"THERMO-ECONOMIC ASSESSMENT OF MUNICIPAL SOLID WASTE TREATMENT TECHNOLOGIES FOR MUMABAI: INSIGHTS FROM EXERGY ANALYSIS"

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4th September, 2015

Outline

- MSW Management scenario in Mumbai
- Motivation
- Objectives
- Exergy analysis
- Exergy analysis of MSW treatment technologies (Landfill, Incineration and Plasma Gasification)
- Conclusions

Municipal Solid Waste Management

- MSW generation in cities in India is increasing with an annual growth rate of 4.25%
- MSW in Mumbai (year-2015) is about 9500 tons/day
- About 90% of the MSW collected is disposed in landfills and open dumps
- Municipal corporations are unable to keep up with increase in MSW generation and lack of landfill space
- Raises variety of health and environmental concerns

Municipal Solid Waste Management

- Many cities, including Mumbai are considering adoption of thermal treatment processes such as incineration and plasma gasification
- Are these appropriate for tropical countries?
- Thermodynamic conversion efficiency of MSW is a function of composition, segregation practice, climate conditions, etc.
- Previous technology assessments are not relevant to the waste composition in tropical megacities

Composition of MSW : India Vs Europe

- Tropical MSW
  - Contains huge fraction of moisture
  - In non-segregated form

Composition of MSW in India and The Netherlands		
Parameters	**Dutch Waste wt %**	**Indian Waste wt%**
Organic Carbon	12.65	30.7
Hydrogen	0.14	1.89
Oxygen	9.63	23
Nitrogen	0.45	0.28
Sulfur	0.18	0.1
Phosphorus	0.10	--
Chlorine	1.13	--
Water	16.35	68.32
Ash	59.33	8.75

Objective

- Compare waste management practices of incineration, plasma gasification, and land filling based on their exergy efficiency, and emissions
- Evaluate the exergetic conversion potential of these technologies in the Indian context while considering local MSW composition, climate, segregation practices, etc.

Exergy

- Exergy is defined as the maximum amount of work that can be done by a subsystem as it approaches thermodynamic equilibrium with its surroundings by a sequence of reversible processes.

$$B = B_{ph} + B_{ch} + B_{ke} + B_{po}$$

$$B = \Delta h - T_0 \Delta S + \Delta \sum_i \mu_i x_i + \Delta(\frac{v^2}{2}) + \Delta(zg)$$

- Always defined w.r.t. reference environment, larger the gradient between system and the reference environment larger will be its exergy
- Exergy is the **ultimate limiting resource**

Exergy

- Energy -First law, Exergy - First and Second Law
- Exergy is not conserved in real irreversible processes
- Exergy losses will result in generation of waste and hence the increase in entropy
- Revealing whether or not and how much it is possible to design more efficient energy systems by reducing the inefficiencies in the existing systems

Exergy

- Physical exergy is given by

$$B_{ph} = (h - h_0) - T_0(S - S_0)$$

- Thermal exergy transfer at constant temperature is given by

$$B_{th} = Q_r(1 - \frac{T_0}{T_r})$$

- The chemical exergy of any compound can be calculated from the standard chemical exergy values of the elements

