Proceedings of NAWTEC16
16th Annual North American Waste-to-Energy Conference
May 19-21, 2008, Philadelphia, Pennsylvania, USA

NAWTEC 16-1954

WASTE-TO-ENERGY IN THE CONTEXT OF GLOBAL WARMING

Peter R. Chromec
Von Roll Environmental Technology Ltd.
Zurich, Switzerland

Francis A. Ferraro
Wheelabrator Technologies Inc.
Hampton, NH, USA

ABSTRACT

In December 2007 the United Nations Framework Convention on Climate Change (UNFCCC) took place in Bali. It was based on the IPCC report no. 4 presented in Barcelona on November 2007. The messages are briefly:

- Warming of the climate system is unequivocal
- Global greenhouse gas (GHG) emissions due to human activities have grown since pre-industrial times
- Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would *very likely* be larger than those observed during the 20th century
- Key mitigation technologies in the waste sector: **Landfill Gas (LFG) methane recovery**; **waste incineration with energy recovery**; composting of organic waste; controlled waste water treatment; recycling and waste minimisation; biocovers and biofilters to optimise methane oxidation

The above by the IPCC proposed mitigation technologies for the waste sector can be categorized regarding specific waste treatment scenarios and their efficiency expressed in kg CO_2 equivalent emitted per ton of waste.

- Landfill w/o LFG recovery 1850 kg CO_2-eq
- Landfill with LFG recovery 250-775 kg CO_2-eq [1]
- Energy-from-Waste plant -1000..-100 kg CO_2-eq [1]

With a population of little over 300 million people and a per capita municipal waste generation rate of 760 kg/person.year, the total waste generated in the USA is about 230 million Mg/year (OECD). With the treatment scenarios discussed above, the following can be stated:

- If all wastes were landfilled waste disposal would correspond to 425 million tons of CO_2 equivalents.
- If all wastes were incinerated in Energy-from-Waste (EfW) plants, the emissions could be reduced by about 500 million tons of CO_2 equivalents (about 9% of today's US CO_2 output) and make the waste management sector a GHG emissions sink.
- The total electricity generated from EfW plants could be as high as 15,000 MW replacing about 50 standard 300 MW power plant units.

To an average US 4 person household about 3 t/year of municipal solid wastes can be allocated, corresponding to an annual difference between landfilling without LFG recovery and EfW treatment of about 6.9 Mg CO_2-eq /year. If this household wanted to achieve the same reduction of CO_2 equivalent emissions by other means than having these wastes burnt in a modern EfW plant, they have the following options:

- Remove one automobile from use
  (EPA: 6.0 Mg CO_2-eq /year)
- Cut household electricity consumption by 80%
  (EIA: 7.8 Mg CO_2-eq /year)

The European parliament commission has proposed to reduce CO_2 emissions in Europe to 20-30% below 1990 levels. In comparison with Europe, annual GHG emissions (CO_2-eq/person·year) in the U.S. today are on a level about double that of the Europe. In order to achieve a similar reduction in the U.S., significant efforts have to be done on all energy fronts. Energy-from-Waste (EfW) is one of them, which at the same time solves a space and pollution problem and does not leave these issues to future generations.

---

[1] Depending on amount of energy recovered and source replaced

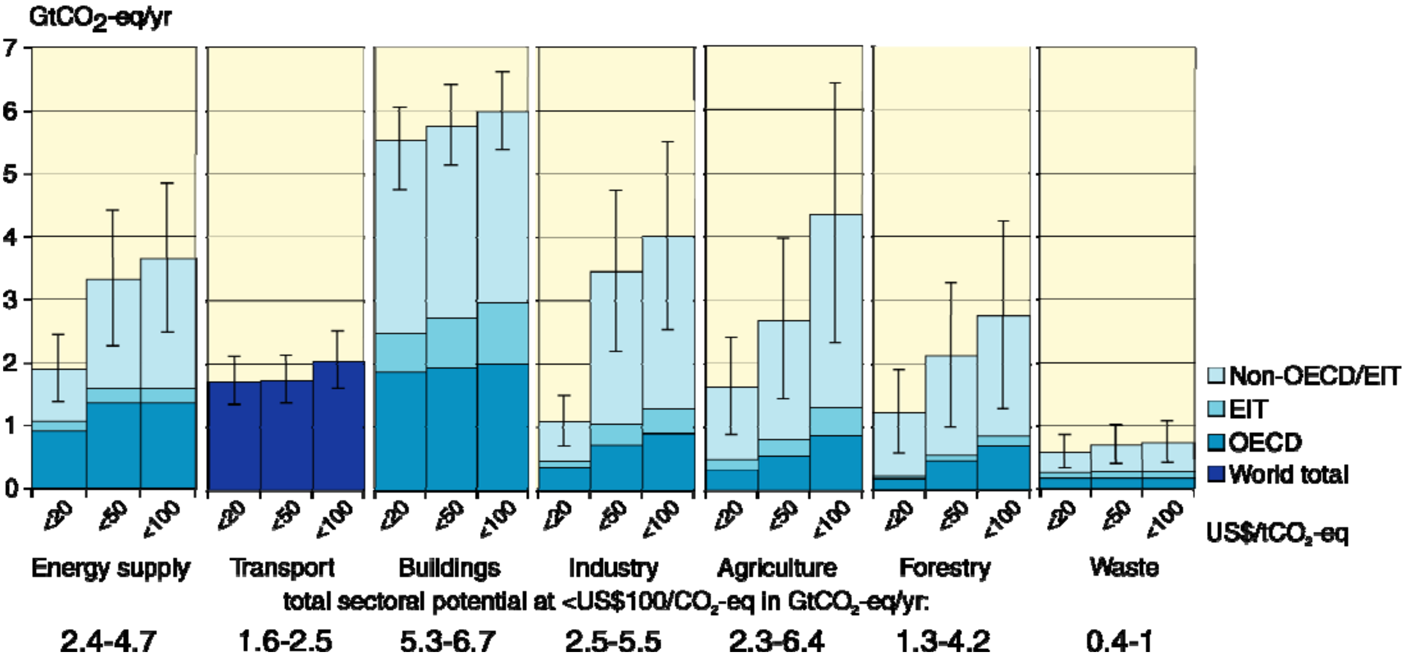


Figure 1: Estimated economic mitigation potential by sector in 2030 from bottom-up studies, compared to the respective baselines assumed in sector assessments. The potentials don’t include non-technical options such as lifestyle changes (1).

