



High-Efficiency Integrated Solid Waste-to-Energy System

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Drivers and Opportunities



- **Landfills not a sustainable solution and rising pressure against landfilling. Need for alternatives**
- **MSW “renewable biofuel”; 65-85% carbon-neutral**
- **Waste to energy (or Energy from waste): Energy production; Volume reduction and conversion of toxic compounds into less harmful forms via combustion**
- **Problems with conventional MSW incineration: poor energy recovery efficiency; corrosion; environmental issues**
- **Alternative: MSW-based hybrid combined cycles for high-efficiency power production; MSW as fuel for bottoming cycle; Gas turbine for topping cycle**



Objectives of this work



- **Design and optimize combined cycle configurations**
- **Establish model for combined cycle power plant; Performance simulations**
- **Assess viability of combined cycles; Evaluate benefits and advantages**
- **Find out potential for net CO₂ emissions reduction**
- **Economic feasibility**
- **Provide accurate and scientific information on feasibility and benefits of EfW from proposed combined cycles**



MSW as fuel and energy recovery potential



- MSW heating value 8 to 12 MJ/kg (average 10.5 MJ/kg), compared to 19 MJ/kg for dry wood, 15 MJ/kg for lignite or 22 MJ/kg for coal
- 740 kWh electricity per T MSW if 25% electrical efficiency

Table 1 Composition and heating value of non-sorted MSW produced typically in Canada

Fraction	% By weight	Material	% By weight (per dry mass)
Food and garden residues	29	Carbon	39
Paper and paperboard	27	Hydrogen	6.4
Plastics and rubber	13	Oxygen	26
Glass	3	Nitrogen	3.5
Metals	3	Sulfur	0.3
Textiles	5	Chlorine	1.2
Other combustibles	14	Phosphorus	0.2
Other non-combustibles	6	Ash	23.4
		Lower heating value	10.5 MJ/kg
		Moisture	31
		Combustibles	45
		Inert	24

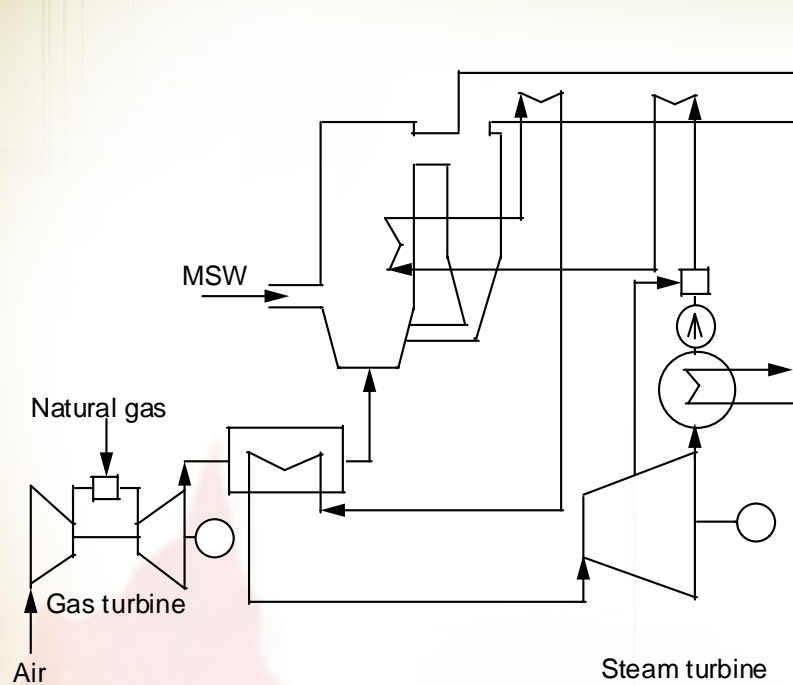
Problems with power production by conventional MSW incineration