$$B_{ch,i}{}^{0} = \Delta G_r{}^{0} + \sum_k \gamma_k b_{ch,k}{}^{0}$$

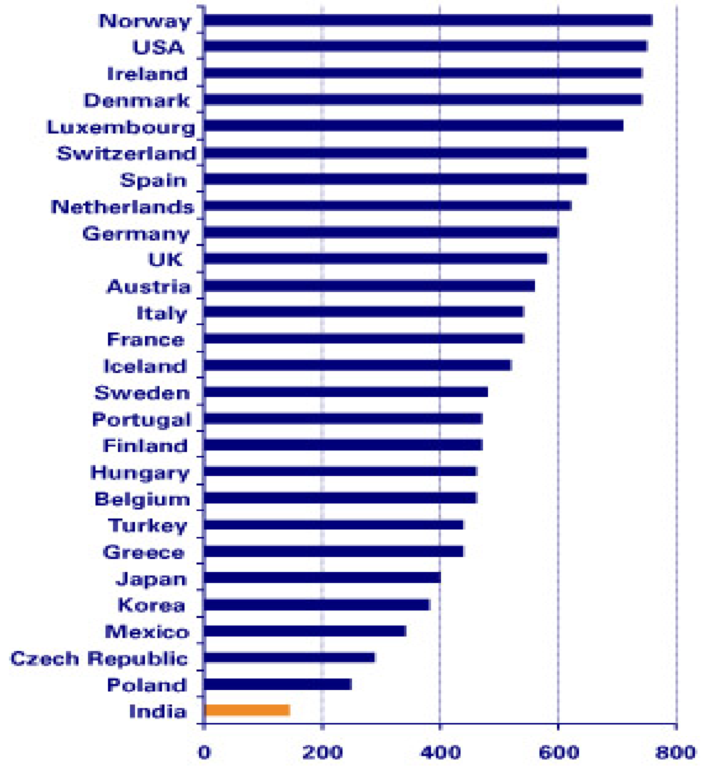
Why exergy?

- Energy utilization does not provide a 'true picture'
- Important knowledge and understanding can be gained and areas identified where large improvements could be obtained by applying efficient technology.

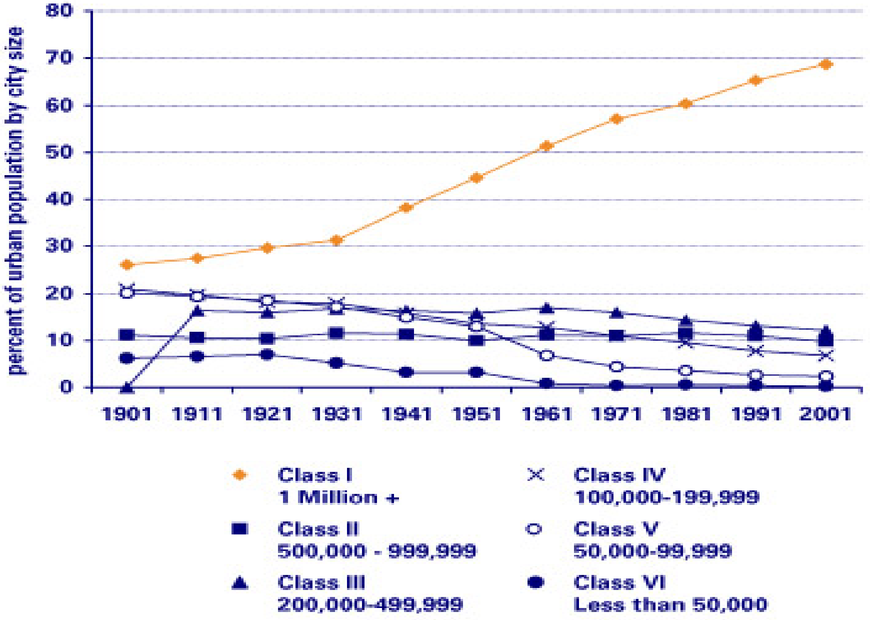
Municipal Solid Waste Management

- In mega cities like Mumbai, municipal solid waste management (MSWM) poses a formidable challenge

Kilograms of municipal solid waste per capita in 2005



Growth of India's cities, especially the largest ones



Sources:
OCED Environmental Data Compendium 2006-2008
2005 EU-India Waste Forum
"Urbanisation in India" by the Indian Statistical Institute, 2006

Landfill

- Most common practice in India and other developing countries for MSWM
- About 90 % of the MSW generated in megacities in India is disposed off in open dumps and landfills
- Main constituents of the biogas generated from landfill are
  - Methane (60 %)
  - CO_2 (40 %)
  - NH_3 and H_2S in small quantities

