THE MUNICIPAL SOLID WASTES AN IMPORTANT BUT PROBLEMATIC RENEWABLE ENERGY SOURCE

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Around 60% by weight of household waste is Paper and bio-waste and, as such, their combustion or the combustion of their degradation products is CO_2 neutral.

This means that the energy released by combustion is revived wholly from R.Sources, such as wood and green wastes, that absorb CO_2 whilst they are growing.

So, generation of energy from landfill gas or from the combustion of the wastes reduces the use of fossil fuels and diverts the methane produced, when waste is land filled thereby contributing strongly towards greenhouse gas (methane + CO_2) reduction targets

Glossary of Terms

Anaerobic – Oxygen free

Biodegradable – Able to be broken down by bacteria.

BOD (Biological Oxygen Demand) – A measure of the amount of material present in water, which can be readily oxidised by micro-organisms.

Carbohydrate – A compound of carbon, hydrogen and oxygen

Cellulolytic – ability to breakdown and digest cellulose

COD (Chemical Oxygen Demand) – A measure of the total amount of chemically oxidizable material present in liquid..

Energy from Waste (EfW) Incineration - The conversion of waste into a useable form of energy e.g. heat or electricity by combustion.

HDPE – High density polyethylene

Inerts – Non-biodegradable materials

Leachate – A liquid that has percolated through or out of some substance e.g. municipal solid waste

Lipids – A fat or wax found in living cells

Methanogenesis – The process by which a consortium of bacteria produce methane.

Municipal Solid Waste (MSW) - Waste from household collection

Phytotoxic – Poisonous to plants

Recycling - Strictly defined as re-processing collected waste materials to produce a secondary raw material.

TOC (Total Organic Carbon) – A measure of the organic carbon in a substance

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PRIMARY BIOMASS PRODUCTION - PHOTOSYNTHESIS

$$6CO_2 + 6H_2O + 2.8 \text{ Jenergy} = C_6H_{12}O_6 + 6O_2$$

An annual insulation of : $3 \cdot 10^{18}$ MJ

$3 \cdot 10^{18}$ MJ + Photosynthesis $\Rightarrow 2 \cdot 10^{11}$ t dry biomass $\Rightarrow 3 \cdot 10^{15}$ MJ Energy

C_3 plants < 1% of insulation to energy

  C_3 plants : molecules with 3 – C atomes

C_4 plants > 2% of insulation to energy

Biomass content : Cellulose or lignitic compounds

  C   45 – 50% wt

  H_2 4 – 6%

  O_2 35 – 45%

BIOMASS : Seasonal SOLAR ENERGY Storage

  Biomass production is a positive energy operation
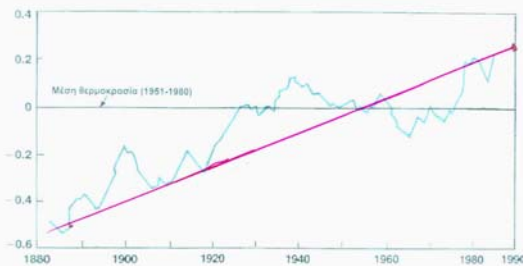
Διείσδυση των Ανανεώσιμων το έτος 2020

228 ΜΤΙΠ*/ EU 15

31,1% Ενεργειακές Καλλιέργειες

Βιομάζα απορριμάτων 24,5%

Ηλιακή Ενέργεια 4,9%

Βιομάζα γεωργικών και δασικών υπολειμάτων 15,2%

13% Υδροηλεκτρικά

6,8% Αλλα

4,4% Αιολική Ενέργεια

Πηγή: TERES II The European Renewable Energy Study, ALTENER Programme

* ΜΤΙ Π: Μέγα Τόνοι Ισοδυνάμου Πετρελαίου
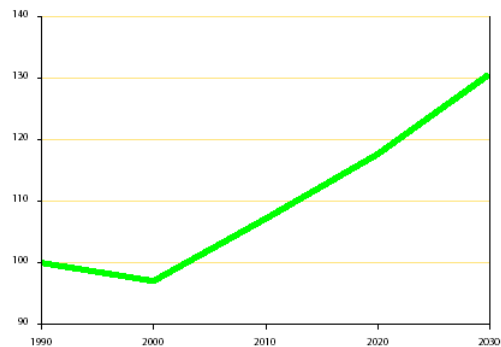

ΑΛΛΑΓΕΣ ΣΤΗ ΘΕΡΜΟΚΡΑΣΙΑ ΤΟΥ ΑΕΡΑ ΤΗΣ ΓΗΣ

Μέση θερμοκρασία (1951-1980)

ΑΛΛΑΓΕΣ ΣΤΗΝ ΠΕΡΙΕΚΤΙΚΟΤΗΤΑ ΤΟΥ ΑΕΡΑ ΣΕ CO₂ (p.p.m)

Basis of projections
Barrels oil equivalent/capita/annum

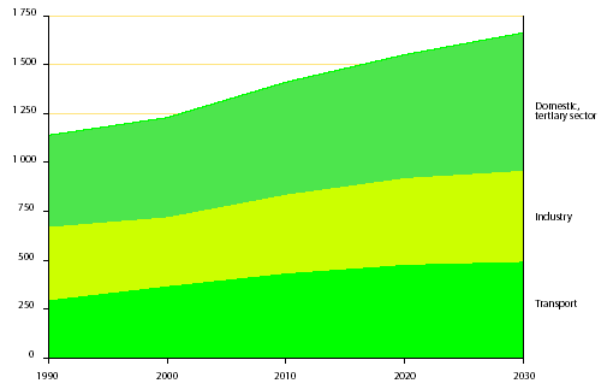|	1990	2000	2010	2020
USA	58	55	50	45
Japan	24	24	23	22
W. Europe	26	26	25	24
E. Europe/USSR	36	35	33	31
Rest of world	4.1	5.5	7	8.5
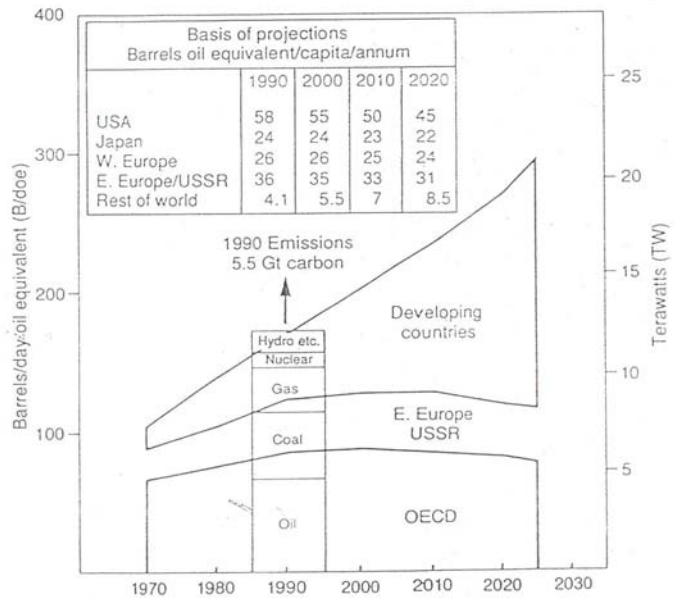
EU-30 – Energy related CO_2 emissions (1990 = 100)

EU-30 — Energy related CO_2 emissions (1990 = 100)