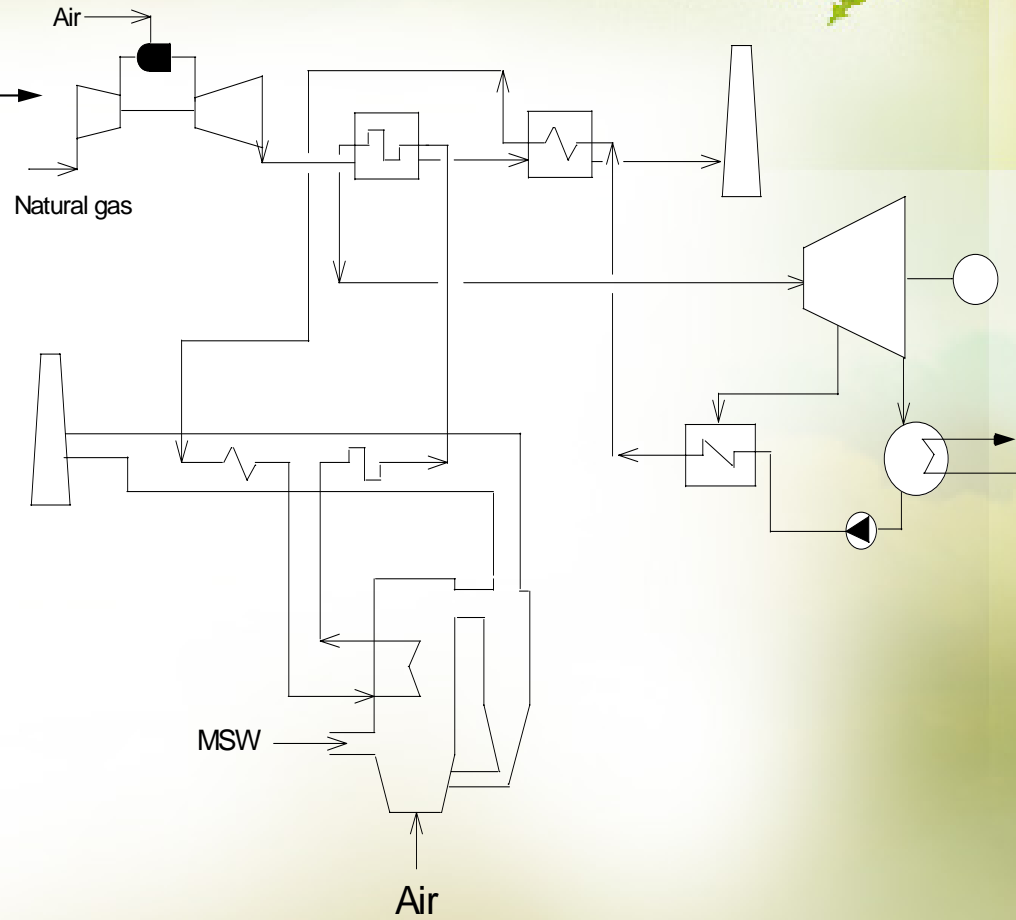
- **Aggressive compounds in flue gases are highly corrosive at high temperature**
- **Low steam temperature has to be used in order to avoid severe corrosion of heat exchangers by flue gases at high temperature. This limits electrical efficiency**
- **Few extraction points on steam turbine because of low steam parameter thereby limiting feedwater temperature and boiler efficiency**



Combined cycle configurations



Basic configuration I



Basic configuration II





Benefits of MSW boiler and gas turbine combined cycles

Increased power output (1+1>2)