INTRODUCTION

In December 2007 the United Nations Framework Convention on Climate Change (UNFCCC) clearly confirmed the need to reduce Greenhouse Gas (GHG) emissions in order to slow down the adverse effects on the world climate. Various sectors were identified together with their potential to reduce GHG emissions. Figure 1 shows these sectors as well as the GHG reduction potential up 3 different “cost per ton CO_2-eq” levels. It is interesting to see that the waste sector has only a relatively small potential of about 0.7 Gt CO_2-eq or 3% compared to the total of 23.4 GtCO_2-eq including other sectors in the entire cost range up to $100 US/Mg CO_2-eq considered. However in the waste sector, similar to the transport and building sectors, most of the mitigation potential can already be achieved at much lower cost of only about $20 US/Mg CO_2-eq. With this in mind policy makers have to establish their strategies and define how much, until when, in which sectors and with which measures they want to contribute to the global GHG reduction goal.

Europe is about to commit themselves to a 20 – 30% reduction of GHG emissions compared to the 1990 level by 2020. According to the European Environment Agency 2007 report (2), between 1990 and 2005 only about 8% reduction has been achieved from about 5621 down to 5177 Tg CO_2-eq. In the same period the waste sector reduced its emissions from 219 down to 149 Tg CO_2-eq, which corresponds to about 32%. It is an interesting question to investigate, under what assumptions and to which extent, in today’s situation and with today’s technologies, the European waste sector could contribute within the second part of the considered period until 2020 to achieve the set GHG emission reduction goal. In parallel, what results could be achieved with a similar waste sector strategy in the USA.

NOMENCLATURE

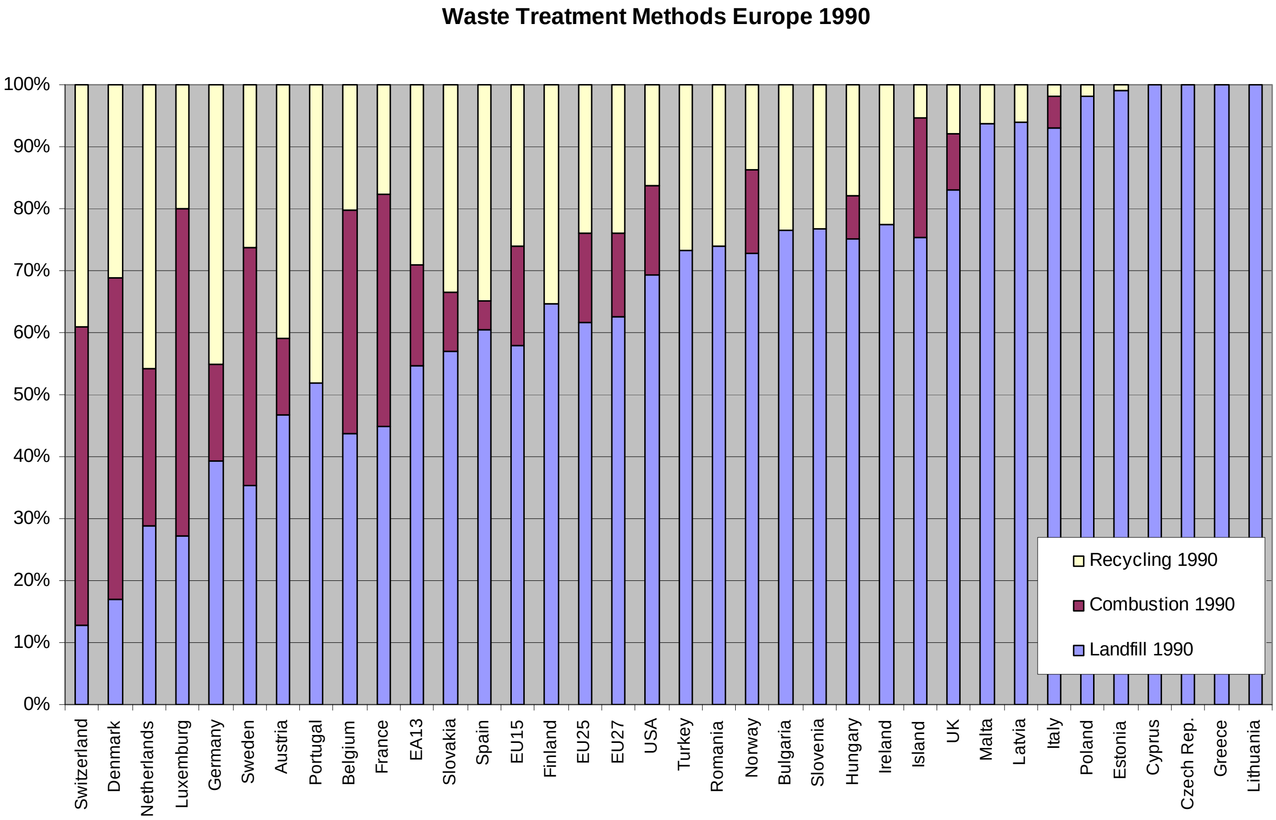
CO_2-eq: denominates GHG (Green-House Gas) emissions in terms of equivalent CO_2 emissions indicated in kg, Mg, Gg and Tg, as an absolute value or referred to a (metric) ton of waste.

Waste amounts are indicated in metric tons, which correspond to approx. 1.1 short tons.

SITUATION IN EUROPE 1990 TILL NOW

As shown in Figure 2, Europe has already made a considerable step towards reduced GHG emissions from waste management. The two graphs are sorted from left to right with increasing CO_2-eq emissions per ton of waste managed. The valuation was done using specific CO_2-eq data as proposed by Dehoust et al. (3). He has determined average European CO_2-eq debit and credit data for the various waste treatment methods based on typical recycled materials and percentages as well as an average electricity and heat generation mix. Using these data the 27 European countries have saved little over 40 Tg CO_2-eq per year GHG emissions due to the changing waste management strategy and despite a 26% increase in total waste generation. Other sources (2) report a reduction of 70 Tg CO_2-eq, but this is due to different reporting methods of various European countries compared to the method used in (3).