**EU-30 (^{5}) — Final energy consumption [in million toe (^{6})]**

Domestic, tertiary sector

Industry

Transport

EU-30 — Energy production by fuel (in million toe)

Renewables

Nuclear

Natural gas

Oil

Solid fuels
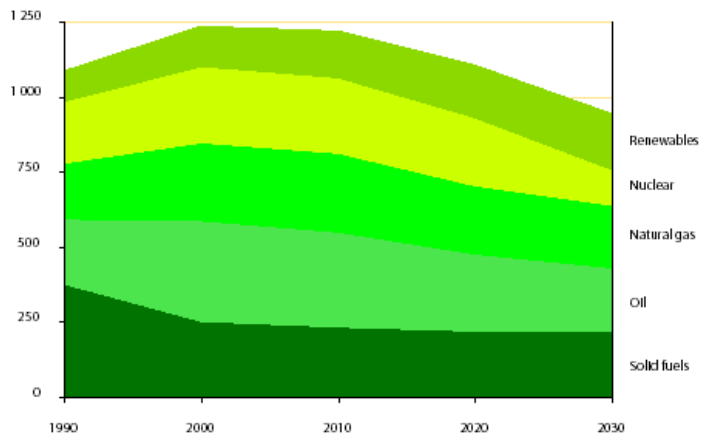
(b) Natural gas reserves are more evenly distributed on the global level, but the European Union is once again unfortunate, with barely 2 % of world reserves, or 20 years' consumption at present rates. 223.2 million toe were extracted in 1997, representing 12 % of world production. Most of these reserves are located in the Netherlands (56 %) and the UK (24 %).

(c) The rate at which Community resources will be depleted depends not only on the extent of known reserves, but also on the price of oil and gas on the world market, and on technological progress. The higher the price of oil, the more companies will invest in prospecting and production. If present oil and natural gas prices could be sustained (around USD 30 in 2000), then large reserves

World oil production cost

NWECS — oil production forecast
Three scenarios — comparison
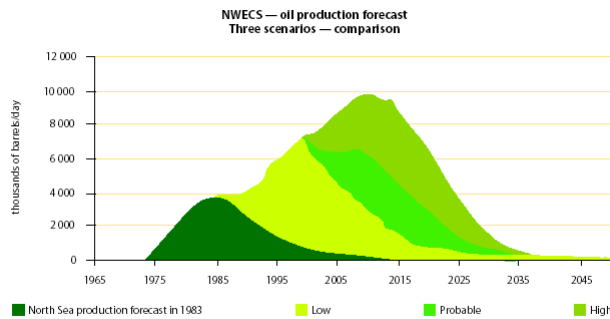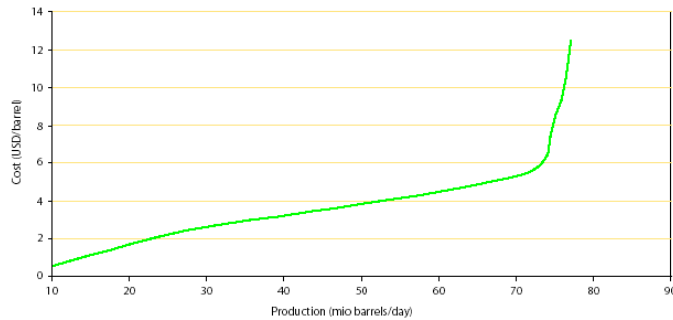
would be brought into production. Amid such uncertainties, however, one thing is clear: if production continues at its present rate, North Sea oil and gas deposits will be exhausted within 25 years. Enlargement will do nothing to increase internal supply (14). Forecasts are usually exceeded notably as a result of technological innovation, as shown in the graph below.

If investment were to pick up, this might also help relieve the prevailing pessimistic outlook. New extraction technologies may mean that, in time, the recovery rate could rise from 20–40 % of deposits to 60 %.

2. Decline in mine production

(a) Solid fuels

In absolute terms, the world has substantial reserves of solid fuel — 4–5 times as much as oil, or some 200 years' supply. 80 % of Europe's fossil fuel reserves are solid fuels (including coal, lignite, peat and oil shale). However, this optimism has to be tempered by the fact the quality of solid fuels is variable and production costs are high.

The Community now produces 1.2 million toe of production). After enlargement, the Union's coal production will more than double. However, while lignite and peat are profitable businesses, European coal is highly uncompetitive compared with imported coal.

Difficult geological conditions and the rules governing social insurance in the European Union cause the average cost of producing European coal to be 3–4 times the international market price (USD 150 per tce compared to USD 40 per tce). Given this context, European coal cannot compete with that of the major coal-exporting countries such as the United States, Australia, South Africa or Colombia. This gap has led producing countries either to cease all production as in Portugal, Belgium and France (in 2005) or to decide to restructure the industry so as to gradually reduce mining activity (Germany and Spain) or to make production competitive with that of imported coal (United Kingdom).

A few years hence, the highly uncompetitive European coal industry will be providing only a tiny proportion of the Union's energy needs, even after taking enlargement into account

[14] In 1999, Norway had 1.77 trillion (thousand billion) cubic metres of proven gas reserves which at current production rates will last 23 years, proven oil reserves at around 11 billion barrels are over half Europe's reserves but at current production rates will last 10 years. However, there are substantial reserves of oil and gas to be exploited in the Barents Sea.

(Poland, Czech Republic, Romania). Although the applicant countries have substantial solid fuel reserves, they will not be able to stand up to international competition, and will have to reduce their mining activities in line with EU policy.

Difficult decisions will have to be taken regarding the future of the European coal industry on account of its lack of competitiveness. One path to explore could be that of maintaining access to certain reserves. To this end, it might be possible to envisage maintaining minimal capacity of coal production in a framework of adequate social measures, which would ensure the maintenance of the equipment and thus guarantee the continuity of good operation, while at the same time allowing European technology to keep its leading position in clean-coal mining and consumption.

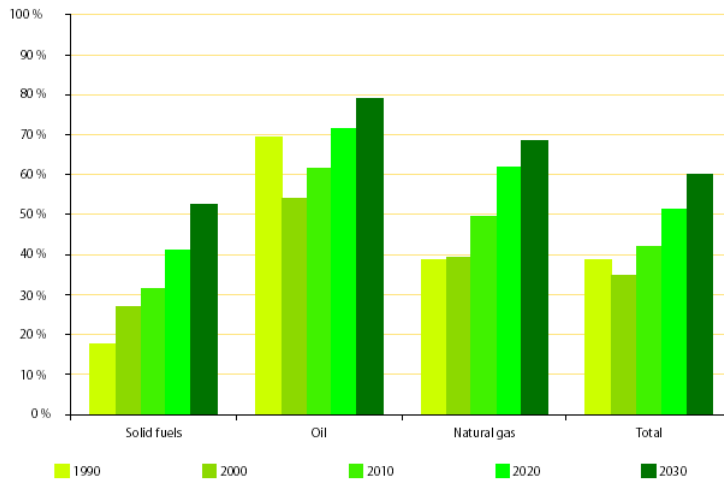### Origin of uranium imports used in the Union
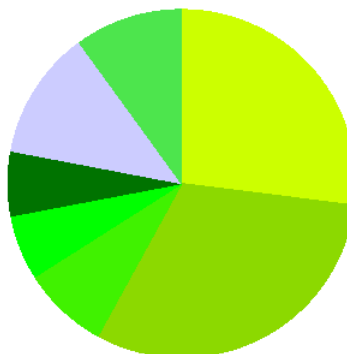
- NIS
- Gabon + Niger
- Australia
- Canada
- USA
- Others
- Namibia + South Africa