Increased efficiency

Reduced environmental loading

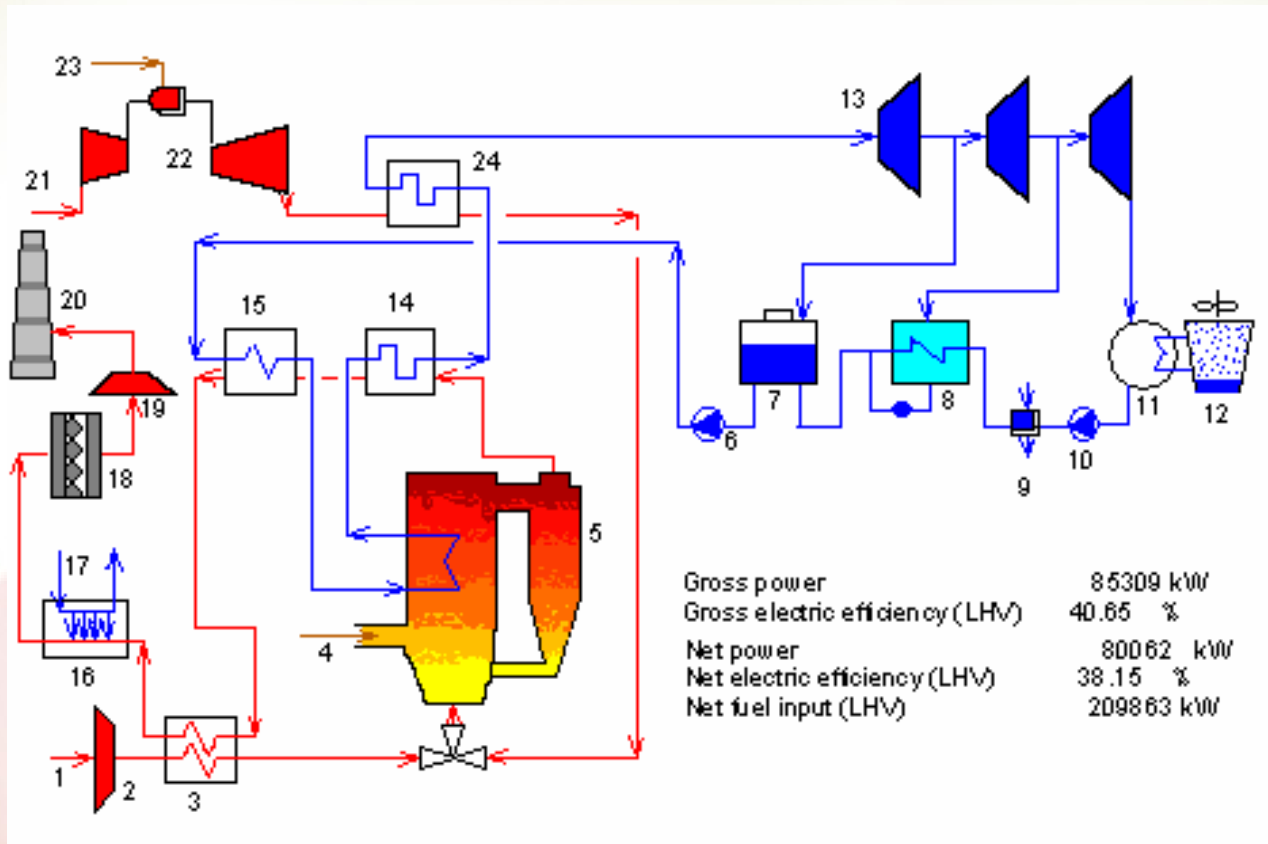
Reduced CO₂ emissions

High flexibility

Educed specific investment (less costly than two separate power plants)



