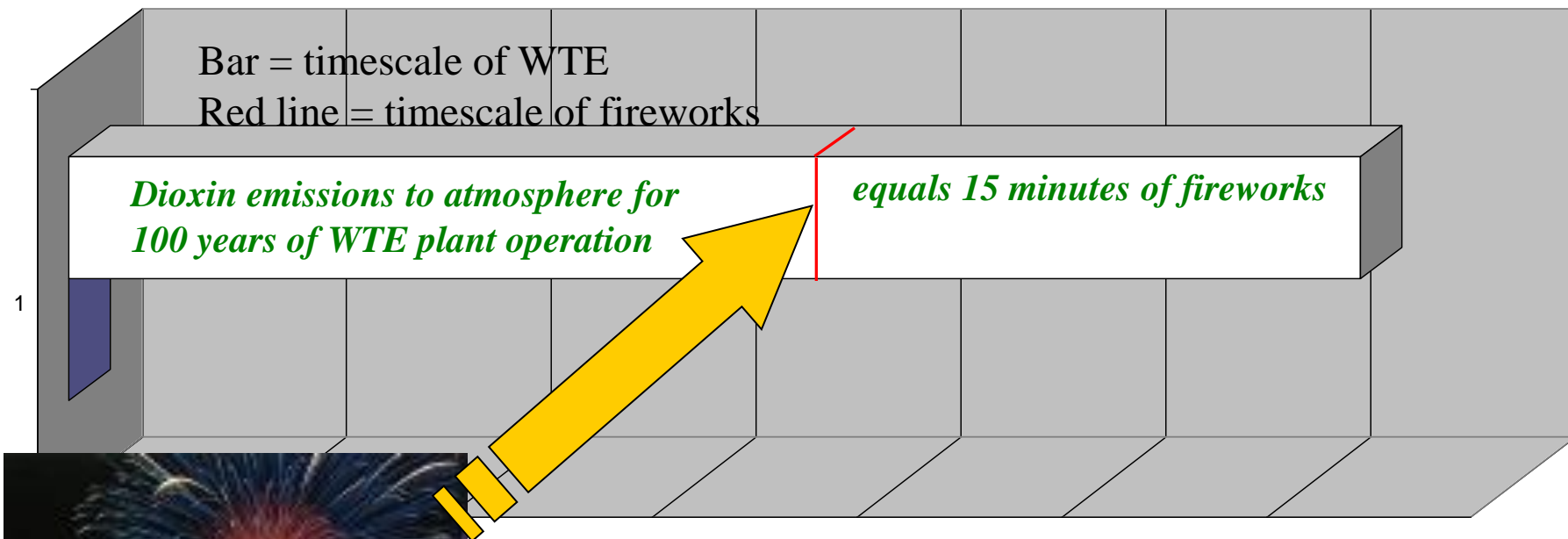


Emissions, mg/Nm ³	Average of 10 WTEs	E.U. standard	WTEs as % of E.U. standard
Particulates	3.06	10	31%
SO ₂	12.2	50	24%
NO _x	123	200	61%
HCl	7.88	10	79%
CO	26.3	50	53%
Mercury	0.01	0.05	20%
TOC	0.92	10	9%
Dioxins, ng TEQ/m ³	0.02	0.10	21%

Representative Emissions for U.S. WTE Operational Facilities

(meeting strict EU standards which are lower than US standards)

Dioxins Reality



Relative concentrations of dioxins

Technology

Pyrolysis, Gasification or Combustion

- | | | |
|--|--|--|
| <ul style="list-style-type: none"> • 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 | <ul style="list-style-type: none"> • Sub stoichiometric air • Lower total volumetric flow • Lower fly ash carry over • Pollutants in reduced form (H_2S, COS) • Char @ Low T • Vitriified Slag @ high T • Scale: ~ 100 tons/day | <ul style="list-style-type: none"> • Excess air • Higher volumetric flowrate • Fly ash carry over • Pollutants in oxidized form (SO_x, NO_x, etc) • Bottom ash • Scale: ~ 1500 tons/day |
|--|--|--|

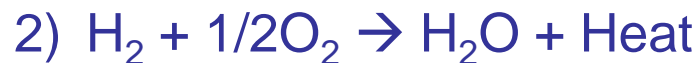
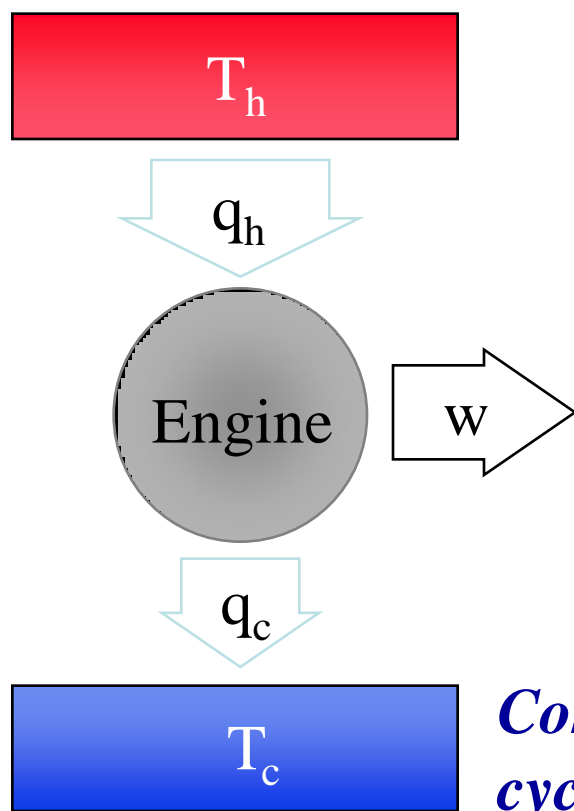
No additional Oxygen
(only heat)
Unconverted solid will remain!