For comparison, the same valuation method has been used for data available from the US EPA (4). It can be seen that the position of the US in 1990 is about equal to the average of the 27 European Union countries (EU27). Between 1990 and 2005



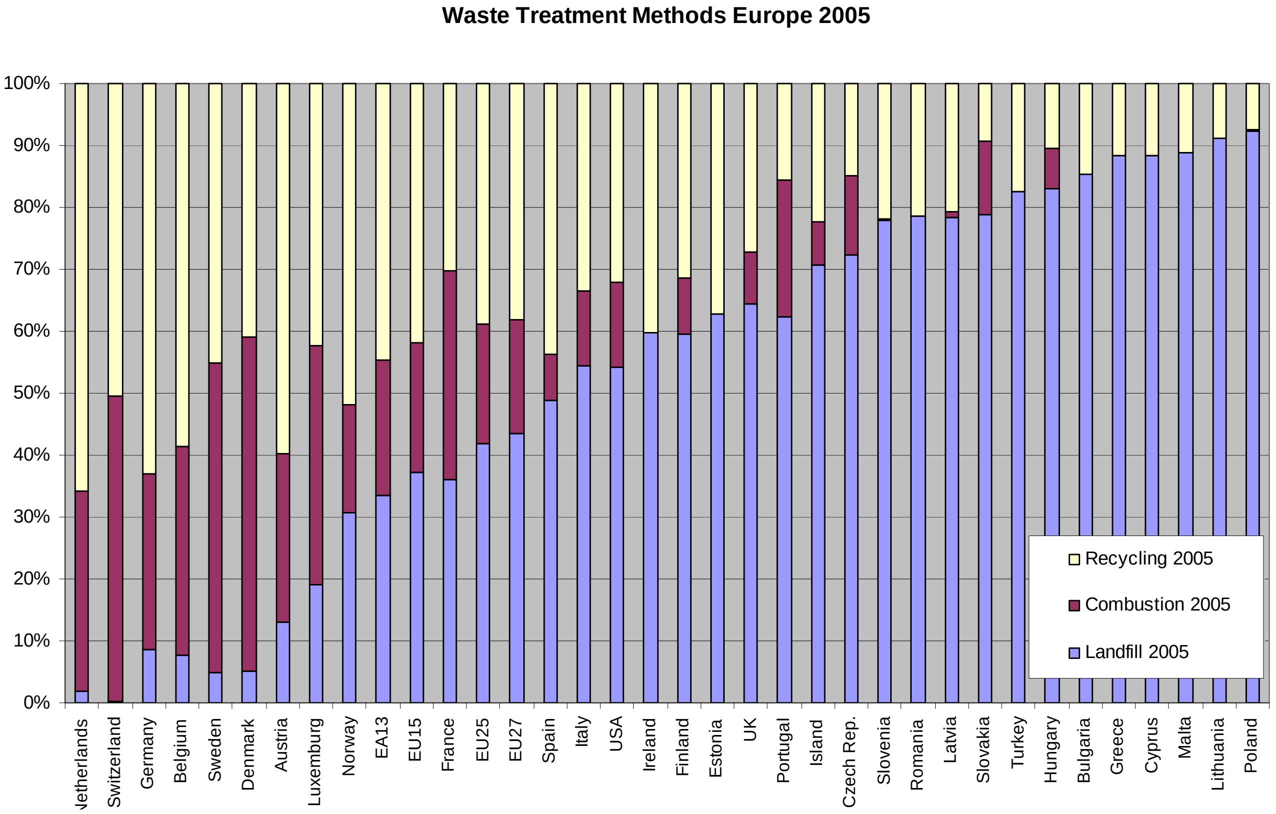


Figure 2: Waste treatment methods in Europe 1990 and 2005. Sorted from left to right with increasing GHG emissions per ton of waste treated. Typical specific factors according to Dehoust et al. (3) are -275 kg CO_2-eq/t for recycled waste, -8 kg CO_2-eq/t for waste treated in EfW plants and +928 kg CO_2-eq/t for landfilled waste. EUROSTAT uses following abbreviations for groups of countries: EA13 – 13 countries using the EURO on 1.1.2007; EU15/25/27 – No of countries of the European Union on 1995-2004/ 2004-2006/ since 2007 respectively (details at http://epp.eurostat.ec.europa.eu)

the USA faced an approximate 20% increase of waste produced and managed to reduce total GHG emissions by approx. 20 Tg CO_2-eq calculated with the same factors as proposed in (3).

The annual savings of GHG emissions per capita, based upon the waste management methods for the period 1990-2005, in terms of Tg CO_2-eq/capita.year:

- USA: 445 → 312, i.e. 30% reduction
- EU27: 243 → 153, i.e. 37% reduction
- EU15: 234 → 129, i.e. 45% reduction

In the following a review is done to evaluate which drivers have been used, mainly in the EU15 countries, to achieve this reduction and what they foresee for the future in order to facilitate the EC 2020 GHG reduction goals.

POLITICAL DRIVERS IN WASTE MANAGEMENT TO REDUCE GHG EMISSIONS

Various routes contribute to the goal of GHG emission reduction. The following principles have been established early. Waste management methods used and priorities of certain routes compared to others vary from country to country.

Table 1

Priority	Potential (neg. values = less CO_2)	Methods, see table 2
1. reduce a)	Both reduce waste per capita (not CO_2-eq/t)	3) 5)
2. reuse a)		3) 5)
3. recycle b)	-50…-2500 kg CO_2-eq/t	1) 4) 5) 6)
4. recover c)	-100..-1000 kg CO_2-eq/t	1) 4) 7) 8)
5. dispose d)	+250..1850 kg CO_2-eq/t	7)

Remarks:

a) Reduction and reuse of materials have other benefits such as less pollution and should be prioritized.

b) According to Dehoust (3), recycling of various materials such as paper, glass, metals have largely different GHG emission benefits – therefore the huge range. Today's European average weighted with actually recycled volumes is -275 kg CO_2/t waste.

c) Recovery here is meant to be energy recovery from thermal treatment and includes the new proposed distinction method between "recovery" and "disposal" discussed below.

d) Disposal here means landfilling. The huge range is due to consideration of possible landfill gas recovery with potential electricity and heat recovery from the landfill gas.

Waste management methods are allocated to the GHG reductions routes they are most supporting. A more detailed overview with country-wise information is provided in by the European Environment Agency (5). Generally it can be said that, following Figure 2, those countries are in front which had early instruments in place, regardless of the type of waste management method. For example Denmark, the Netherlands and Switzerland were early to introduce a landfill ban, while Austria, Belgium and Germany early established a packaging material collection system – Austria and Belgium combined with a landfill tax. Denmark, Sweden and Switzerland also had early deposit-refund schemes for certain materials.

Table 2

Waste management method	Remarks
1) Landfill tax	a)
2) Other tax	a)
3) MSW collection tax (pay per bag)	a)
4) Landfill ban	b)
5) Packaging tax and collection	a) c)
6) Separate collection of MSW fraction	c)
7) Premium energy purchase price or ETC (emission trading credits)	a)
8) Distinction between 'recovery' and 'disposal' in thermal treatment	b)

Remarks:

a) Market-based instrument
b) Administrative instrument
c) Organizational instrument

PROPOSED R1-FACTOR TO DISTINGUISH BETWEEN DISPOSAL AND RECOVERY IN EFW PLANTS

The current discussion in Europe is about the distinction between "recovery" and "disposal" in EfW plants. After the "Strasbourg Incinerator" court case (6, discussion in 7) there has been a lot of interpretation about this issue, especially if the court ruling was in line with the political intention originally pursued with this administrative instrument established to define a waste management strategy. Looking at the GHG reduction potential shown in Table 1, it is clear that thermal treatment of wastes has a potential that is rather comparable with recycling and that the "Strasbourg" ruling needs clarification.