EU-30 — Total energy (in million toe)
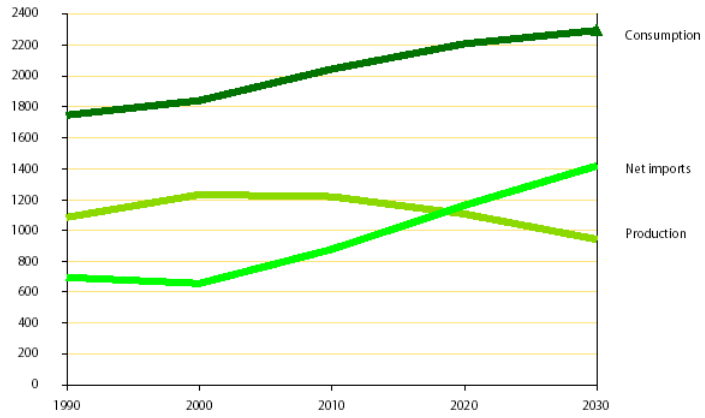
EU-30 — Dependence according to energy product

Three main points emerge from the Green Paper:

— The European Union will become increasingly dependent on external energy sources: enlargement will not change the situation: based on current forecasts, dependence will reach 70 % in 2030.

— The European Union has very limited scope to influence energy supply conditions: it is essentially on the demand side that the EU can intervene, mainly by promoting energy saving in buildings and the transport sector.

— At present, the European Union is not in a position to respond to the challenge of climate change and to meet its commitments, notably under the Kyoto Protocol.

Table: Share of oil and gas in total energy consumption in 1998, 2010, 2020 and 2030

	1998	2010	2020	2030
EU	64 %	66 %	66 %	67 %
EU-30	61 %	63 %	65 %	66 %

Table: Projected increase of CO_2 emissions in 2010, 2020 and 2030 related to 1990 (base year of the Kyoto Protocol)

	2010	2020	2030
EU	+5 %	+12 %	+22 %
EU-30	+7 %	+18 %	+31 %

Table: Projected import dependence of EU, and EU-30 in 1998, 2010, 2020 and 2030

	1998	2010	2020	2030
EU	49 %	54 %	62 %	71 %
EU-30	36 %	42 %	51 %	60 %

EU-30 — Renewables (production/consumption in million toe)
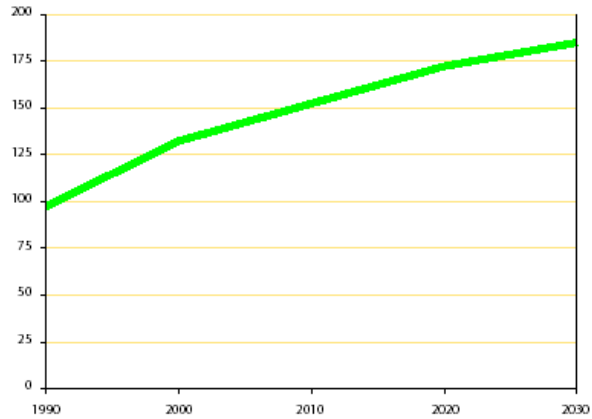
European commission projections for the European renewable energy market

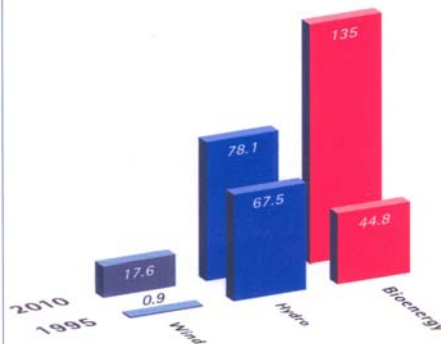Units – Millions of Tonnes of Oil Equivalent (Mtoe)

Bioenergy currently accounts for 3% of EU energy consumption. The European Commission's White Paper "Energy for the Future – Renewable Sources of Energy" proposes to increase that to 8.3% by 2010; to supply 50% of all renewable energy in the EU, equivalent to 135 millions tonnes of oil annually.

The European Commission's 'Campaign for Take Off' sets targets for:

- 1,000,000 (10,000 MWth) new dwellings heated by biomass by 2003.
- 10,000 MWth of combined heat and power biomass installations by 2003.
- 1,000 MW of Biogas Installations by 2003 (Anaerobic Digestion of wet biomass).

ENERGY FROM MUNICIPAL SOLID WASTES

Figure 1 Typical Composition of MSW

Legend: Paper, Putrescibles, Textiles, Unsorted Fines, Misc. Combustibles, Misc. Non-combustibles, Wood, Glass, Garden Waste, Ferrous Metal, Non-ferrous Metal, Plastic Film, Dense Plastics
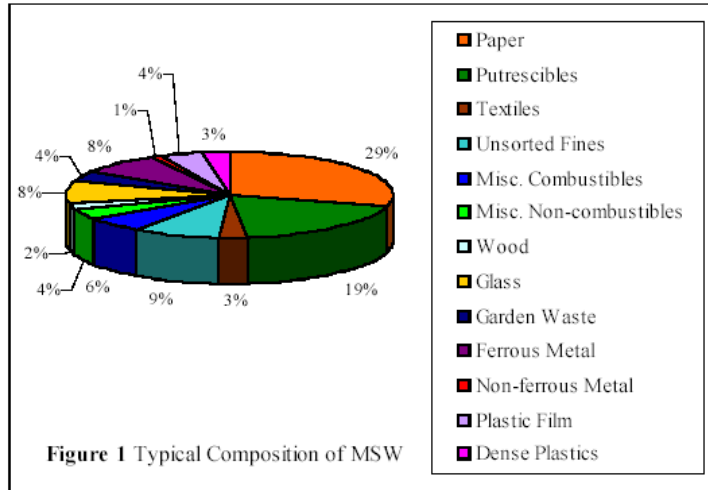
Composition of Urban Typical Collection and Civic Amenity Wastes as Delivered to Landfill (Source: Waste Management Paper No 26A, 1992)

Constituent	Weight % (as received)
Paper	29.2
Putrescibles	19.0
Textiles	3.0
Unsorted Fines	8.6
Miscellaneous Combustibles	5.8
Miscellaneous Non-combustibles	4.0
Wood	2.2
Glass	8.4
Garden Waste	3.8
Ferrous Metal	8.0
Non-ferrous metal	1.0
Plastic Film	4.2
Dense Plastics	2.8

Moisture content = 33% by weight
Bulk density, uncompressed = 170 kg/m^3
Gross calorific value = 9,260 kJ/kg
Net calorific value = 7,630 Kj/Kg

The Energy Content of Municipal Solid Waste

The energy content of waste can be calculated by a number of techniques, including the modified Dulong equation which is based upon the percentage content of carbon (C), hydrogen (H), oxygen (O) and sulphur (S), and by the use of calorimetry. An equation based upon the percentage (by weight) of food waste, cardboard and paper, plastic, and rubber has also been developed (Khan and Abu-Ghararah, 1991). Using this method, derived values have been shown to be approximately 1-10% higher than values derived using the modified Dulong equation. (It is not necessary to go into the details of these calculation techniques, as it is their results that are of use in this unit). The energy stored within wastes can be utilised in a number of ways. The most common methods are energy from waste (EfW) incineration (with or without energy recovery) (see glossary), and the collection and combustion of landfill gas (in which case much of the stored energy is retained within the methane gas).