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

Much additional Oxygen (or air)
Heat comes from reactions

Combustion Option

Primarily generate heat



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

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

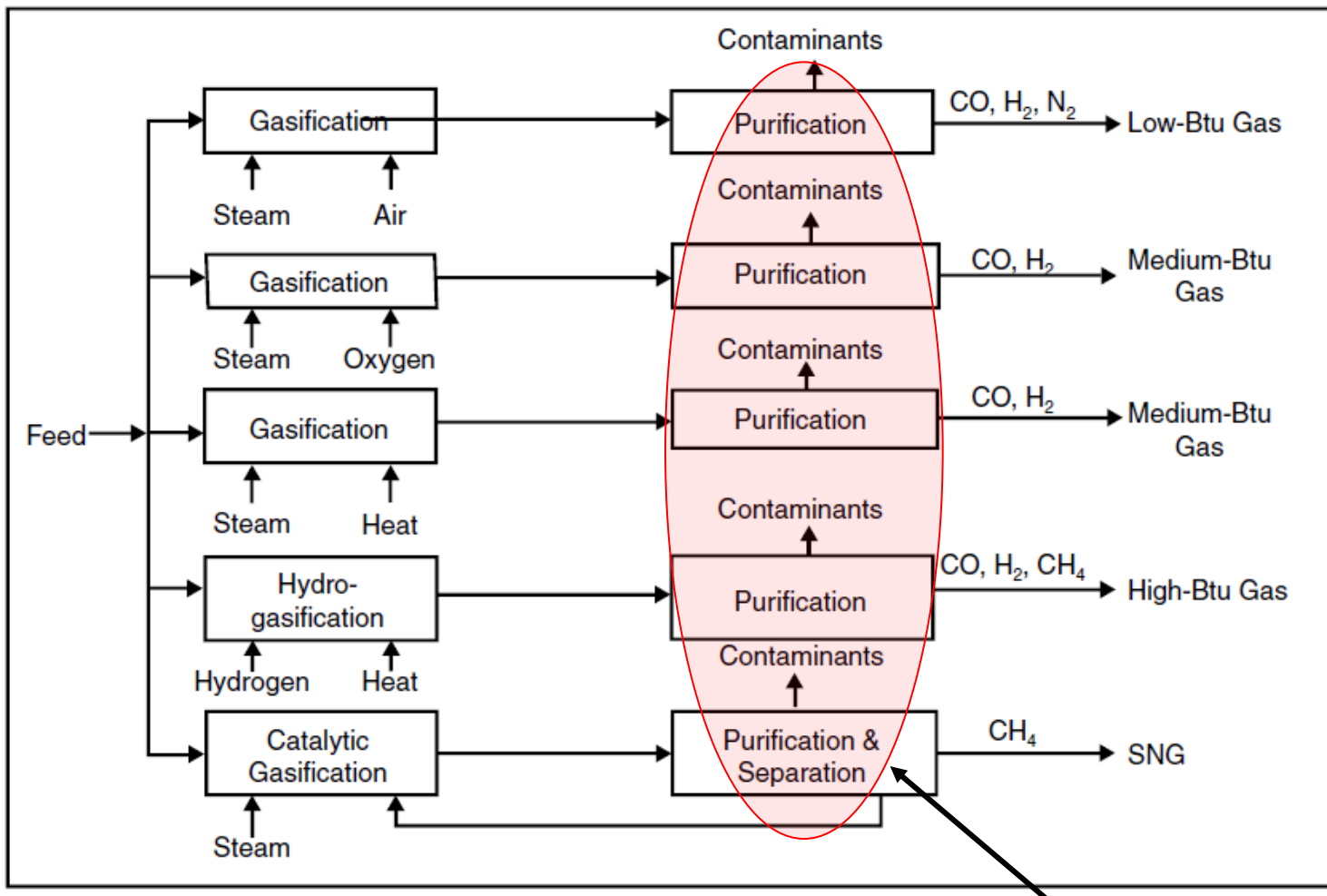
$$\therefore \eta = 1 - |T_c| / T_h$$

Combustion systems are constrained by Carnot cycle to extract work (i.e. electricity, power)

Gasification Option

Rezaiyan and Cheremisinoff

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



Work needs to be done here

Figure 1.1 Gasification methods.

Gasification status

- 163 commercial gasification projects 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 – 2013 Pilot
- Energos (Sweden, UK) building plants @ <150,000 tpy