An amendment of the Waste Framework Directive has been proposed and discussed (8) that clearly classifies EfW plants as "recovery" operations if they meet minimum efficiency standards. This is done by defining the R1-factor as follows:

(1) $R1 = (Ep-(Ef-Ei))/(0.97x(Ew+Ef))$
(2) $Ep = 2.6xEe + 1.1xEh$
Where:
Ee and Eh is annual energy produced as electricity and heat
Ef is annual energy input from fuels other than wastes
Ei is the annual energy imported excl. Ef and Ew
Ew is the annual energy of the waste (based on LHV)

The factors in formula (2) represent the GHG emissions saved if electricity and heat production in the EfW plant does not need to be produced elsewhere (according to (9) credits are 0.78 kg/kWh for electricity and 0.36 kg/kWh for heat and are

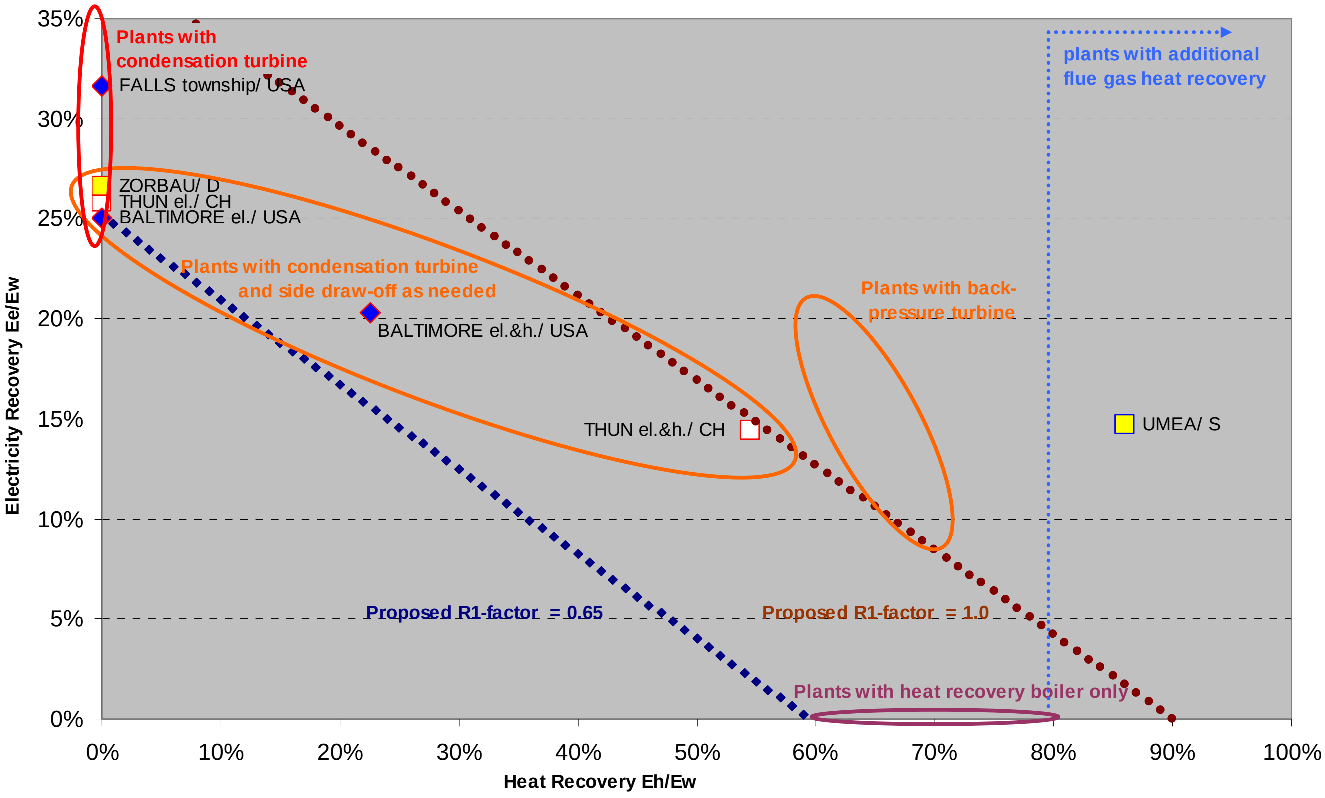


Figure 3: Electricity vs. Heat recovery

always a factor of the fuel mix and efficiencies of the existing energy production methods).

According to (10) it is valid for most plants to simplify formula (1) assuming that Ef and Ei are about 1% and 2% of Ew each.

Combining the simplified formula (1) with formula (2) yields $R1_s$ (simplified R1)

(3) $R1_s = (2.6xEe/Ew + 1.1xEh/Ew – 0.03)/0.9603$

Using simplified formula (3) a graph can be drafted showing minimum requirements for European EfW plants to be qualified as recovery units with an overall energy efficiency of 0.65. Figure 3 shows this line together with indications about plant standards in line with this concept as well as the relative position of some typical EfW plants which are described in the Annex. Plants on the $R1_s = 0.65$ line represent a GHG emission credit of about 125-175 kg CO_2-eq/t of waste treated. More efficient plant configurations can reach $R1_s = 1$ corresponding to a GHG emission credit of about 425-475 kg CO_2-eq/t of waste treated or even more. This allows a comparison of the overall GHG emissions per ton of waste treated with different methods (Table 3).

At the end it is the political framework which determines the waste management solutions that will preferably be implemented. To reduce GHG emissions, residents of an area where landfilling without LFG recovery is the disposal method have the following options:

Table 3

Method	kg CO_2-eq/t	Debit/credit
Landfill	1850	Debit
Landfill, LFG to flare	775	Debit
Landfill, LFG to power	425	Debit
Landfill, LFG to power & heat	250	Debit
EfW plant, $R1_s = 0.65$	- 150	Credit
EfW plant, $R1_s = 1$	- 450	Credit

Table 4: Equivalent GHG reduction options for a 4-person family according to (9):

Change waste handling	Alternative GHG reduction option
LFG recovery to flare	Recycle 1/3 of their waste
LFG recovery to power	Sustain 1 acre of pine forest
LFG recovery power & heat	Avoid using 200 propane cylinders (e.g. for barbecues)
EfW plant, $R1_s = 0.65$	Remove 1 passenger vehicle from use
EfW plant, $R1_s = 1$	Do without electricity at home

In Europe, the landfill ban for untreated wastes is a law and the tendency is to build future EfW plants with an R1-factor above 0.65. Wielenga (8) established a scenario for Europe where 60% of the waste should be recycled (including composting and fermentation) and 40% treated in EfW plants with R1=0.65. Achieving that, Europe's waste management sector could contribute another 140 Tg CO_2-eq/a credit to Europe's total GHG emissions and would in fact become a net GHG sink. Assuming an average cost of \$50 US/t CO_2-eq (Figure 1), this would entail additional cost of \$7 Billion US per year, corresponding to about 1.5‰ of the GDP. Since the level of achievement of this goal is also strongly connected to the GDP per person in a country it remains to be seen until when and to what extent Europe is able to reach such a theoretical goal.