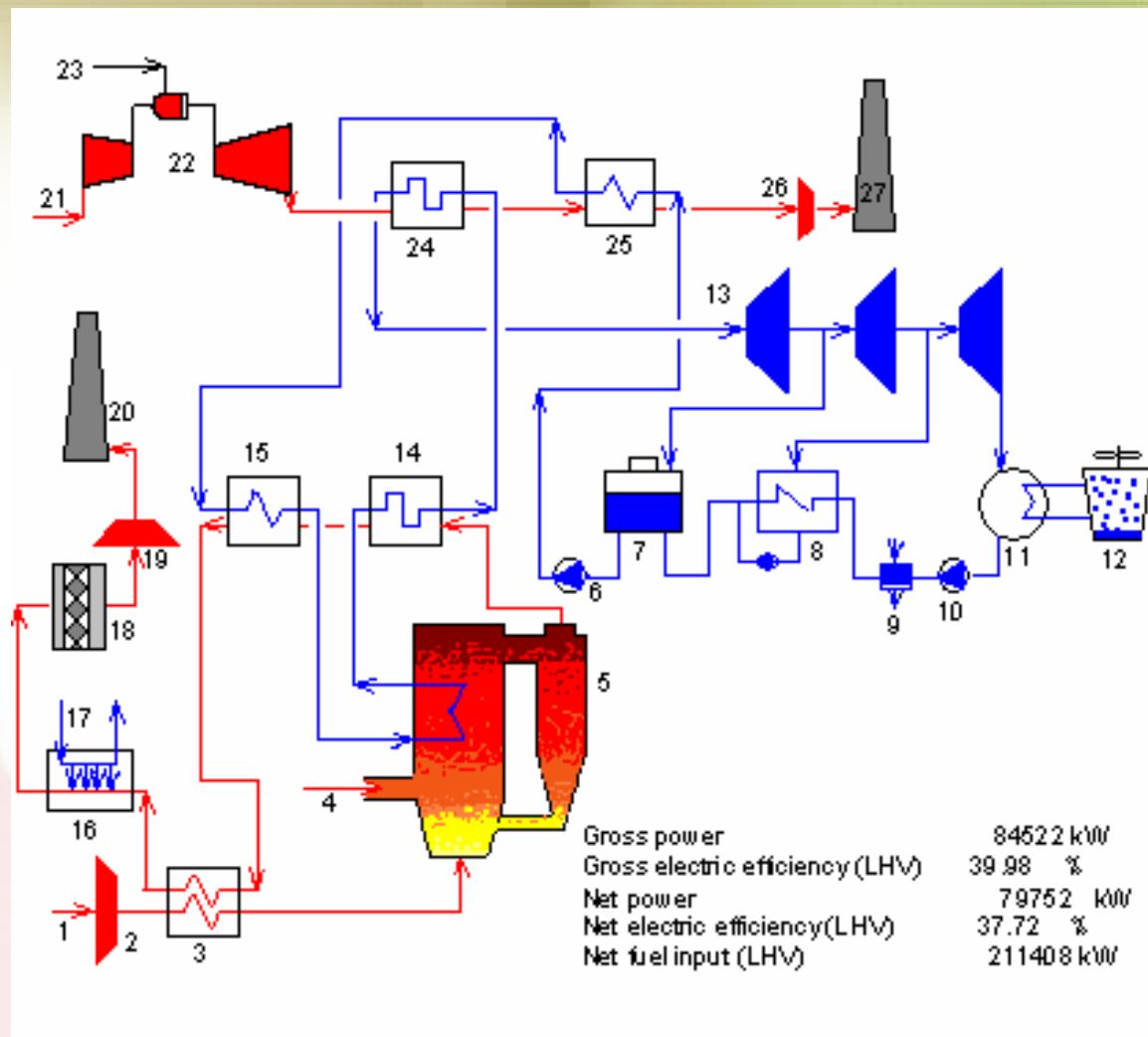
Model for MSW/natural gas combined cycle power plants



- 1 Combustion air; 2 Fan; 3 Air heater; 4 MSW input; 5 MSW boiler; 6 Water pump; 7 Deaerator; 8 Feedwater heater; 9 Makeup/Blowdown; 10 Water pump; 11 Water-cooled condenser; 12 Cooling tower; 13 Steam turbine; 14 Superheater; 15 Economiser; 16 Scrubber; 17 Water source; 18 Selective catalytic reactor; 19 Fan; 20 Stack; 21 Air source; 22 Gas turbine; 23 Natural gas input; 24 Superheater; 25 Economiser; 26 Fan; 27 Stack