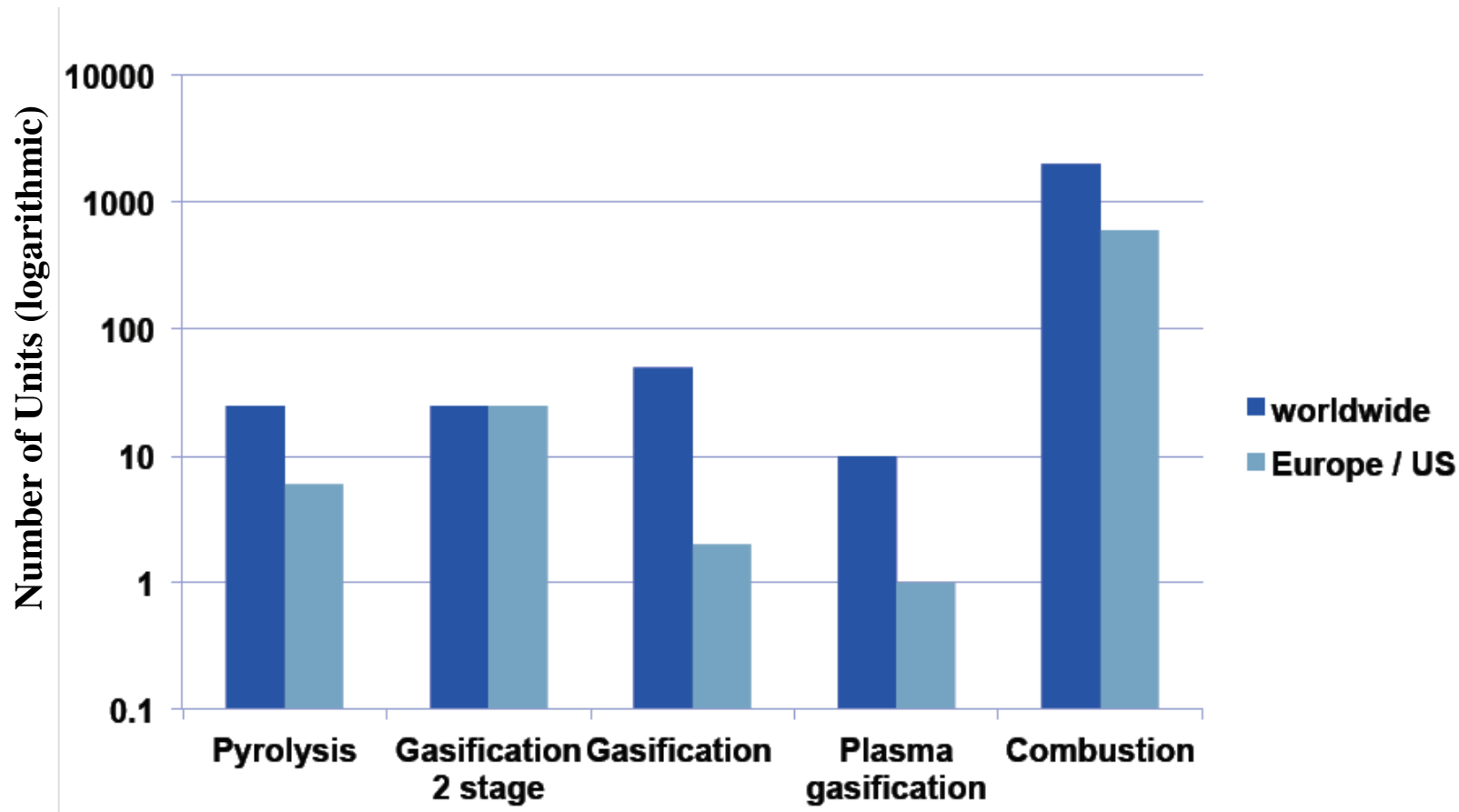
Totaling ~ **35 million tpy (metric)**

Combustion Status

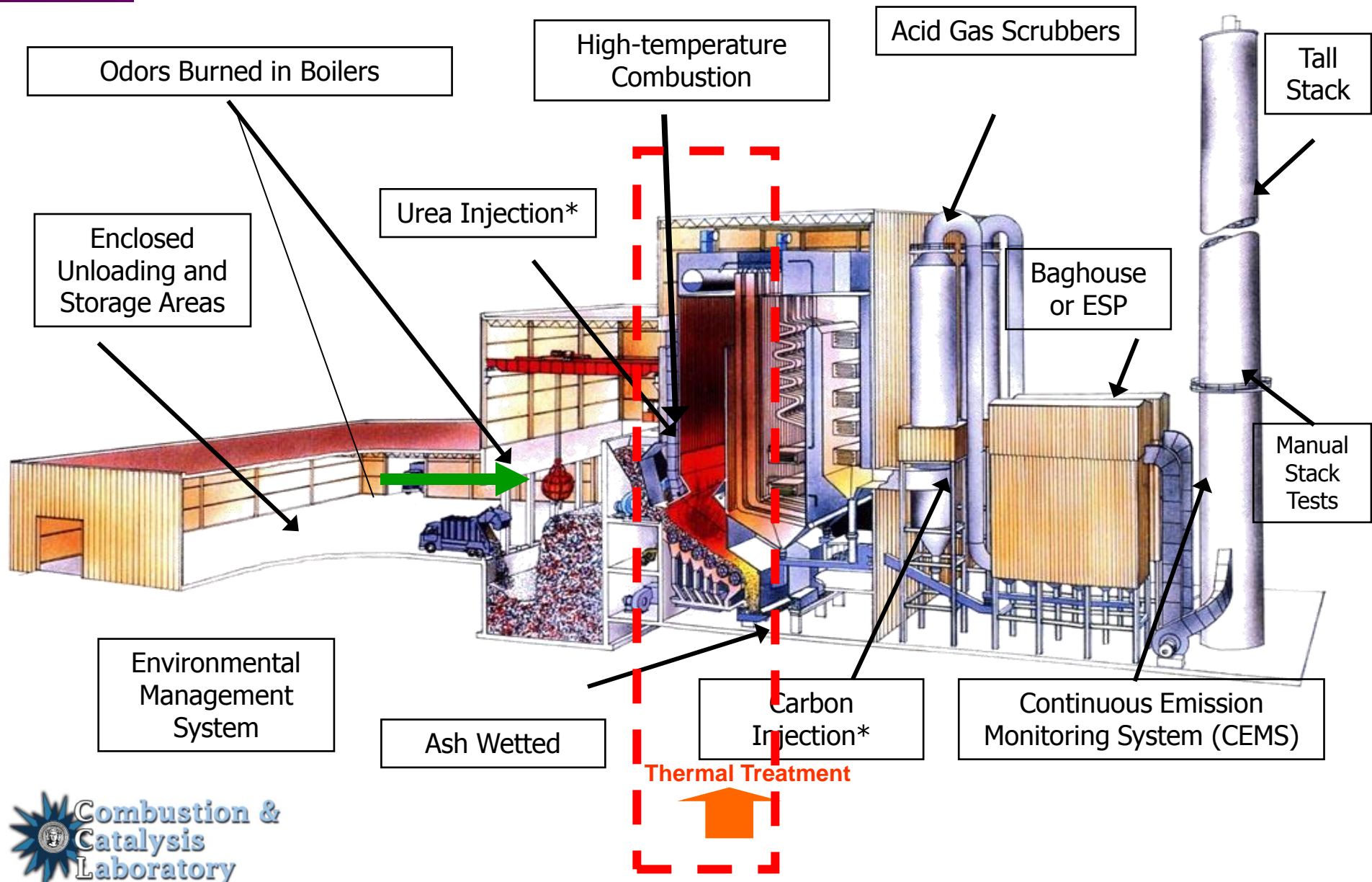
(metric tons)