CONCLUSIONS

There is a 2 Mg CO_2-eq emitted per ton of waste variance in GHG emissions depending upon the waste treatment technologies selected.

About half of these emissions can be avoided by landfill gas recovery, whereas older and less productive landfills can flare off the gas while in newer and more productive landfills energy should be recovered as power and if possible as heat. This option requires lowest investment and can also be used on existing landfills.

The only methods contributing a CO_2 credit to waste management are recycling and energy recovery in EfW plants. Especially if new installations are necessary EfW plants can be built close to power and heat consumers which turn waste management from a net source to a net sink regarding GHG emissions. This will at the same time minimize cost and emissions for possibly long range waste transport which all has not been considered in this paper.

Various government policies used in Europe since the ‘80s and ‘90s to guide waste management into the right direction seem to work. The discussion about the R1-factor is an example that legislation once introduced may have to be amended if the jurisdiction shows that in is not in line with original ecological goals.

ACKNOWLEDGMENTS

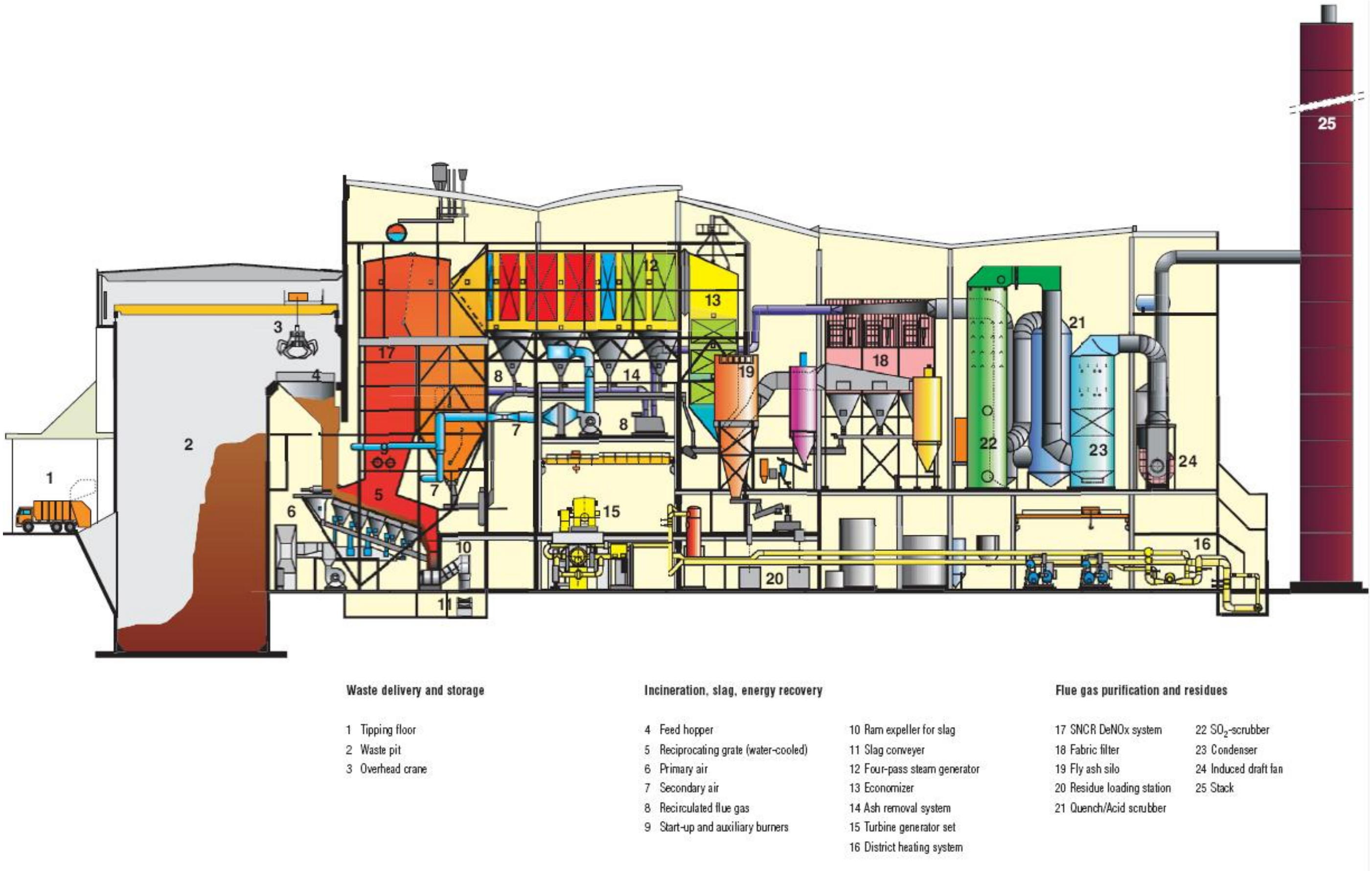
Thanks to Dave Raymond and Son Le Mong for providing and checking data as well as to Raymond Burelle for critical reading.