Configuration I





Configuration II



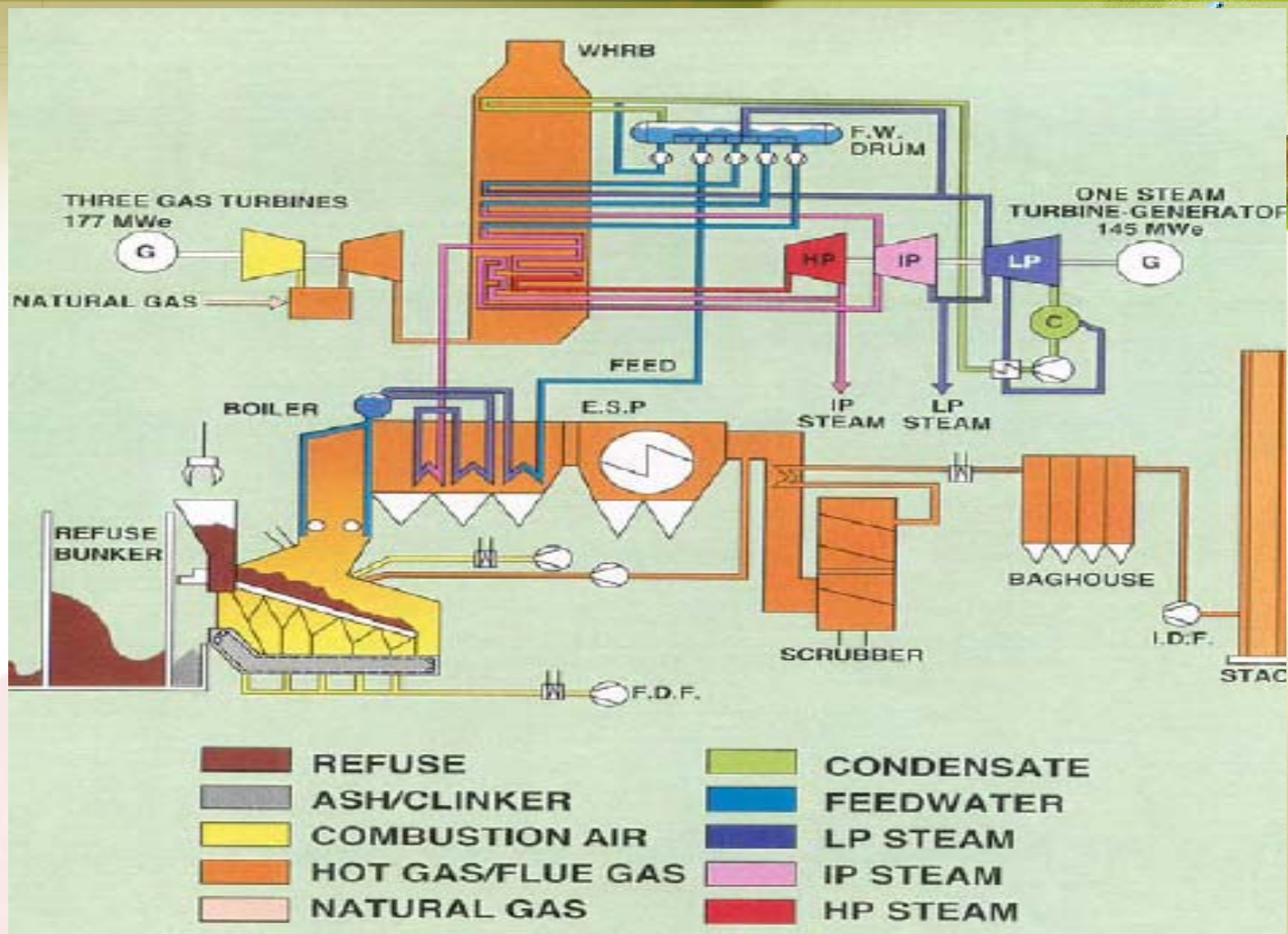


Figure 2: Schematic of the Combined Process

Summary of modeling results for combined cycle power plants

Power plant summary	Conventional MSW power plant	Configuration I	Configuration II
MSW input, kW	126304	126122	127667
Natural gas input, kW	0	83741	83741
Gas to MSW ratio	0	0.664	0.656
Gross power output, kWe	35584	85309 (ST55309+GT30000)	84522 (ST54522+GT30000)
Plant auxiliary, kWe	3490	5246	4770
Net power output, kWe	32094	80062	79752
Net electrical efficiency, %	25.41	38.15	37.72
MSW-based efficiency, %	25.41	32.1	31.5
Marginal efficiency, %	0	57.0	56.8

MSW-based efficiency:

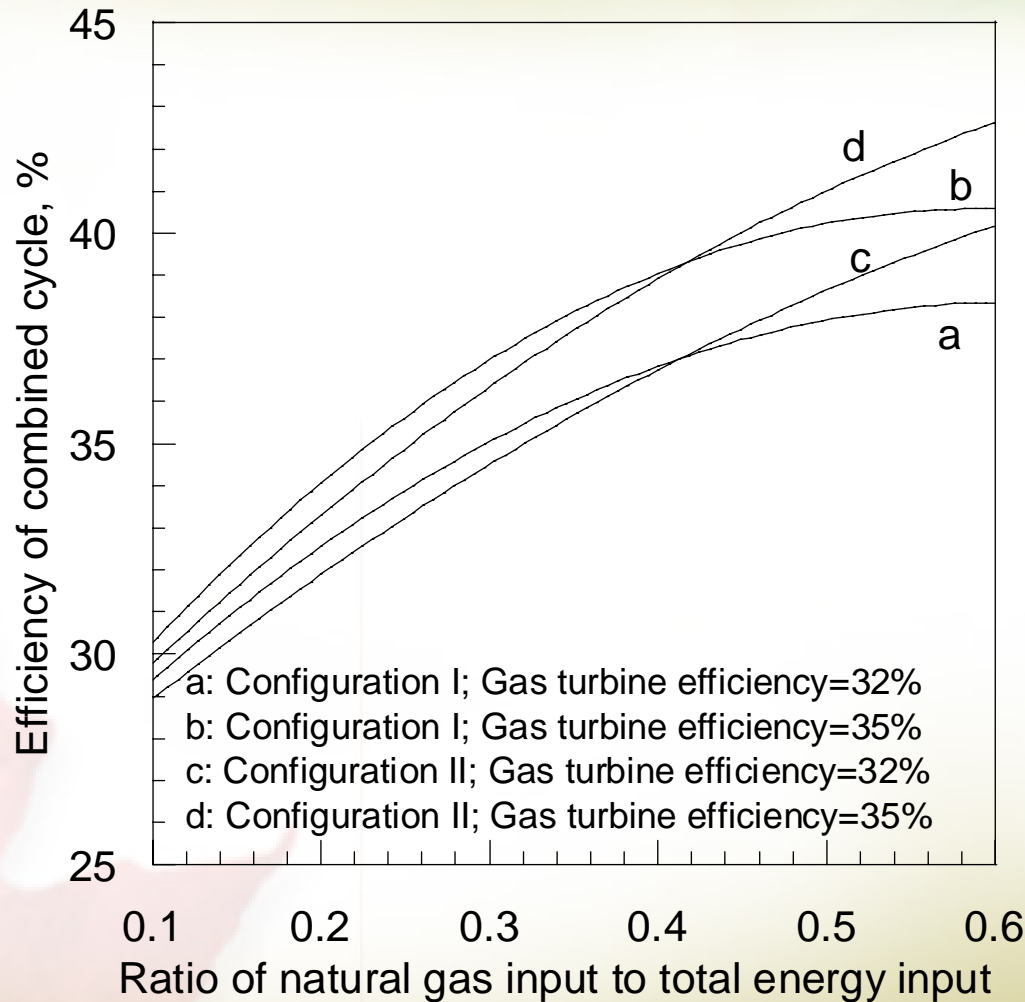
$$\eta_{el,MSW} = \frac{P_G + P_S - \eta_{CC} Q_G^f}{Q_{MSW}^f}$$

Marginal efficiency:

$$\eta_{el,G}^m = \frac{P_G + P_S - P_{S0}}{Q_G^f}$$



Electrical efficiency as a function of ratio of natural gas input to total energy input



Flue gas cleaning systems



- **Pollutants from flue gases: particulate matter, cadmium, lead, mercury, dioxin/furan, hydrochloric acid, sulphur dioxide, nitrogen oxides and organic matter**
- **State-of-the art flue gas treatment:**
 1. **Removal of fly ash**
 2. **Wet scrubbing or dry lime spray scrubber – remove acid gases such as SO₂, HCl and HF**
 3. **Powdered activated carbon (PAC) absorption or activated carbon filtering – remove heavy metals such as mercury as well as dioxins/furans**
 4. **Baghouse filtering – remove most types of particulate matter**
 5. **Selective catalytic reduction (SCR) – reduce NO_x .**