Average calorific value of components of MSW

Material	CV MJ/kg wet weight (moisture content 20-30%)
Dust and cinders	9.6
Paper	14.6
Vegetables	6.7
Metal	nil
Glass	nil
Rag	16.0
Plastic	37.0
Unclassified	17.6

Landfill Sites

For waste management, **the sustainable landfill** could be interpreted as "today's" waste to deal today and not passing it on, for future generations to deal with.

So, the achievement of the acceptable final storage quality has to be completed within 30 years, or in one generation, that is consistent with the 30 – year post – closure monitoring period of the European Landfill Directive and RCRA in the U.S.A.

That means that, waste must be either pre-treated to a state close to final storage quality, or the stabilisation within the landfill must be accelerated.
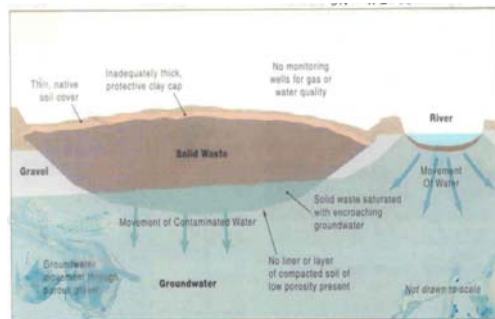
a) Old-Style Sanitary Landfill
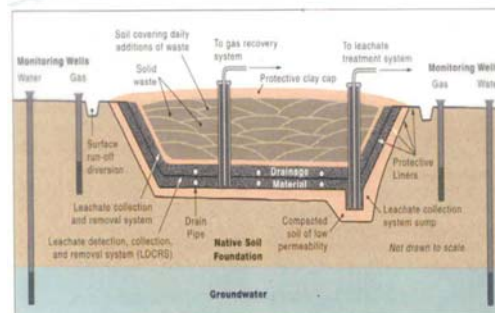
b) Modern Sanitary Landfill

The **biodegradable** elements of waste disposed to landfill are vegetable matter, paper and cardboard and to some extent, textiles. The composition of municipal refuse varies from country to country and will vary from season to season. In the developed world it typically contains about 60% carbohydrate, 2.5% protein and 6% lipid (see glossary), the balance being comprised of "inerts" (see glossary) and plastics. Carbohydrates therefore comprise approximately 85% of the **biodegradable** material within municipal refuse, the overall breakdown of which can be represented by the equation:

$$C6H1206 > CH4 + CO2 + Biomass + Heat$$

(Carbohydrate) (Methane) (Carbon dioxide) (Bacteria)

Methane gas is a high-energy fuel with approximately 90% of the energy stored in carbohydrate being retained in the methane. The conversion of carbohydrate to methane is therefore a highly energy efficient process, and much of the energy stored in the carbohydrate is contained within the methane gas. **Because of the high-energy value, the methane can be used beneficially as a heating fuel and for energy production.**

Figure 5: A schematic showing the main stages in the production of biogas
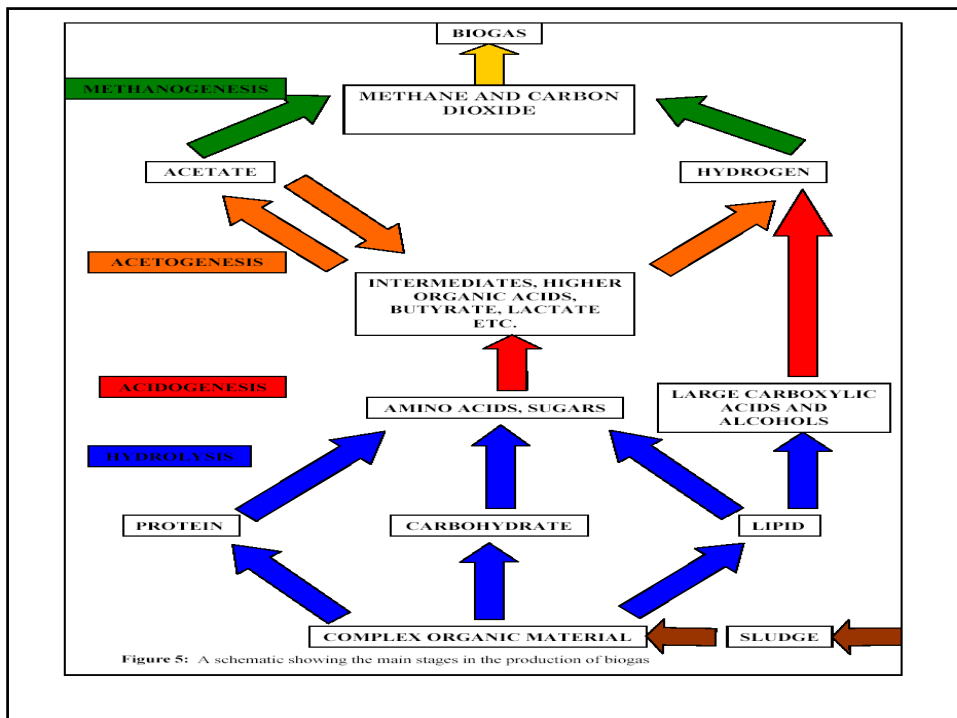
Typical composition of landfill gas

Component	Typical Value (% volume)	Observed Maximum (% volume)
Methane	63.8^1	88.0^2
Carbon Dioxide	33.6^1	89.3^1
Oxygen	0.16^1	$20.9^{1.3}$
Nitrogen	2.4^1	$87.0^{2.3}$
Hydrogen	0.05^4	21.1^1
Carbon Monoxide	0.001^4	0.09^2
Ethane	0.015^4	0.0139^2
Ethene	0.018^4	-
Acetaldehyde	0.005^4	-
Propane	0.002^4	0.0171^2
Butanes	0.003^4	0.023^1
Helium	0.00005^4	-
Higher Alkanes	$<0.05^2$	0.07^1
Unsaturated Hydrocarbon	0.009^1	0.048^1
Halogenated Compounds	0.00002^1	0.032^1
Hydrogen Sulphide	0.00002^1	35.0^1
Organosulphur Compounds	0.00001^1	0.028^1
Alcohols	0.00001^1	0.127^1
Others	0.00005^1	0.023^1

1   Data taken from Waste Management Paper No 26
2   Published data supplied by Aspinwall & Company
3   Entirely derived from the atmosphere
4   Taken from Guilani, A J "Application of conventional oil and gas drilling techniques to the production of gas from garbage" American Gas. Association Transmission Conference, Salt Lake City, Utah, 5-7 May 1980
5   Landfill gas is usually saturated with water vapour, up to 4% by weight, depending on the gas temperature. At 25°C a value of 1.8% by weight is typical
6   When undertaking initial confirmatory analysis by gas chromatography, the first five compounds listed above are usually identified when looking for the presence of landfill gas.
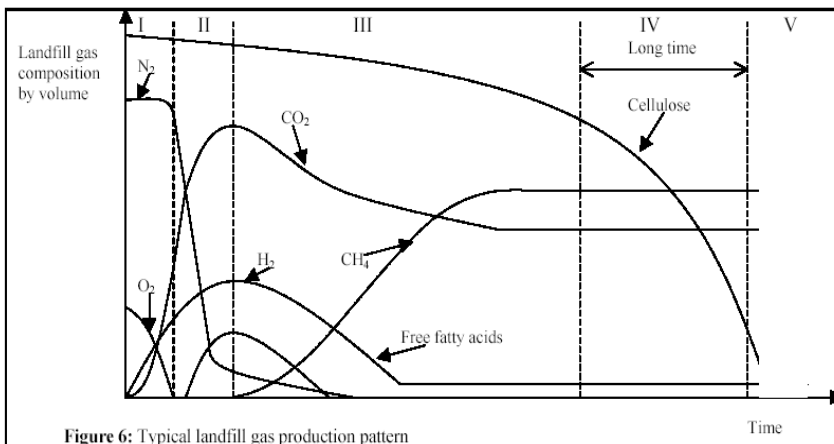
Figure 6: Typical landfill gas production pattern