- 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)

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

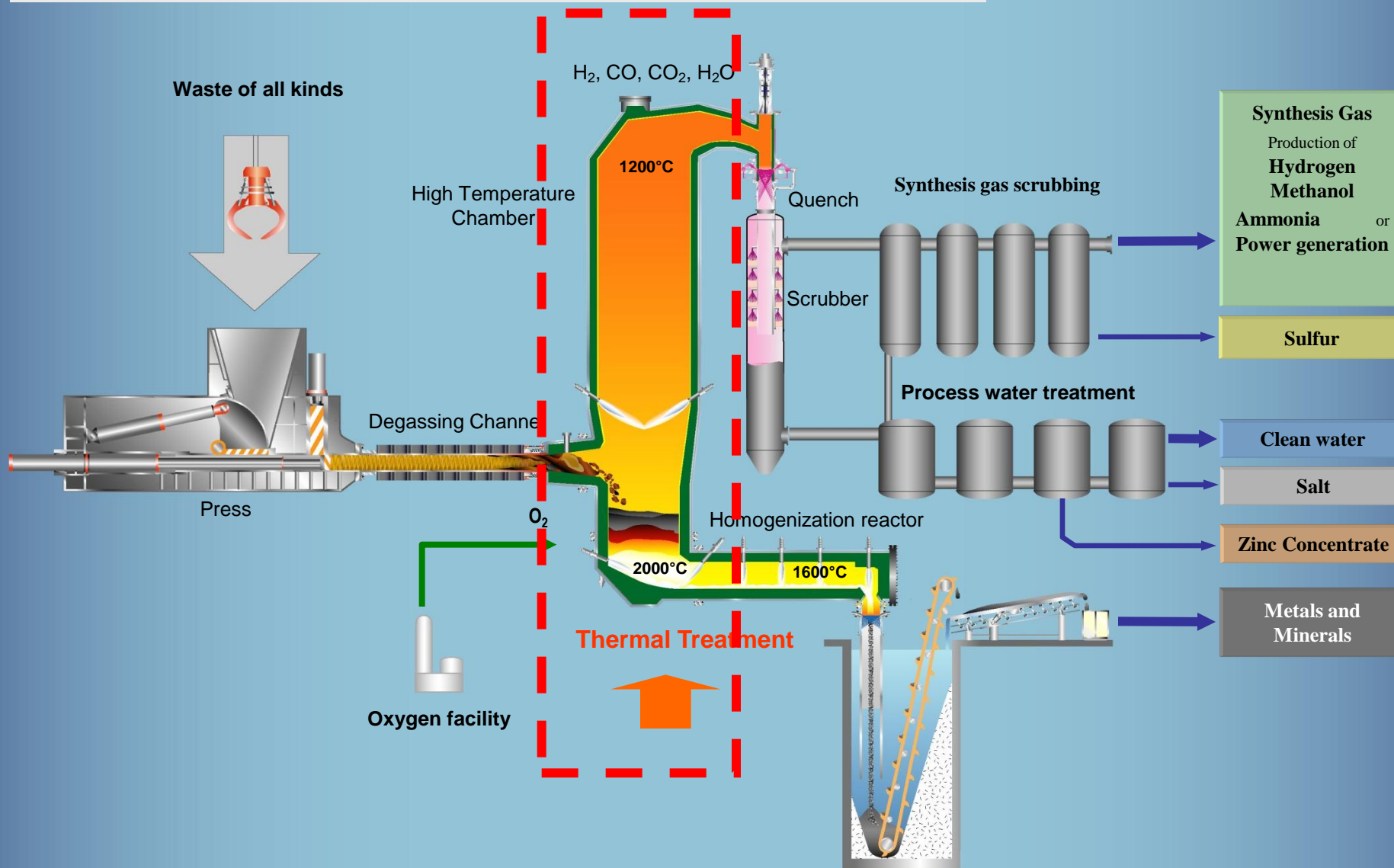


Typical Waste-to-Energy Plant



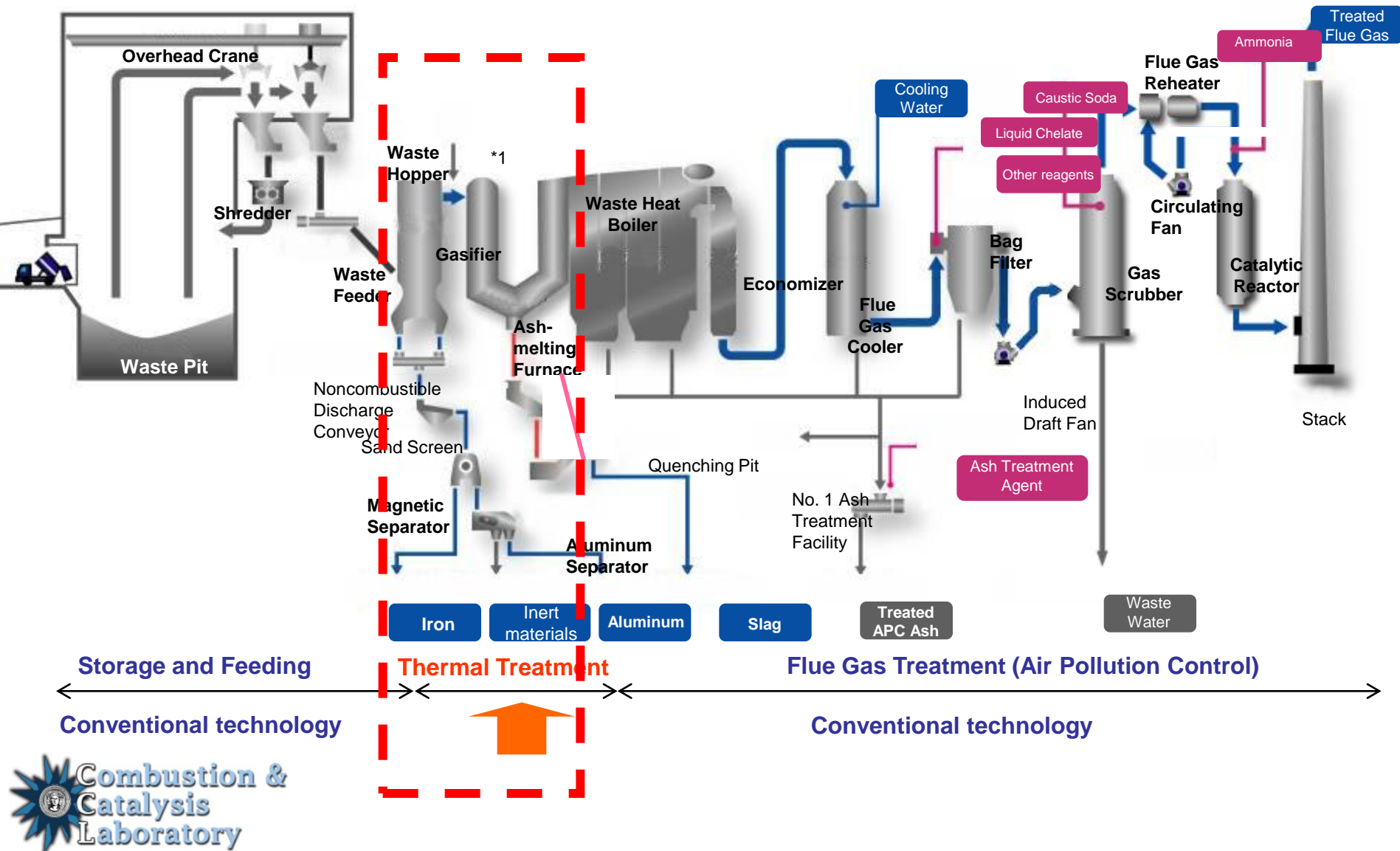
The Thermoselect Process (Interstate Waste Technologies, U.S.)