Emissions from an EfW power facility



Table 8 Measured emission data of an EfW power facility

Parameter	A-7 Emission limit*	Average 2004 stack test data
Particulate matter	17 mg/Rm ³ *	5.2
Cadmium	14 µg/Rm ³	1.3 µg/Rm ³
Lead	142 µg/Rm ³	9.3 µg/Rm ³
Mercury	20 µg/Rm ³	8.7 µg/Rm ³
Dioxins and Furans (TEQ)	80 pg/Rm ³	8.4 pg/Rm ³
Hydrochloric acid	18 ppmv	15.3 ppmv
Sulphur dioxide	830 µg/Rm ³	3.41 µg/Rm ³
Nitrogen oxides	110 ppmv	49.5 ppmv
Organic matter	100 ppmv (facility limit 50 ppmv)	1.8 ppmv

*Guideline A-7, Ontario, Canada, Combustion and air pollution control requirements for new municipal waste incinerators



Potential for CO₂ emissions reduction by EfW and combined cycles



1. **Avoided methane credit; CH₄ greenhouse factor: 25 more than CO₂**
2. **65-85% carbon-neutral (CO₂ bioderived)**
3. **Less fuel input or CO₂ emissions per unit power due to high efficiency**

Table 5 CO₂ emissions from MSW based power plants

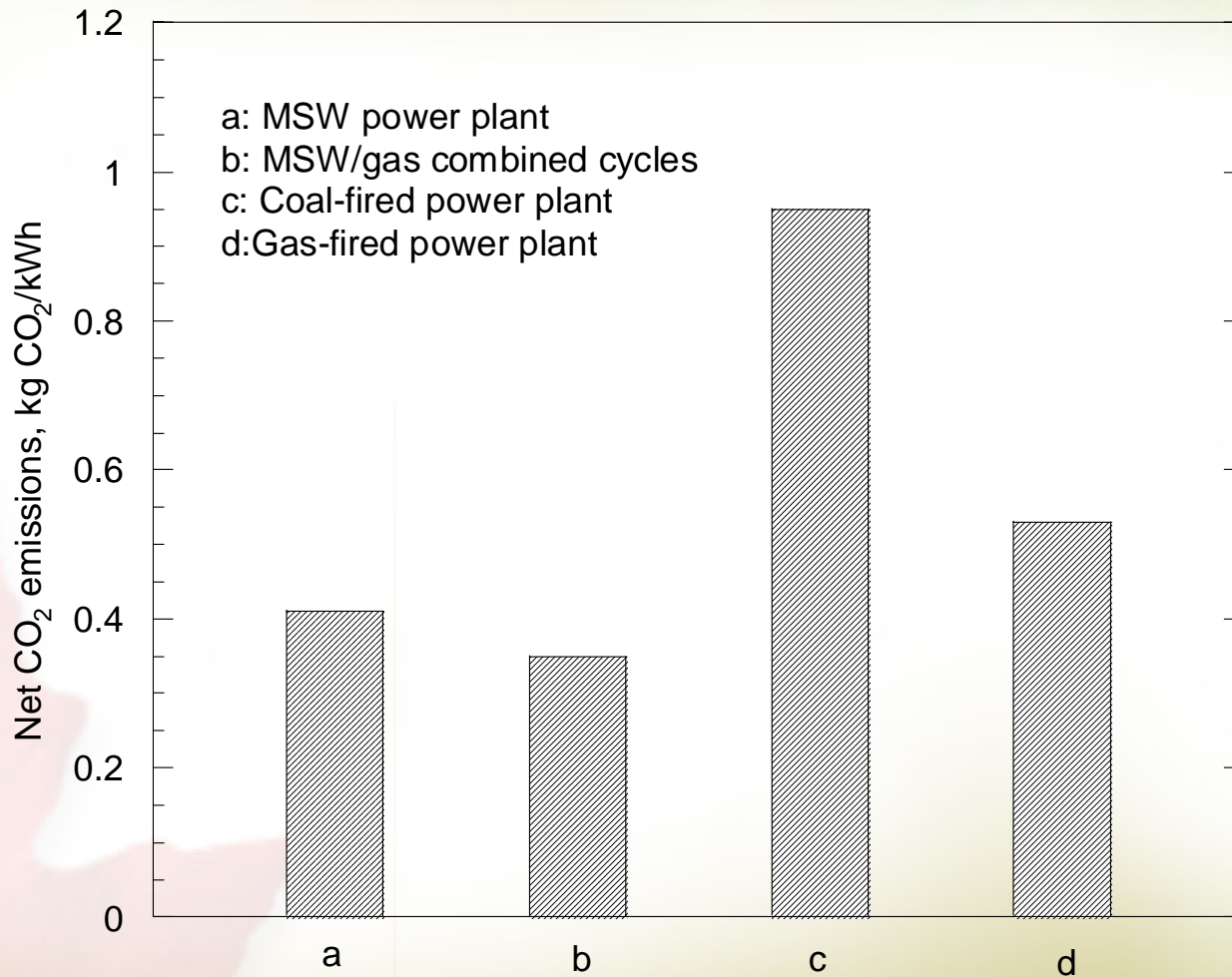
	MSW steam power plant	MSW/gas combined cycle power plant*
Electricity from MSW, kWh/t MSW	740	850
CO ₂ emissions from MSW power plant, kg CO ₂ /kWh	1.24	1.08
Bio-derived CO ₂ from MSW power plant, kg CO ₂ /kWh	0.83	0.72
Net CO ₂ emissions, kg CO ₂ /kWh	0.41	0.36