Landfill

- The volumetric flow rate of all the constituents of the LFG are determined using the Landfill Air Emissions Estimation model

$$Q_{CH_4} = L_0 R (e^{-kc} - e^{-kt})$$

where, Q_{CH4} = Methane generation rate at time t, m^3 /yr;

Lo = Methane generation potential = 10 m3 of CH_4/Mg refuse;

R = Average annual refuse acceptance rate in Mumbai during active life = 2737500 Mg/yr;

e = Base log, unit less; (e=2.718)

k = Methane generation rate constant = 0.04yr-1; [10]

c = Time since landfill closure, yrs (c = 0 for active landfills); and

t = Time since the initial refuse placement = 5yrs.

Landfill

Basics for calculation	Constituent gases from Land Fill	Volumetric flow rate Q (m^3/yr)
2.74E+06 Tonnes/yr	CH_4	4.96E+06
	CO_2	3.97E+06

Assumption-All landfill gas generated from 7500 tonnes MSW is collected over a period of 5 Years

Landfill

Basics for calculation	Time since the initial refuse placement	Constituent gases from Land Fill	Volumetric flow rate Q (m^3)
7500 Tonnes	5yrs	CH_4	1.36E+04
		CO_2	1.09E+04

Landfill

- Exergy analysis of Landfill system
- The combustion reaction of methane

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$

- Heat exergy released through the above reaction is

$$dH = dQ\,(1 - \frac{T_{ref}}{T})$$

$$\left(\frac{\Delta H}{Mole}\right) = H_{f\ product} - H_{f\ reactant} + \int_{Tref}^{T} C_{p,product}\, dT - \int_{Tref}^{T} C_{p,reactant}\, dT$$

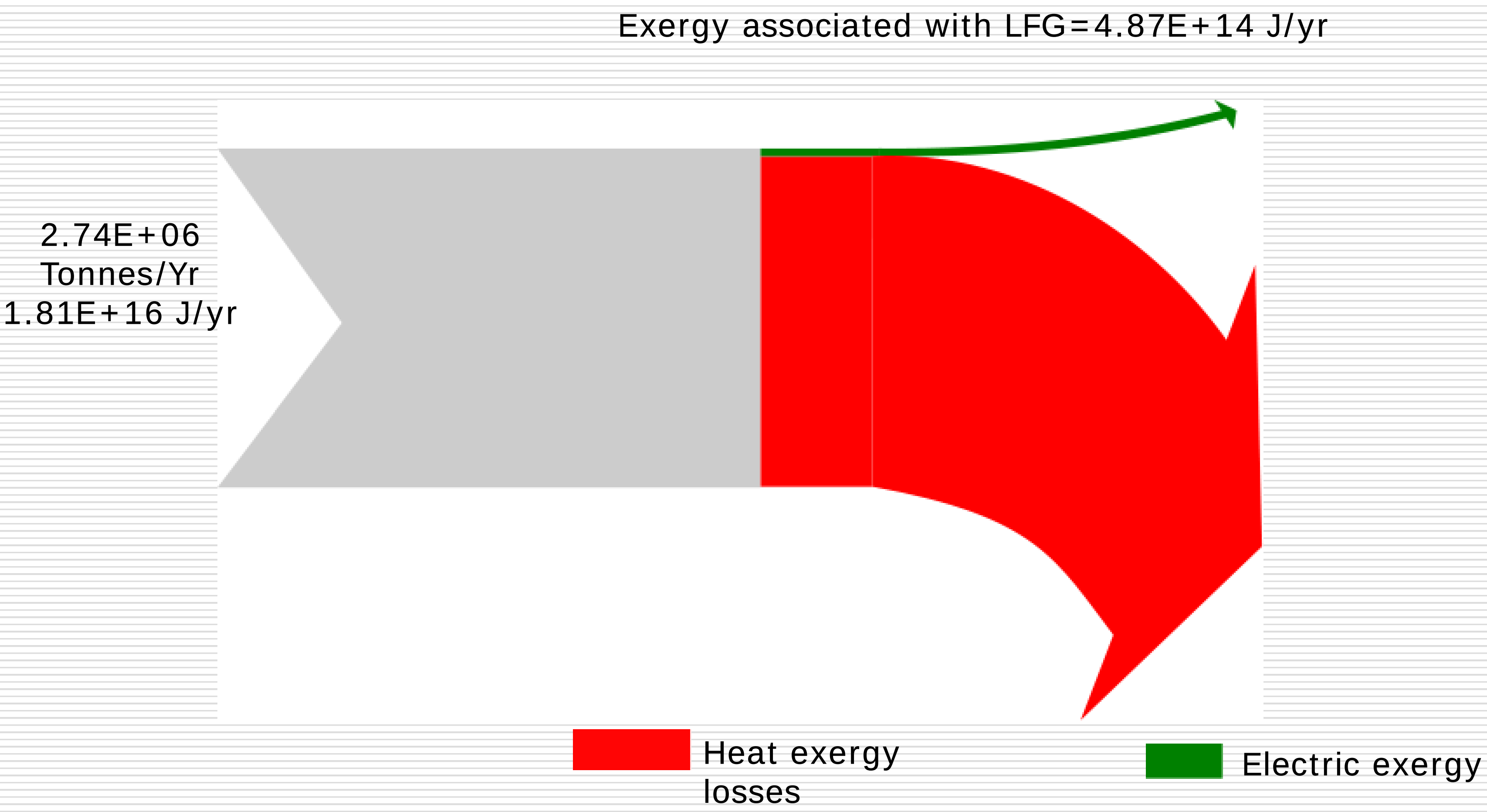
$$\Delta H_{total} = \left(\frac{\Delta H}{Mole}\right) \times no\ of\ moles$$