THERMOSELECT



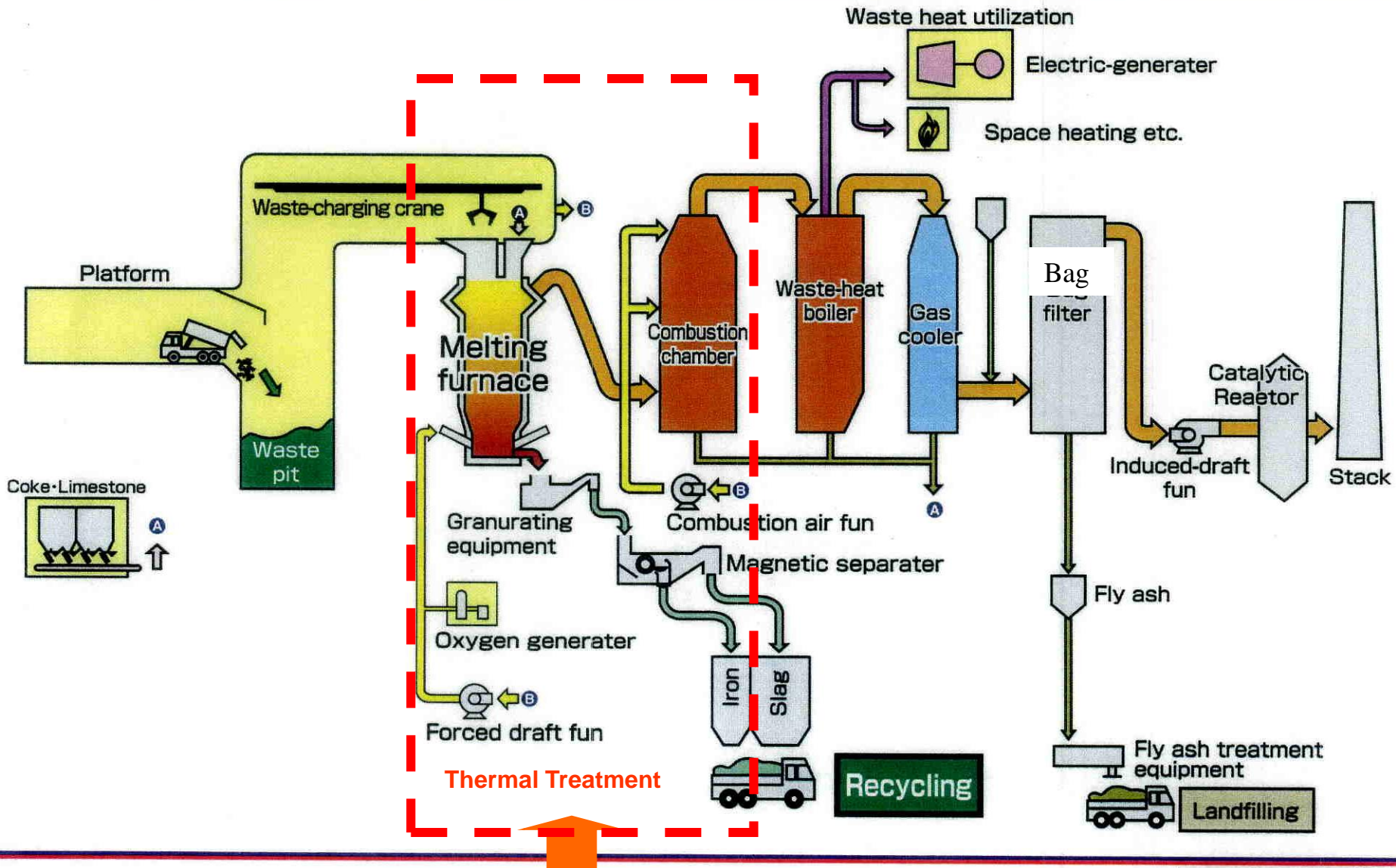
Ebara Fluidized-bed TwinRec/TIFG Technology