REFERENCES

1) Summary for Policymakers of the Synthesis Report of the IPCC Fourth Assessment Report, DRAFT COPY 16 NOVEMBER 2007 23:04
2) European Environment Agency: Annual EC greenhouse gas inventory 1990-2005 and inventory report 2007, Version 27.May 2007
3) Dehoust Günther et al., Status Report on the Waste Sector's Contribution to Climate Protection and Possible Potentials, Environmental research plan of the federal ministry for the environment, nature conservation and nuclear safety, Research Report 205 33 314, August 2005
4) EPA, Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2005
5) European Environment Agency, The road from landfilling to recycling: common destination, different routes, 2007
6) Strasbourg Incinerator, ECJ, 13.2.2003, Case C-458/00, Commission v. Luxembourg
7) Beyer Peter and Hansen Wenke, Analysis and interpretation of the judgments of the European Court of Justice C-458/00 and C-228/00, 15.October 2003
8) Wielenga Kees, Waste-to-Energy and the revision of the Waste Framework Directive, February 2008
9) http://www.epa.gov/cleanenergy/energy-resources/calculator.html
10) Reimann Dieter O., CEWEP Energy Report (Status 2001-2004), October 2005 (update July 2006)

ANNEX A

EXAMPLE FOR HIGHEST ENERGY EFFICIENCY: UMEÅ/SWEDEN POWER AND DISTRICT HEATING STATION



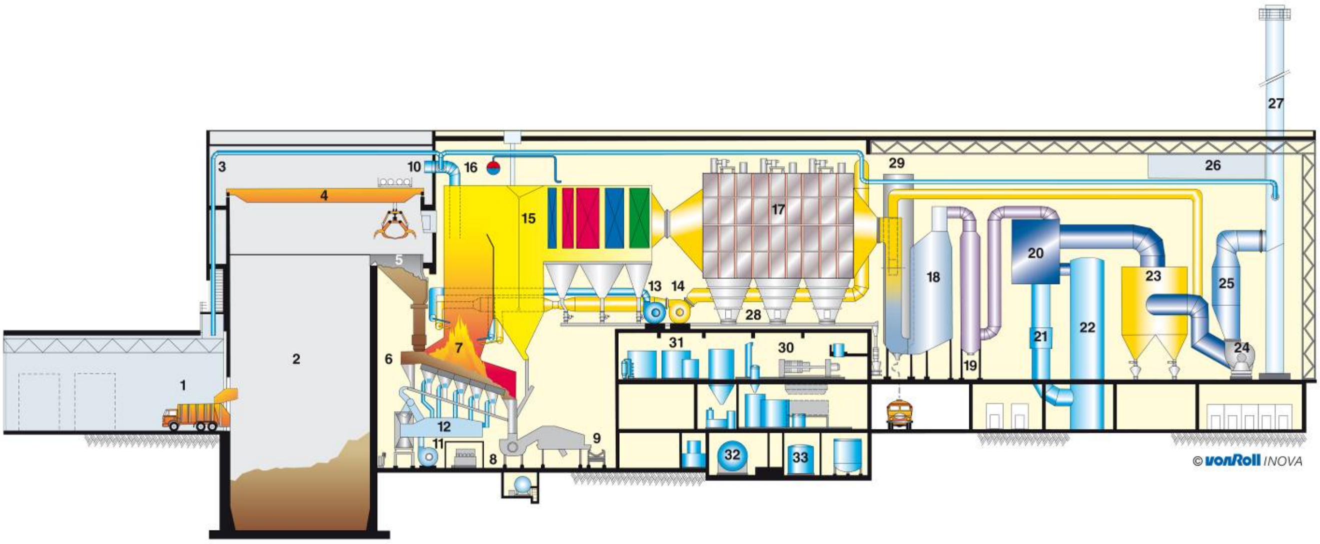
The Umeå plant generates electricity and heat by burning pre-sorted waste and residues from the wood products manufacturing industry. It offered an opportunity to expand the Umeå district heating network, thus helping minimize the consumption of high-priced electricity. Thus, the overall efficiency reaches close to 100% (of the LHV) thanks to effective recovery of excess heat from power generation and in flue gases. Located only four kilometres outside the city, the new plant has a negligible impact on the environment, not least because a highly efficient flue gas cleaning system.

Electrical Efficiency (Ee/Ew)	15%
Thermal Efficiency (Eh/Ew)	85%
CO_2-eq emissions (kg/t of waste as per (3))	-1000 (credit)
$R1_s$ – factor (as per formula 3)	1.35

The plant consists of one process incorporating a grate combustion system, a steam generator with turbine, a fabric filter, a flue gas treatment system with condensation and heat pumps, and a wastewater treatment system.

ANNEX B

EXAMPLE FOR A MODERNE AND EFFICIENT URBAN FACILITY: MSWIP THUN/ SWITZERLAND



Waste receiving and storage

1 Unloading hall
2 Waste pit
3 Waste pit ventilation
4 Waste crane

Combustion and steam generator

5 Feed hopper
6 Ram feeder
7 Reciprocating incineration grate
8 Ram ash expeller
9 Slag handling
10 Primary air intake
11 Primary air fan
12 Primary air distribution
13 Secondary air fan
14 Flue gas recirculation fan
15 Four-pass steam generator
16 Boiler drum

Flue gas cleaning

17 Electrostatic precipitator
18 SCR DeNOx and catalyzer
19 Economiser
20 Gas/gas heat exchanger
21 Quench
22 Von Roll Inova wet scrubber
23 Bag filter
24 Induced draft fan
25 Silencer
26 Emissions measurement
27 Stack