$$\Delta H_{total} = 1.6 \times 10^{11}\ KJ$$

Exergy analysis of landfill

- Collection efficiency of the landfill gas is assumed to be 60%
- Landfill gas generation rate is high up to first 5 years after that it slows down
- Total heat exergy associated with LFG for 5 yrs is 4.87E+14 J

Grassmann diagram for landfill



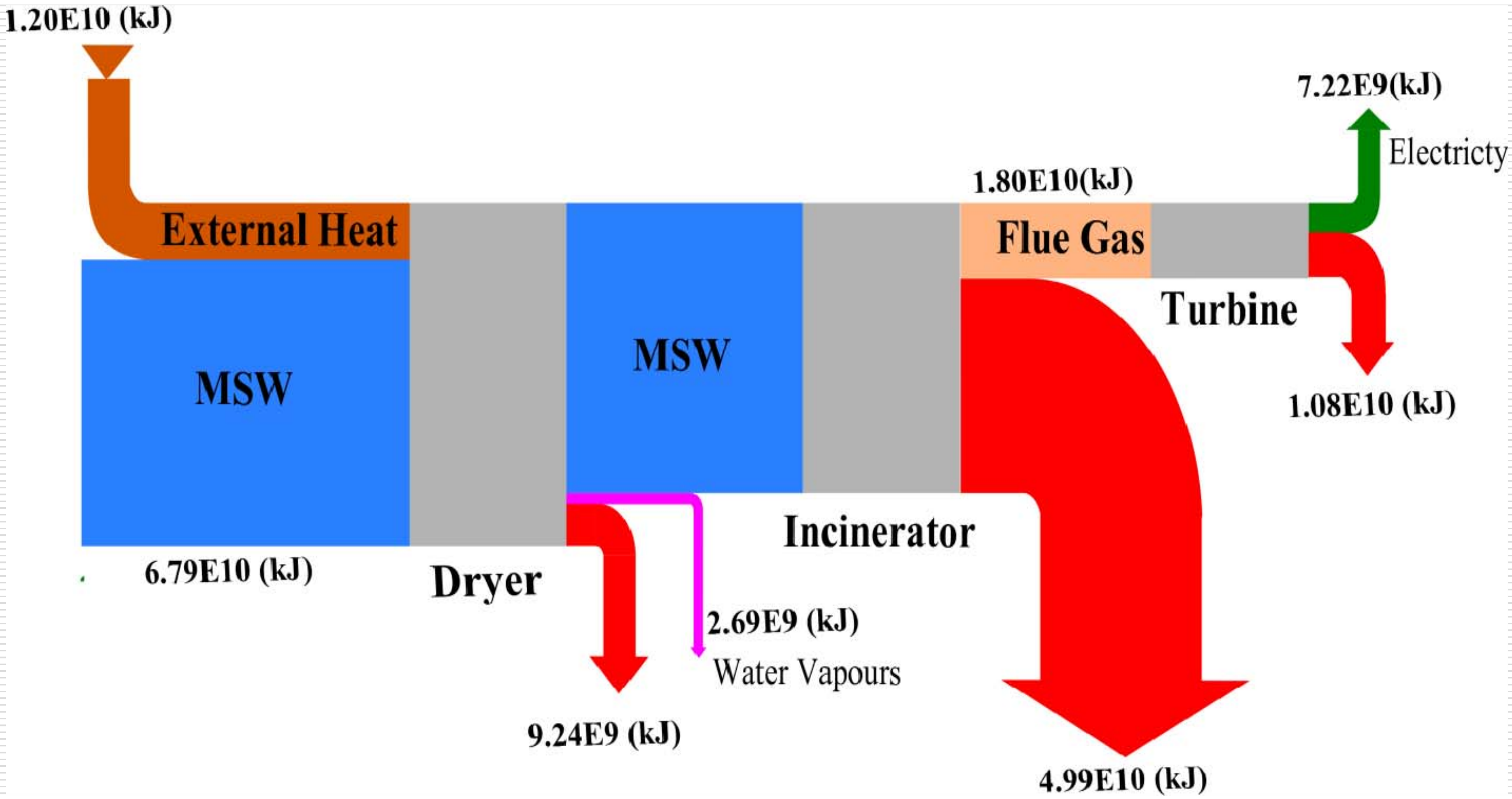
Incineration

- Thermal process in which the MSW is oxidized (combusted) in presence of excess oxygen.
- MSW converted into CO_2, H_2O, NO, SO_2, HCl, and bottom ash
- High moisture in MSW makes incineration inefficient

Incineration

- In 1987, 300 t/Day capacity MSW incineration plant was constructed at Timarpur, New Delhi.
- Was shut down after 6 months due to poor performance
- Currently there are small incineration units for treating hospital waste, and some industrial wastes