Table 6 Comparative CO₂ emissions from fossil fuel power plant and CO₂ reduction achieved by EfW power generation

	Coal-fired power plant, kg CO ₂ /kWh	Gas-fired power plant, kg CO ₂ /kWh
CO ₂ emissions from fossil fuels	0.95	0.53
Reduction of CO ₂ emissions by MSW steam power plant	0.95-0.4 =0.54	0.53-0.41 =0.12
Reduction of CO ₂ emissions by MSW/gas combined cycle power plant*	0.95-0.36 =0.59	0.53-0.36 =0.17



Net CO₂ emissions



Economic analysis



$$COE = \frac{C_{capital} + C_{O\&M} + C_{fuel} + C_{disposal}}{P_{el}t}$$

$$C_{capital} = C_{RF} C_{investment}$$

$$C_{RF} = \frac{i(1+i)^n}{(1+i)^n - 1}$$



Annual capital cost, O&M costs and cost of electricity (COE)*



Item no.	Description	Costs					
		Autonomous MSW power plant		Configuration I		Configuration III	
		Annual cost, k\$	cent/kWh	Annual cost, k\$	cent/kWh	Annual cost, k\$	cent/kWh
1	Capital cost, C_{capital}	6782	2.817	9399	1.609	8973	1.500
2	O&M costs, $C_{\text{O&M}}$	4629	1.923	4758	0.815	4758	0.795
3	Natural gas cost, C_{fuel}	0	0	12656	2.16	12656	2.11
4	Disposal cost, C_{disposal}	5071	2.107	5071	0.868	5071	0.848
5	Total cost	16482		31884		31458	
6	Power output, MWe	32.094		77.868		79.752	
7	Operating hours, h/yr	7500		7500		7500	
8	COE, cent/kWh	6.847		5.452		5.253	
9	MSW capacity, t/yr	360100		360100		360100	

***MSW tipping fees not considered. MSW tipping fees (\$35–\$85/ton) provide a large source of income.**



Summary



- **MSW and natural gas hybrid combined cycles dramatically increase energy recovery efficiency and offer many advantages**
- **Both MSW and natural gas are used with higher efficiency in hybrid combined cycles compared with separate single-fuel power systems.**
- **Increased power output**
- **High flexibility**
- **Reduced specific investment and lower COE**
- **Reduced CO₂ emissions**