Consumables and residues

28 Ash removal
29 Fly ash storage
30 Fly ash washing
31 Wastewater treatment
32 Ammonia water tank
33 HCl storage tank

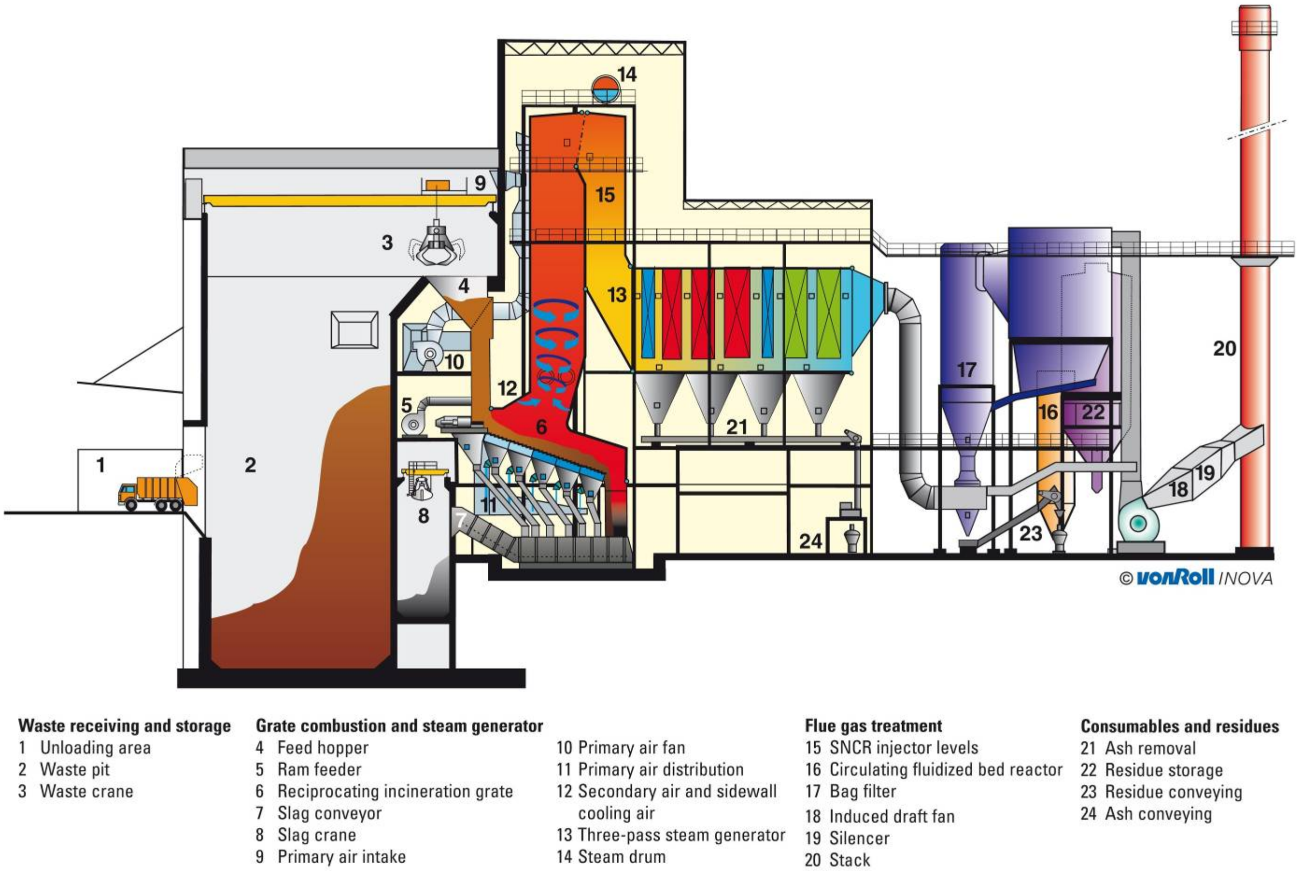
The MSWIP Thun is located on shores of the lake, in the economic hub of the Bernese tourist region known for its snow-clad mountains and picturesque landscapes. The plant produces about a third of the electricity consumed in the city of Thun, and also provides district heating for adjacent public-sector facilities. Because of the plant's close proximity to the city of Thun, particular attention was paid to minimize noise and odour pollution resulting from both delivery activities and plant operation. About 40 percent of the waste is brought by rail and is unloaded at the plant in an enclosed hall. To prevent odour emissions, air for the combustion system is drawn in from the waste pit and the unloading area.

Energy recovery takes place in a turbine generator set consisting of an extraction/condensation turbine with regulated low-pressure extraction and ports for district heat output. The plant is designed to produce a maximum of 12 MW of electricity and 25 MW of district heat.

Electrical Efficiency (Ee/Ew)	14.4-26.1%
Thermal Efficiency (Eh/Ew)	0-54.5%
CO_2-eq emissions (kg/t of waste as per (3))	-290…-660 (credit)
$R1_s$ – factor (as per formula 3)	0.68…0.98

ANNEX C

EXAMPLE OF AN ECONOMIC WASTE POWER PLANT: ZORBAU/ GERMANY



The incineration plant comprises two process trains; each with a maximum waste capacity of 21 t/h MSW. A “calorific value navigator” integrated into the instrumentation and control system adjusts the combustion conditions rapidly and reliably to changing waste fractions and properties. This technique ensures optimal burnout of the varying wastes and an optimized turbine operation production of electricity.

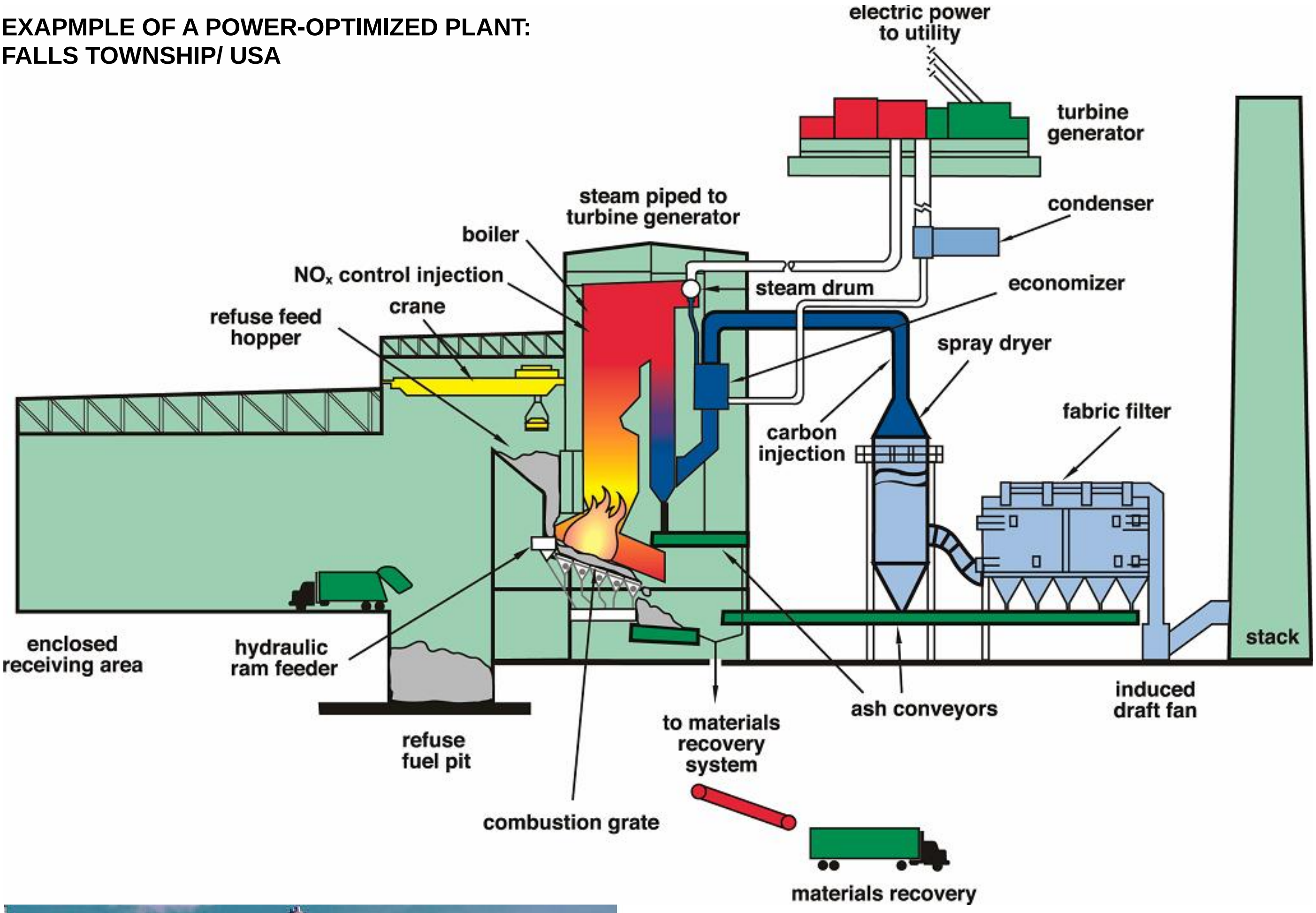
Flue gas treatment keeps the plant in compliance with the limits of European emission regulations at all times, even when handling waste with elevated levels of pollutants. This takes place in two stages: destruction of nitrogen oxides by SNCR (selective non-catalytic reduction) followed by a TURBOSORP® semi-dry treatment for safe removal of gaseous pollutants as well as heavy metals and dioxins.