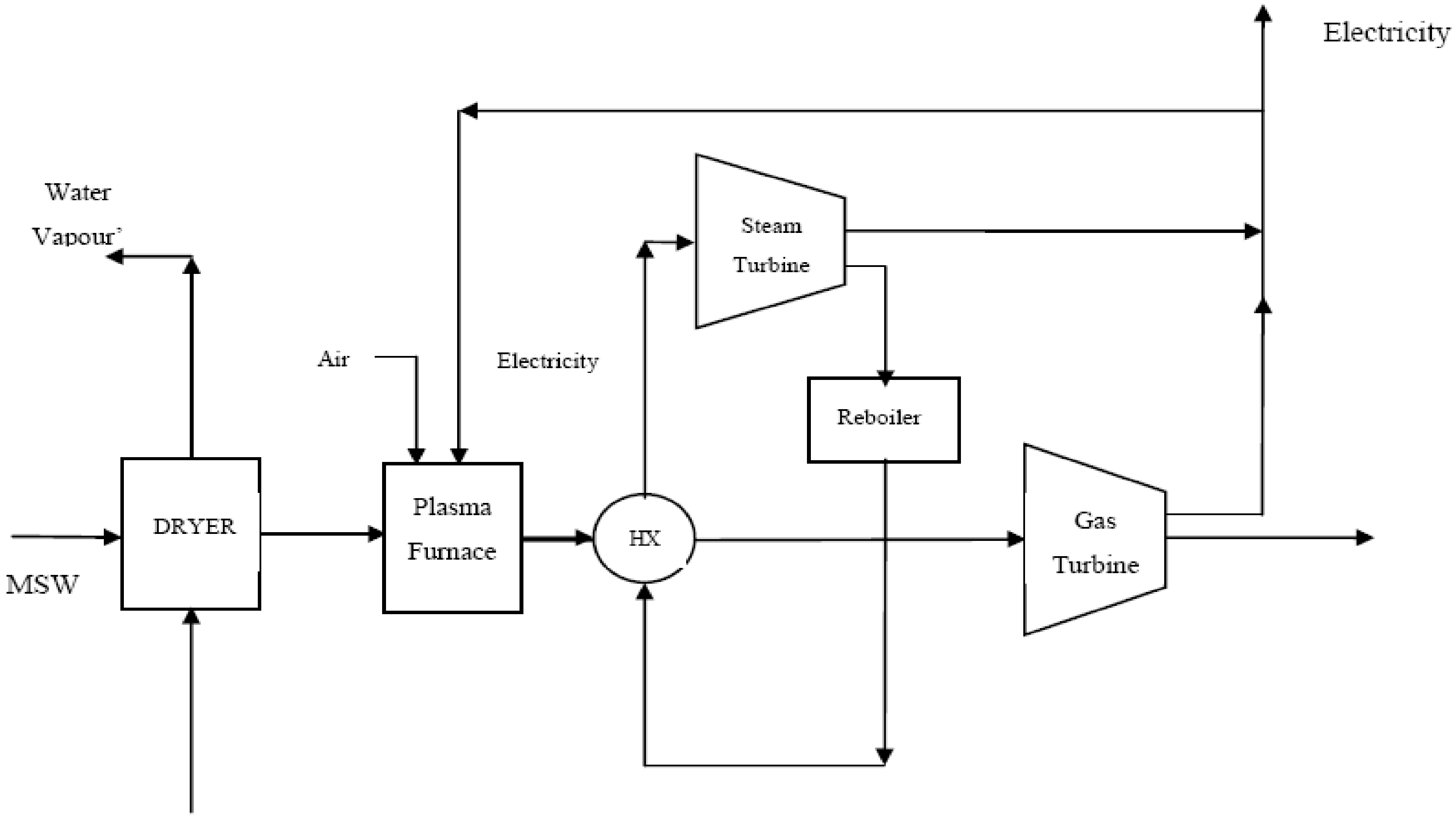
Grassmann diagram for Incineration



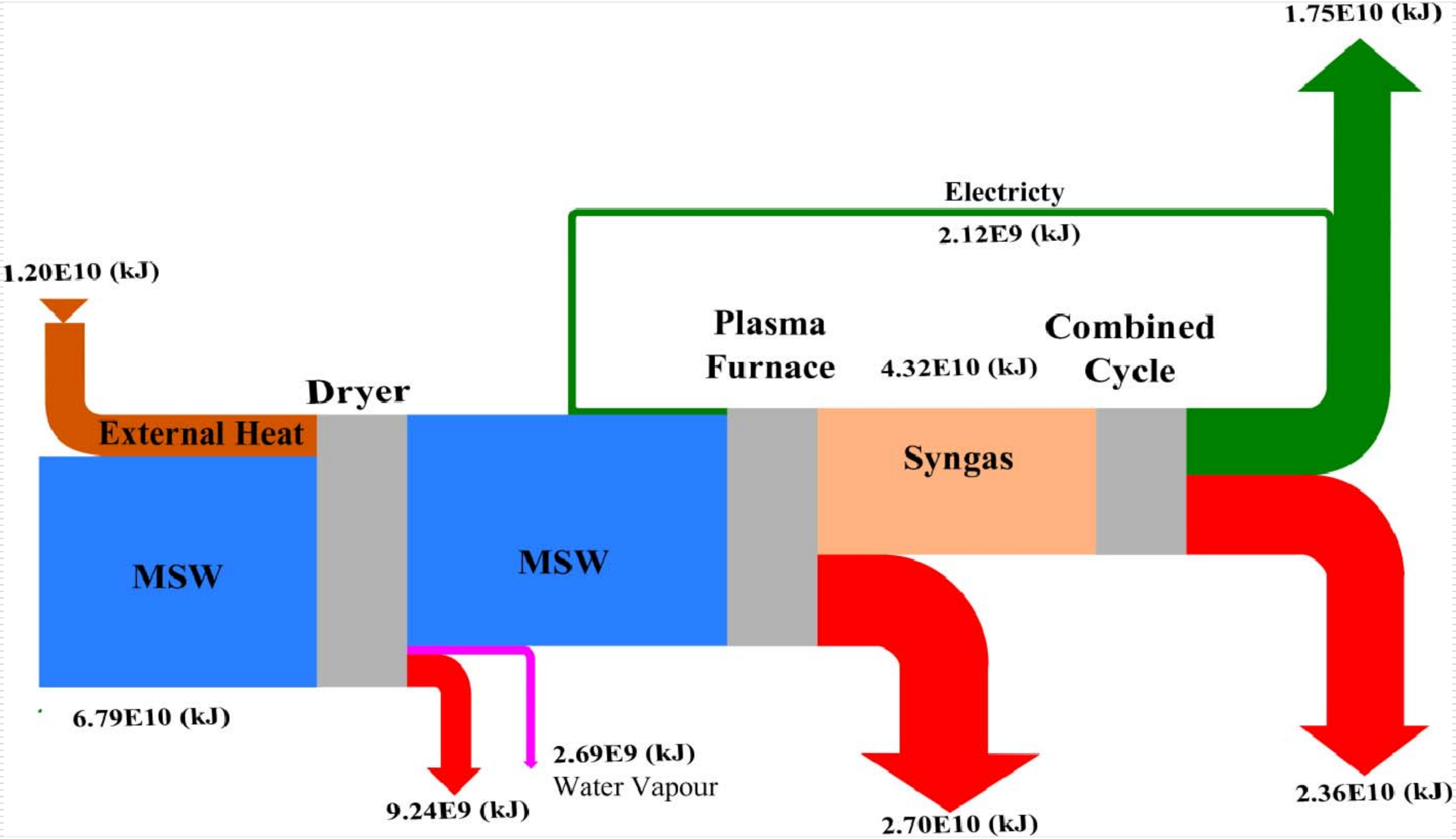
Plasma Gasification

- Increasingly popular new technology for MSW treatment
- Uses an external heat source (electricity) to gasify the waste
- Syngas (CO, H_2) produced from plasma gasification of MSW

Plasma Gasification



Grassmann Diagram for Plasma Gasification



Comparison

Particulars	Unit	Landfill collection System	Incineration	Plasma Gasification
Basis	Tonnes	7500	7500	7500
Exergy Efficiency	%	0.89	8.88	22.91
Total Fixed capital cost	Million Rs	1,376	10,741	64,889
Total Working capital cost	Million Rs	59,487	4,61,188	4,72,138
Net Revenue	Million Rs	66,322	5,14,335	7,95,678
Profit	Million Rs	5,459	42,406.31	2,58,652
Estimated Tipping fees for a payback period of 5 yrs	Rs/tonne	996	7485	10300

Conclusions

- Most developing megacities need to move away from land filling MSW and are considering thermal processing
- In Indian context, considering the composition of MSW, both thermal processes for energy conversion are relatively inefficient
- Exergy efficiency of these thermal processes can be improved by minimizing the exergy losses related to drying and steam stroke vapours to electricity conversion operations

Conclusions

- In Indian context thermodynamic conversion potential for plasma gasification is higher hence it is more efficient in comparison to Incineration
- Need to consider other programs such as waste segregation, sustainable consumption and decentralized MSWM

THANK YOU