Process Flowsheet



The Nippon Steel WTE Process

Basic Flow Chart of Direct Melting System

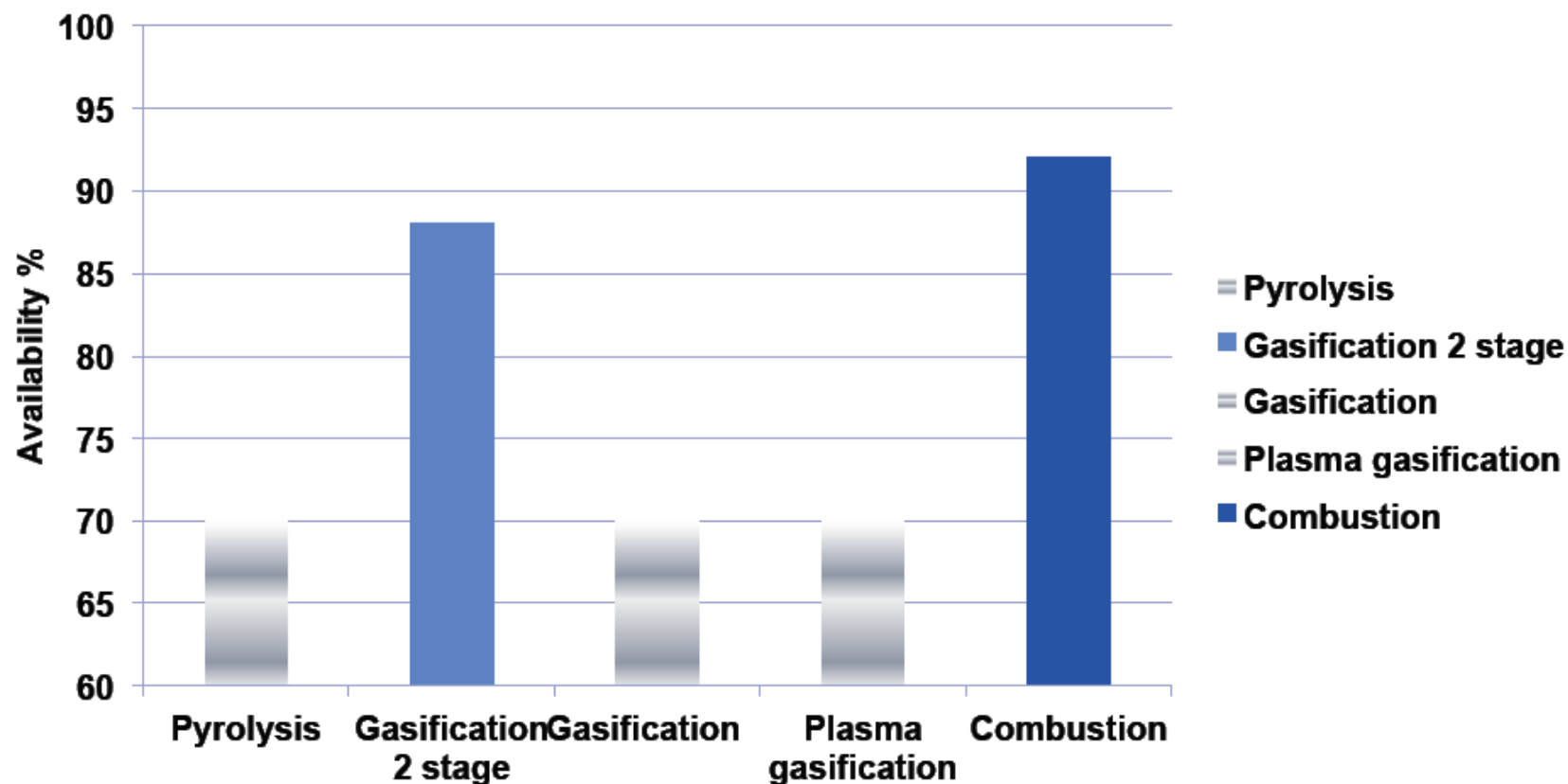


Comparison Summary for Plasma Systems

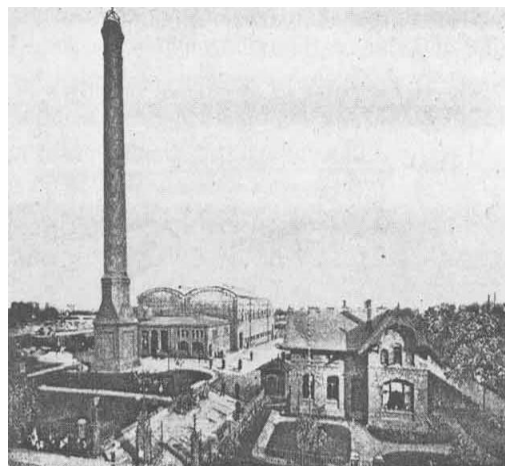
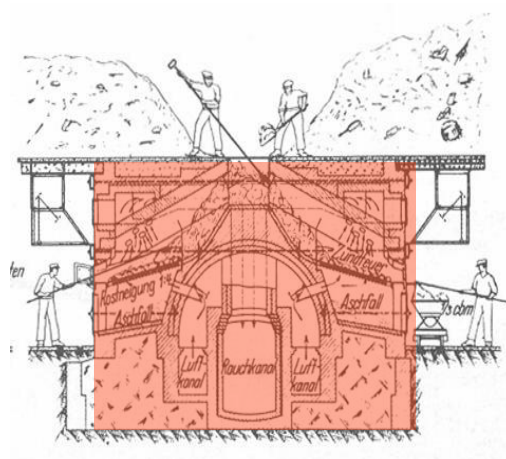
Technology	Energy (kWh/ton)	Capital Costs (\$/ton)
InEnTec	530	~77 (est)
Alter NRG	617	81
Europlasma	605	86
Plasco	530	86
Newer WTE	650	74
Grate WTE (US avg)	550	60

Efficiency comes at a cost

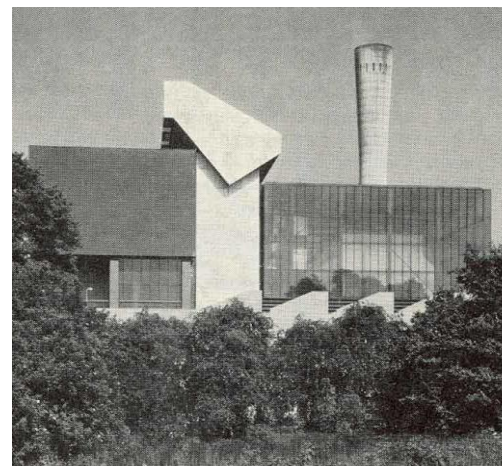
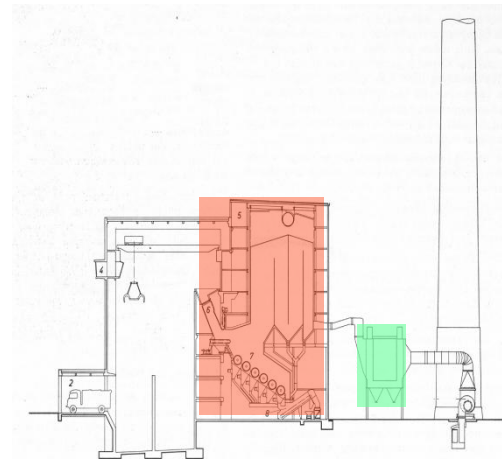
Availability (known or unknown) %



History of MSW Thermal Treatment 1900 - 2000

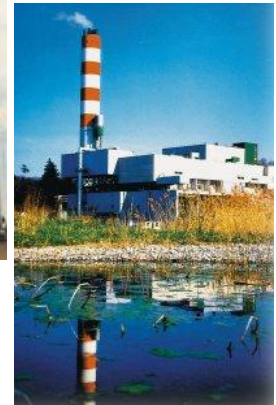


1896



1970

Combustion (WTE) Facilities Today



What's Next

- Next generation combustors – higher energy density
 - Low NO_x operation
 - Approach 3+ MW m⁻²
 - Injection of halogen scavengers
- Liquefaction of wastes (T ~ 300 – 500 °C)
 - Removal of O₂
- Gasification to fuels and chemicals
 - Enerkem
 - Solena Group Inc
- Novel uses of ash – catalytic and property adjustment
- LFGTE Applications and LFG to fuels



City College of New York (CCNY)



Columbia University



What is WERT

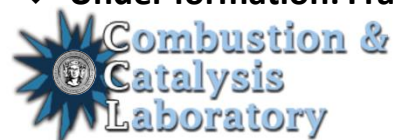
The Waste-to-Energy Research and Technology Council (WERT) is a top-tier-technical group that brings together engineers, scientists, and managers from industry, universities, and government with the objective of advancing the goals of sustainable waste management globally.