The energy produced in the combustion process is used to supply enough electricity for currently 40 000 households. Future plans call for additional use of this energy in a cogeneration scheme for district heating once the expansion of the nearby industrial park has been completed.

Electrical Efficiency (Ee/Ew)	26.4%
Thermal Efficiency (Eh/Ew)	0%
CO_2-eq emissions (kg/t of waste as per (3))	-150 (credit)
$R1_s$ – factor (as per formula 3)	0.69

ANNEX D

EXAPMPLE OF A POWER-OPTIMIZED PLANT: FALLS TOWNSHIP/ USA



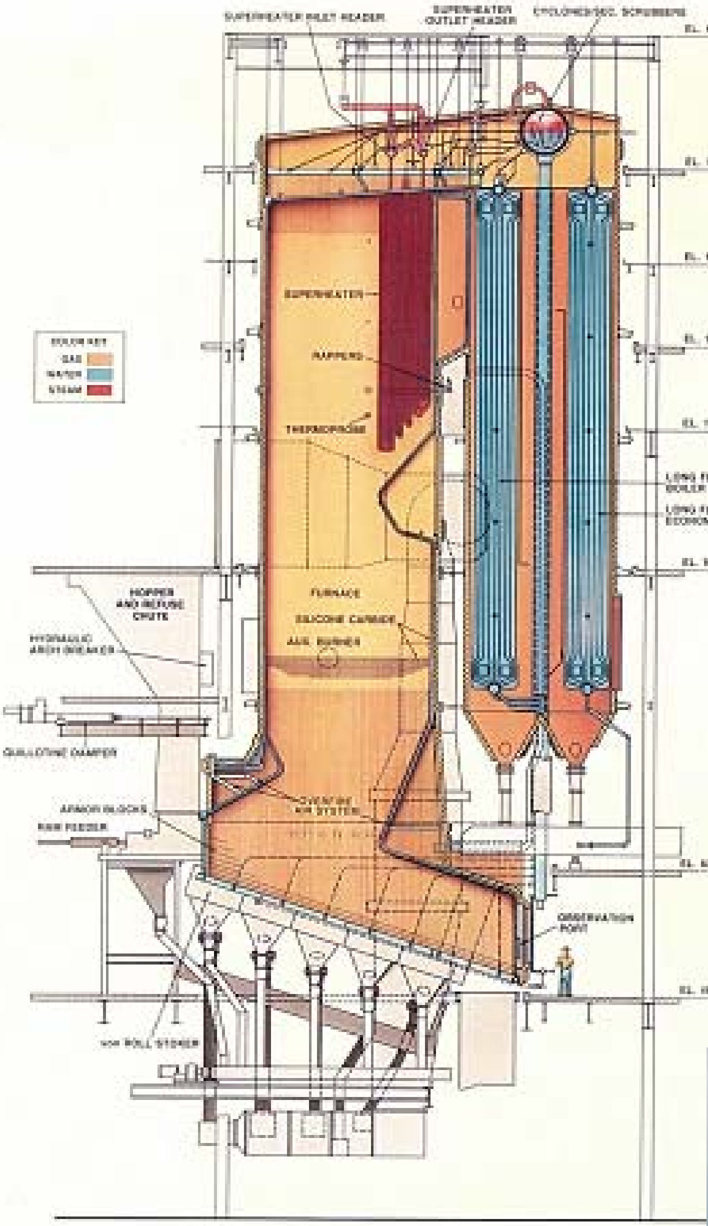
Located in Falls Township, Pennsylvania, the Wheelabrator Falls waste-to-energy facility provides disposal of municipal solid waste for eastern Pennsylvania while generating electricity for sale to Public Service Electric and Gas Company. The Falls facility processes up to 1500 tons per day of municipal solid waste, and at full capacity, has a generating capacity of 53,000 kilowatts of electrical energy per hour, enough energy to power more than 60,000 Pennsylvania homes

The Plant, which began operating in 1994, consists of two (2) 750-ton/day mass-burn, waterwall boilers with Von Roll reciprocating grates, operating at 1300 psig/930oF, producing 416,000 pounds of steam per hour. The plant is equipped with selective non-catalytic reduction system for NOx control, spray dryer absorber scrubbers, fabric filter baghouses and a powdered activated carbon injection system.

Electrical Efficiency (Ee/Ew)	31.6%
Thermal Efficiency (Eh/Ew)	0%
CO_2-eq emissions (kg/t of waste as per (3))	-310 (credit)
$R1_s$ – factor (as per formula 3)	0.83

ANNEX E

EXAPMPLE OF A POWER AND HEAT PRODUCING PLANT: BALTIMORE/ USA



Located in Baltimore, Maryland, the Wheelabrator Baltimore waste-to-energy facility provides disposal of municipal solid waste for the City and County of Baltimore, Maryland while generating electricity for sale to Baltimore Gas & Electric Company. The Baltimore facility processes up to 2,250 tons per day of municipal solid waste, and at full capacity, has a generating capacity of 60,000 kilowatts of electrical energy, enough energy to power more than 65,000 Maryland homes. The Baltimore Plant also supplies steam to the Baltimore City heating loop, providing about one-half of the steam requirements of the heating system.

The Plant, which began operating in 1985, consists of three (3) 750-ton/day mass-burn, waterwall boilers with Von Roll reciprocating grates, operating at 850 psig/825oF, producing 510,000 pounds of steam per hour. The plant is equipped with selective non-catalytic reduction system for NOx control, spray dryer absorber scrubbers, high efficiency electrostatic precipitators and a powdered activated carbon injection system.

Electrical Efficiency (Ee/Ew)	20.3-25.8%
Thermal Efficiency (Eh/Ew)	0-22.6%
CO_2-eq emissions (kg/t of waste as per (3))	-130…-240 (credit)
$R1_s$ – factor (as per formula 3)	0.67…0.78