Factors affecting gas and leachate production

- Water Content in the waste

  Wopt: 40-80%

  Wmini : 25%

  Wtypical: 30%

- Waste Particle Size and Density

  favorable : low packing densities

- Temperature

  low, middle, high

- Phoptim. : 6.8 – 7.7

Landfill Leachate

Leachate Composition and Properties

Landfill leachate is comprised of the soluble components of waste and the soluble intermediates and products of waste degradation which enter water as it percolates through the waste body.

The amount of leachate generated is dependent upon a number of factors which can be summarised as follows:
• water availability
• landfill surface conditions
• refuse state
• conditions in the surrounding strata

Measures of each of the above determine the water balance equation, a simplified version of which appears in the UK Department of Environment Waste Management Paper 26 (1986):

Lo = I - E - aW

where
Lo = Free Leachate retained at site (equivalent to leachate production - leachate leaving the
site)
I = Total liquid input
E = Evapotranspiration losses
a = Absorptive capacity of the waste
W = Weight of waste deposited
Good landfill practice normally requires that Lo is negative or zero and therefore that no excess leachate is produced
i.e.$I - E < aW$
A predicted unfavourable water balance (net liquid production) at the design stage would require the selection of an alternative site or the redesign of engineering and operational parameters in a way that would reduce the input (I) or increase the output (E) in the above equation, and thus reduce the amount of liquid arising within the landfill.
The factors affecting water availability include precipitation, surface run-off, groundwater intrusion, irrigation, liquid waste disposal and refuse decomposition. Surface run-off, groundwater intrusion and irrigation can be controlled through effective site design and operation.
Surface conditions that may affect leachate generation include vegetation, cover material (density, permeability, moisture content etc.), surface topography and local meteorological conditions.

Typical Composition of Leachates from Domestic Wastes at Various Stages of Decomposition (all figures in mg/1 except pH value)

Determined	Fresh Wastes	Aged Wastes	Wastes with high moisture contents
pH	6.2	7.5	8.0
COD	23800	1160	1500
BOD	11900	260	500
TOC	8000	465	450
Volatile acids (as C)	5688	5	12
NH_3-N	790	370	1000
NO_3-N	3	1	1.0
Ortho-P	0.73	1.4	1.0
CI	1315	2080	1390
Na	9601	300	1900
Mg	252	185	186
K	780	590	570
Ca	1820	250	158
Mn	27	2.1	0.05
Fe	540	23	2.0
Ni	0.6	0.1	0.2
Cu	0.12	0.03	-
Zn	21.5	0.4	0.5
Pb	0.40	0.14	

Source: Waste Management Paper 26A (DoE)

Leachate Migration

The importance of pollution prevention through hazard reduction and containment has already been emphasised. Once leachate escapes to the surrounding environment effective control is lost, as discussed previously and remediation can be too difficult, too expensive, or both for effective protection of sensitive receptors to be ensured. However, as part of a risk management process, it is important to understand the factors that control the fate of leachate upon escape. Our knowledge of hydraulics and attenuation factors is increasing, but because of the complex nature of the sub-surface region, accurate prediction of leachate fate is, in most circumstances, impossible.

Upon escape, landfill leachate will move into the surrounding environment in a way that will be determined by a range of factors, the most important of which will be the nature of the surrounding geology and hydrogeology. Escape to surface waters may be relatively easily controlled and the pollutant fate will vary according to the nature of the receiving waters. Escape to groundwater may be much more difficult to control and will almost certainly be more difficult to clean-up. In this case, the pollutant fate will be dependent upon a range of factors associated with the nature of the various phases of the sub-surface region.

Leachate Control

Use of landfill liners like:

- Natural Liners
- Geomembranes
- Liner Combination

Landfill Gas

➢**Components**
- methane : 50-60% (v/v)
- CO_2 : 30-40% (v/v)
- H_2, O_2, N_2 : small %
- Hydrogen sulphide (H_2S): low levels but can reach 35% (v/v)

➢ **Landfill Gas Migration**
- concentration gradient (diffusive flow)
- pressure gradient (viscous flow)

Diffusion = f $\left(\frac{1}{\sqrt{d}} \right)$

So, CH_4 migrates 1.65 times faster than CO_2
  Migration factors: environmental, climatic, geophysical

➢ **Control of Landfill Gas**
- Controlling waste inputs
- Controlling the processes within the waste (ex. Changing moisture)
- Controlling the migration process (reduce pressure, barriers etc)
  - **a. Passive Control**
    - **-** gas wells
    - - vent trenches
  - **b. Active Control**
    - - array of vertical and horizontal pipes and blower

Energy Production

In many circumstances, little more gas than 100m^3/t is collected, but the production is much more.

For effective utilisation in gas engines or turbines, the methane content of landfill gas should be approximately 50%. However, where gas collection is used primarily for the control of migration and the protection of `sensitive targets' then the methane content of the gas is often much less than 50% in order to maintain a flame at the gas flare. For this reason, **it is important to clearly identify at the outset whether the gas collection system is for gas control or energy generation**. Local site conditions may require the use of both types of system where, for instance, peripheral wells are used for gas migration control and central wells are used for collection with subsequent utilisation for electricity production. It is also possible for wells to be designed and built to accommodate both systems and to be switched from one to the other when the situation demands. In this case, the cost of such a system will be much higher than a simple system and this must be accounted for when calculating the **economic feasibility**.

The high moisture content of landfill gas and the presence of trace corrosive gases requires that the collected gas should be pre-treated before combustion in a gas engine.

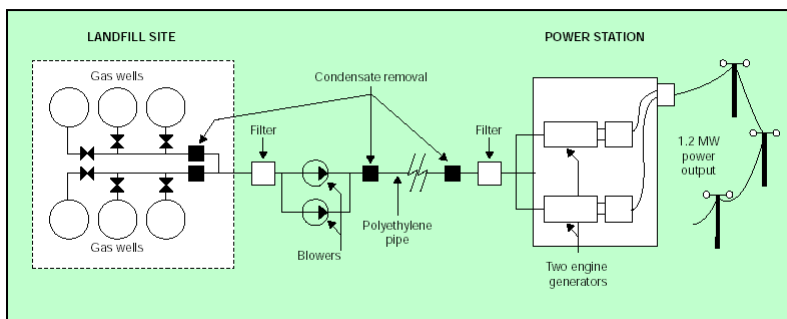No future of Landfill Gas because:

➢ limited Void Space

➢ E.Commission Landfill Directive

• biodegradables to landfill (75% in 5 years, 50% in 8 years, 35% in 15 years)

• gas collection on all sites is an obligation

• pre-treatment before land fill is an obligation

• packaging waste regulations

Schematic of the Landfill Gas Plant
Middleton Broom, U.K.
{Capacity of about 1,2 Mwe}

Economics

The total capital cost for the energy recovery project was approximately £1.1 million (1991 prices). This included the installation of the gas pipeline, electrical connection costs and all power generation and ancillary plant, but excluded the gas collection system as this was already in place. Operating costs, based on exported power and excluding the price of consumables such as oil etc, have amounted to around £0.014/kWh.