A truly international organization: Sister organizations in many nations

- ❖ WERT, U.S. (2002)
- ❖ SYNERGIA, Greece (2007)
- ❖ WERT, China (2008)
- ❖ CEFWC, Canada (2008)
- ❖ WERT, Germany (2009)
- ❖ WERT, Japan (2010)
- ❖ WERT-Brasil, Brazil (2010)

www.wtert.org
www.wtert.gr
www.wtert.cn
www.wtert.ca
www.wtert.eu
www.wtert.jp
www.wtert.com.br

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



[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 \(Greece\)](#)



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[Collage of Mechanical and Energy Engineering Zhejiang University \(China\)](#)



[Chongqing Waste to Energy Technology Research Institute \(China\)](#)



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

October 21-23, 2013 • San Antonio, TX

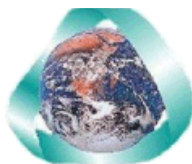
Conference Supported by ASME-MER and WTERT

Welcome Conference Information Registration Conference Location Exhibition & Sponsorship

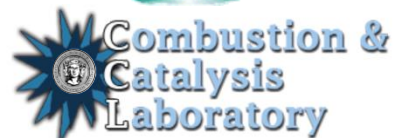
Beginning in 2013, the IT3/HWC conference will be organized in odd years in partnership with the Waste-to-Energy Research and Technology Council ([WTERT](#)) and the Materials and Energy Recovery Division ([MER](#)) of the American Society of Mechanical Engineers ([ASME](#)). These groups will be involved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



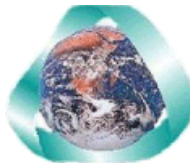
**Chemical Engineering
Department**



**Earth Engineering Center
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Acknowledgements



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Chemical Engineering Department



The City College
of New York



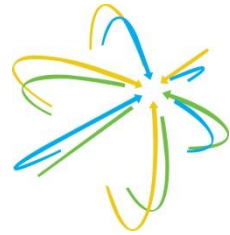
Sustainability in Urban Environment

- Capstone project (Engineering, Science & Architecture)

“An Integrated Waste-to-Energy Plan for New York City”



You, The Audience for Attention



Questions?



Thank you for attending!

Continue the conversation about WTE technologies on the [\[insert group page name\]](#) on asme.org.

Join us for the next webinar in [July 2013](#) on the topic of [Wind Power](#).

Learn more:

go.asme.org/energyforum



Appendix



About the Presenters



Steve Goff
Covanta Energy

Steve Goff is Vice President of Research & Development for Covanta Energy Corporation, where he is responsible for leading Covanta's research and technology development efforts. Key areas under his responsibility include the evaluation and development of new thermal conversion technologies, including combustion and gasification, for municipal solid waste and other renewable solid fuels, boiler and power generation technologies, emissions control technologies, and ash treatment and reuse methods.

Mr. Goff joined Covanta in 2005 with the acquisition of American Ref-Fuel Company, where he had worked since the formation of the company in 1985. Mr. Goff has over 30 years of industrial experience in Energy from Waste and other environmental and high-temperature process industries. He earned his B.S. in Chemical Engineering from Villanova University, and his M.S. in Chemical Engineering from Lehigh University.



About the Presenters



John Norton
Norton Engineering LLC

John Norton operated two Solid Waste Combustion Plants (each with a 750 TPD capacity) as the former Director of the Dayton, Ohio Solid Waste Management Department. He is a Registered Professional Engineer and is a Board Certified Solid Waste Expert by The American Academy of Environmental Engineers (BCEE).

Since 1976, Mr. Norton has provided consulting services in civil, mechanical, and electrical engineering and environmental matters: Solid waste management plans, designs, construction, operation, and troubleshooting, as well as stormwater systems modeling, design, and monitoring, and analysis.



About the Presenters



Dr. Marco Castaldi

The City College of The City University of New York (CUNY)

Marco Castaldi was born in New York City and received his B.S. Ch.E. (Magna cum Laude) from Manhattan College. His Ph.D. is in Chemical Engineering from UCLA and he has minors in Advanced Theoretical Physics and Astrophysics. Prior to joining CCNY he was Associate Professor at Columbia University's Earth & Environmental Engineering Department. Professor Castaldi has approximately 50 peer-reviewed research articles, 32 peer-reviewed conference papers, 3 book chapters and 11 patents in the fields of catalysis, combustion and gasification.

Some of his research findings have been covered by The New York Times, The Observer, CNN, and other trade publications. In addition, he is the Editor of the North American Waste to Energy Conference (NAWTEC) Series (ISBN: 978-0-7918-4393-2), Editor of the Waste to Energy text published by Woodhead Publishing, Editorial Board Member of Waste and Biomass Valorization published through Springer (ISSN: 1877-2641) and Catalysts (ISSN 2073-4344).