The Company receives £0.057/kWh for the exported electrical power.

The energy recovery project is owned by Broom Energy Ltd, a wholly owned subsidiary of Combined Landfill Projects Ltd.
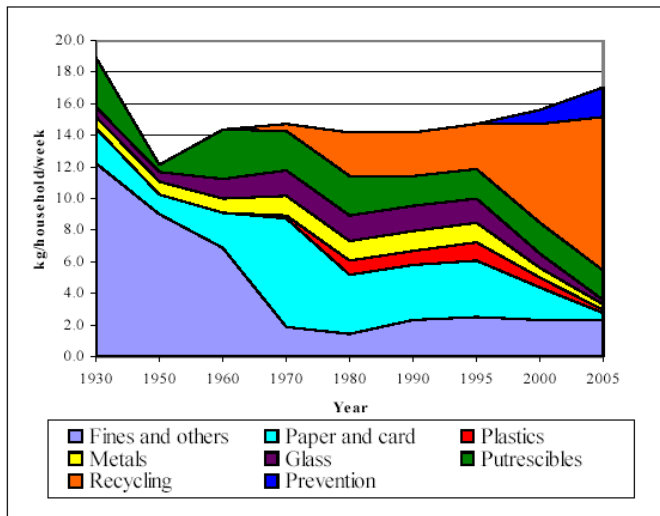
Waste - Incineration

The recovery of energy from municipal solid waste (MSW) falls within the category of renewable energy and has received increasing attention in recent years. This has been strongly influenced by a drive to reduce the burning of fossil fuels, thereby reducing the release of pollutants such as gaseous nitrogen and sulphur oxides (NOx and SOx). Russotto, (1996) has calculated that if all combustible waste were incinerated, it could provide as much as 5% of western Europe's domestic energy needs.

ETSU has calculated that electricity-only schemes will reduce fossil carbon emissions by 29% c.f. 78% for CHP schemes.

The combustion of waste as a fuel is seen by many as a preferable alternative to landfill,

where appropriate, and has received much support as a waste treatment option. However, according to Wallis and Watson (1995), recycling materials saves 2-5 times the amount of energy recoverable by combustion. They cite (anon., 1992) that even plastics recycling to materials is several times more advantageous than recycling to energy. However recycling is not always feasible (e.g. for reasons of material contamination, or because of the lack of markets), and there is significant potential for further development of incineration as a major waste management option.

Past and possible future changes in amount and composition of UK domestic waste

Legend: Fines and others, Paper and card, Plastics, Metals, Glass, Putrescibles, Recycling, Prevention

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Looking for the Best Practicable Environmental Option (BPEO)

BPEO is:

"the outcome of a systematic consultative and decision making procedure which emphasises the protection of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefit or least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term".

Recycling scenarios
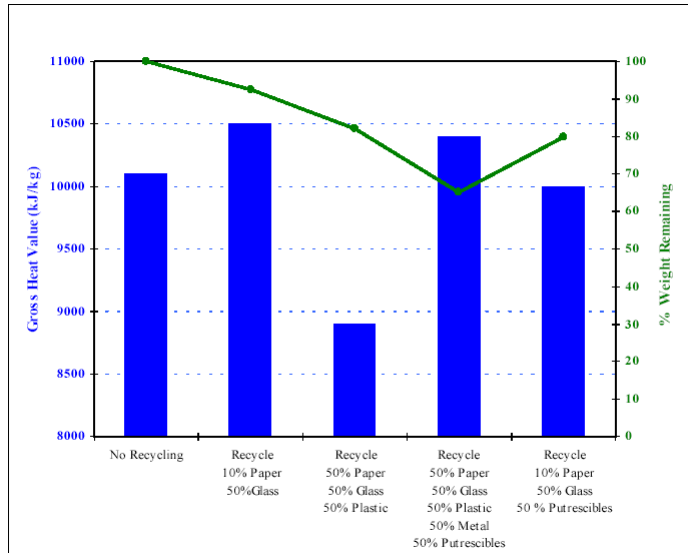
The reasons for the interest in incineration include

Shortage of landfill space

- Many governments give targets to the waste disposal authorities for the recovery of energy from municipal waste.
  European Union support for renewable energy.
- Willingness of relevant authorities to award long-term (25 years) waste disposal contracts
- Establishment of large international waste management companies within Europe Contributed to the sustainable development
- Better emissions control and incinerator design in our days

On the other hand

"Energy recovery from waste offers important advantages. It is likely that a substantial proportion of wastes will always require disposal, because recycling them is technically impossible or financially unrewarding. The coupling of energy recovery with disposal helps reduce emissions of greenhouse gases, not only in comparison to waste incineration without energy recovery but also in comparison to landfill with energy recovery. There can be a beneficial impact on pollution abatement systems. Last but not least, income from the sale of electricity (and where feasible, heat) helps close any gap between the cost of waste incineration and the cost of landfill. We believe that these advantages can be obtained without breaching emission standards".

Comparison of household waste management in different European countries [1]Incluedes composting [2] Primarily with energy recovery
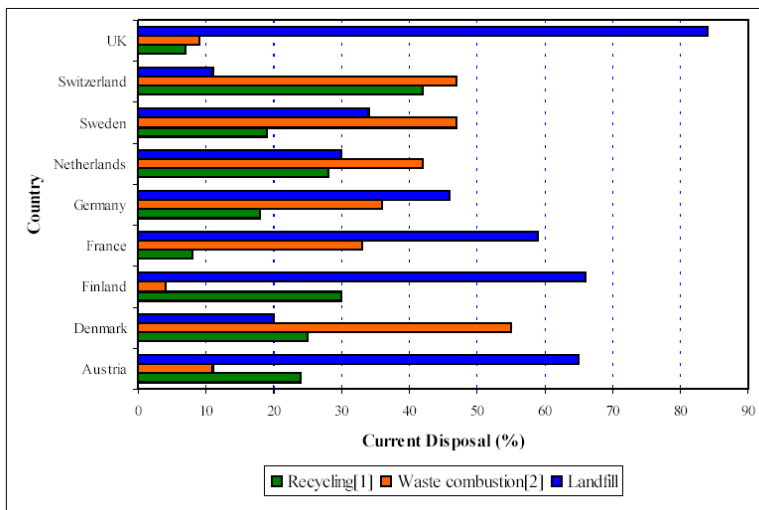
The European Energy from Waste Coalition (EEWC) says that "energy from waste should be positioned to the public as a natural complement to the other recovery options: reduction, re-use and recycling with a number of important benefits.

Energy from waste:
• Provides an alternative energy source saving finite resources by replacing fossil fuels (every 3 tonnes of MSW burned saves 1 tonne of coal)
• Extracts value as energy from materials that are not recyclable
• Sterilises waste enabling safe disposal of residues
• Offers an efficient and cost-effective method of recovering materials such as metals for recycling
• Destroys contaminants and pollutants in waste allowing for more easily controlled monitoring and measuring of these products

Reduces the volume of waste by 90% and the weight by 70% saving landfill space and transport costs.

European countries' policies regarding landfill

Country	Policy regarding landfill
Switzerland	Combustible waste to landfill banned from 2000
Finland	Policy to increase combustion and reduce landfill
Netherlands	Combustible waste to landfill already banned
Denmark	Ban on combustible waste to landfill being implemented
Austria	Combustible waste to landfill banned from 2004
Sweden	Policy to increase combustion and recycling
Germany	Combustible waste to landfill banned from 2004
France	Combustible waste to landfill banned from 2002, expect combustion to rise to 57% and recycling to 23%
UK	Recycling target 25% and recovery target of 40%. New waste strategy under preparation.

Refuse – Derived (RDF)

RDF is made by refining municipal solid waste in a series of mechanical sorting and shredding stages to separate the combustible portion of the waste. Either a loose fuel, known as fluff, floc or coarse RDF (c-RDF), or a densified pellet or briquette (d-RDF) is produced (Anon., 1993). Early development of the process occurred in the UK and Italy where there are a number of RDF plants. Other plants are used throughout Europe (including Germany, the Netherlands and Switzerland), and in the USA. As a general rule d-RDF is easier to handle, store, and transport, although c-RDF requires less refining and processing and can avoid the need for drying the product (a potential source of odour). The costs associated with c-RDF are reduced correspondingly. As with other incineration processes, the ash product must be disposed elsewhere (often to landfill) and cannot operate independently of other waste management facilities. Furthermore, a large percentage of input waste may be rejected [e.g. around 60% of input material at Byker RDF plant, Newcastle, UK is rejected (Anon., 1993) and will also require alternative means of disposal. RDF has not enjoyed a great deal of success within the UK and a number of plants have closed. However, Fibre Fuel Ltd is an example of a recent success in this field, while an RDF incinerator still operates on the Isle of Wight.

Typical % by weight MSW Composition

Dust and cinders 9.0%
Unclassified 4.7%
Plastics 11.0%
Glass 8.0%
Textiles 4.5%
Metals 7.8%
Vegetable matter 24.0%
Paper and cardboard 31.0%
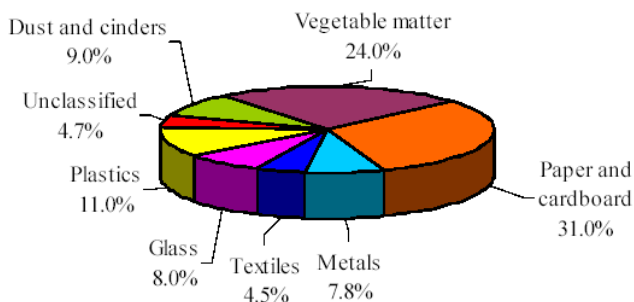
Ultimate analysis and gross calorific value of MSW
(From Porteous, 1997)

Material	% by weight
Carbon	24
Hydrogen	3.2
Oxygen	15.9
Nitrogen	0.7
Sulphur	0.1
Water	31.2
Chlorine	0.7
Ash and inerts	24.2

Properties of MSW (Source: Porteous 1997)

CV	10,600 MJ/kg
Moisture	31.2% w/w
Combustibles	44.6%
Inerts	24.2%

MSW has a calorific value of 10,600MJ/Kg (table 6) which is approximately 1/3 that of industrial coal.

One ton of municipal waste is equivalent to:
• 2.5t steam (400oC, 40 Bar)
• 30t hot water
• 200kg oil
• 500kWh electricity

(Source: Porteous 1997)

Combustion Considerations

Incineration is a thermal oxidation process in which carbon is oxidised to carbon dioxide and hydrogen is oxidised to water:

$C + O_2 = CO_2$

$2H + \frac{1}{2} O_2 = H_2O$
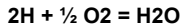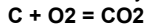
The Relative atomic mass (RAM) of each of the elements involved is shown in table

The relative atomic masses of carbon, oxygen and hydrogen

Element	RAM
Carbon	12
Oxygen	16
Hydrogen	1

This means that 12g of carbon require 32g of oxygen and produces 44g CO_2. Therefore 1g of carbon requires 2.67g (=32/12g) of oxygen and produces 3.67g (44/12g) of CO_2.

Also, 1g of hydrogen requires 8g of oxygen to produce 9g H_2O

From the ultimate analysis (table) MSW contains 24% carbon and 3.2% hydrogen by weight i.e. 1g of MSW will contain 0.24g of carbon and 0.032g hydrogen.

0.24g carbon requires 0.24 x 2.67g = 0.641g oxygen

0.032g hydrogen requires 0.032 x 8g = 0.256g oxygen.

But there is 0.159g oxygen already present (from the ultimate analysis in table 5) and hence the amount of oxygen required to complete combustion = (total required)-(oxygen already present) = (0.641g + 0.256g) - 0.159g = 0.738g (per g MSW).

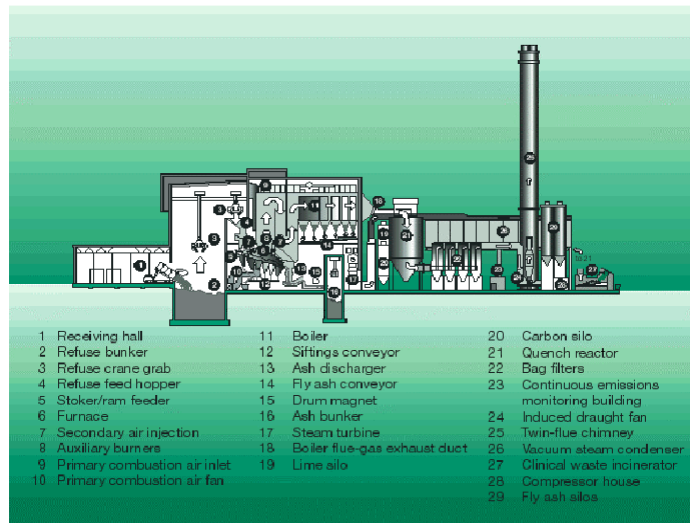Now air comprises 23.15% oxygen and 76.85% nitrogen by weight and hence the air equivalent to 0.738g O_2 is 3.21g. So 3.21g air is required to burn 1g MSW.

From Porteous (1997): if we assume 100% excess air (i.e. twice as much air present as is needed) then 6.4g air will be required to burn 1g MSW and therefore the total input will be 7.4g material. The output from the combustion of MSW is shown in Table

Outputs from MSW combustion (from Porteous 1997)

Material	Mass (g)
CO2	0.881
H2O	0.288
O2	0.738
N2	4.9
HCl	0.007
Ash residue	0.242
Water vapour (from MSW)	0.312
Total output (rounded off) = 7.4	

A typical schematic of a modern EfW plant (After CADDET –
see http://www.caddet-re.org/)

1 Receiving hall
2 Refuse bunker
3 Refuse crane grab
4 Refuse feed hopper
5 Stoker/ram feeder
6 Furnace
7 Secondary air injection
8 Auxiliary burners
9 Primary combustion air inlet
10 Primary combustion air fan
11 Boiler
12 Siftings conveyor
13 Ash discharger
14 Fly ash conveyor
15 Drum magnet
16 Ash bunker
17 Steam turbine
18 Boiler flue-gas exhaust duct
19 Lime silo
20 Carbon silo
21 Quench reactor
22 Bag filters
23 Continuous emissions monitoring building
24 Induced draught fan
25 Twin-flue chimney
26 Vacuum steam condenser
27 Clinical waste incinerator
28 Compressor house
29 Fly ash silos

Rotary Kilns

These are the most flexible type of design and can treat a range of different materials, but are not generally favoured for the combustion of MSW, where moving grate or fluidised beds are often preferred. The rotary kiln action ensures agitation and mixing of wastes and exposure to air (oxygen), ensuring optimal burnout of wastes. The speed of rotation of the kiln can be controlled and this also facilitates control over the burning process by adjusting the waste retention time within the kiln. However, this agitation can also increase the carryover of particulates beyond the kiln. This can be controlled to some extent through use of a reducing atmosphere, lower gas velocities and controlled flow direction. For most waste applications an ashing kiln is used (c.f. slagging kiln) which operates at lower temperatures and does not produce a molten slag. In some circumstances sand soda ash and glass can be added to help protect the refractory lining from damage by large objects.

Other incinerators are: Fixed, Hearth and Multiple Hearth, Fluidised Bed

Comparison of Mass burn and Fluidised bed incineration

Factors to be compared	Fluidised bed incinerator	Mass burn incinerator
Moving parts	No	Yes
Single stream capacity	>350t/d	>1200t/d
Combustion:		
Mixing	Turbulent	Mild agitation
Rate	Rapid	Slow
Completeness	Complete	Often incomplete
Air ratio	1.5 − 2.0	1.8 − 2.5
Load	400 − 600kg/m2h	200 − 250kg/m2h
Fuel size	200mm	300mm
Combustion residue		
Unburnt carbon	0.1% w/w	3 − 5% w/w
Volume	smaller	larger
State	dry	wet
Putrescibles	none	yes
Iron recovery	easy	difficult
Fly ash		
Volume	Larger	Smaller
unburnt	>1%w/w	3 − 7% w/w
Flue gas		
Volume	Smaller	Larger
NOx	Air ratio control	Added chemicals
Operation		
Stop	Few minutes (no unburnt fuel)	Few hours (unburnt fuel remains)
Restart after		
8h	5min	1h
w/end	30 min	2h
Ash disposal		
Ash quality	Dry and "clean"; traces of unburnt material	Wet with contaminants
Final disposal	Less volume, less secondary pollution	Larger volume, greater potential for secondary pollution
Waste composition	Any high CV waste	Plastics can cause problems

Steam Raising

The heterogeneous nature of MSW means that heat conversion is not as efficient as with mono-fuels, but nevertheless achieves 80% efficiency (85% with fluidised bed boilers) in the conversion from fuel to steam. When converting waste energy to steam, one of the major factors that affect the efficiency of conversion is the temperature and pressure of the steam at which it enters the boiler tubes. For MSW the presence of chlorine in the hot gas and its corrosion potential limit gas conditions to approx. 40 bar and 400°C. The overall thermal efficiency of EfW is approx. 22-25% for electricity only c.f. 40% for coal-fired power stations and 12 – 15% for nuclear power stations (Porteous, 1997). However, when used for supply of district heating as well as electricity, the thermal efficiency increases to 60 – 80% (Porteous, 1997).

Emission Controls

Comparison of gaseous emission standards and typical design emission levels

	EfW requirements under IPR 5/3	European Hazardous waste Directive	Typical design emission levels	Nottingham CHP incinerator (dry absorption system) - guaranteed	Nottingham CHP incinerator (dry absorption system) - measured
Particulates (mg/Nm^3)	30	10	10 - 15	10	0.9
HCl (mg/Nm^3)	30	10	10	30	20
HF (mg/Nm^3)	2	1	1	2	<0.1
SO2 (mg/Nm^3)	300	50	70	100	36
Nox (mg/Nm^3)	350		250 – 300	450	274
THC (VOC) (mg/Nm^3)	20	10	10	20	<5
Dioxins (ng/Nm^3)	1	0.1	0.1 – 0.5	1	0.006
Dioxins (ng/Nm^3) - target	0.1		-		
CO (mg/Nm^3)	100	50	50	100	5
Metals (mg/Nm^3)	1 (As, Cr, Cu, Pb, Mn, Ni, Sn) 0.1 (Cd, As)	0.5	0.5 (As, Ni, Pb, Cr, Mn, Cu)	1	<0.1
Cadmium	0.05				
Mercury	0.05				

Dioxins

Of these the emissions which are seen by many as being of greatest concern are the dioxins for which emission limits have been set at 1.0 nanogram TEQ.m-3. New plants often achieve the target value of 0.1 nanograms per cubic metre (equivalent to ¼ standard sugar lump dissolved in Loch Ness - volume 7,000,000,000 cubic metres (Porteous, 1997).

Dioxins comprise a family of more than 2000 chlorinated organic compounds, which are structurally very similar. "Dioxin" is generally used to refer to a group of compounds made up of 75 isomers of poly-chlorinated dibenzo-p-dioxins and 135 poly-chlorinateddibenzo furans (PCDD's and PCDF's). These compounds can be toxic to animal species, the most toxic being 2,3,7,8 tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD). (2,3,7,8-TCDD) was the dioxin present in agent orange (a defoliant used in the Vietnamese war) and was the major toxic chemical in the Seveso disaster in Italy in 1976. The amount of any particular dioxin is expressed in terms of equivalents of TCDD and is referred to as the toxic equivalent (TEQ).

Although dioxins are destroyed during the incineration process, they can reform during cooling of the hot gases. This generally occurs in the temperature range 200-400oC. Older incinerators exercised little control over dioxin emissions, but new incinerators must meet very strict limits for emission of dioxins to atmosphere and according to Porteous (1997) incinerators are net dioxin destroyers. (Table). Figure 7 shows the UK emissions of dioxins to the atmosphere.

Fate of dioxins in EfW plant (from Porteous, 1997)
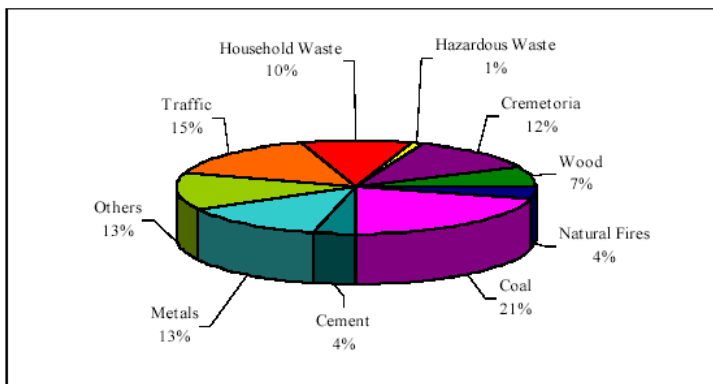
	Old Plant	New Plant
Waste in ug/kg	100	100
Bottom ash	<10	<10
Boiler residue	32	<3
Gas cleaning	800	<20
Flue gas	100	<1

UK emissions of dioxins to the atmosphere.
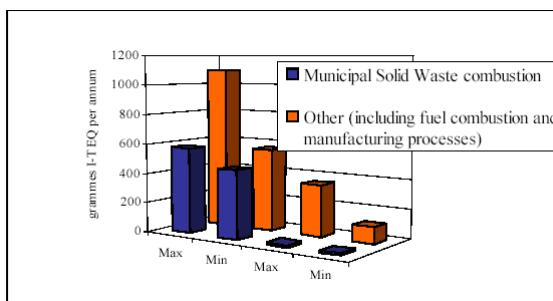
Sources of dioxins

Dioxins in household waste samples

Laboratory and sample	England	Wales	Scotland
1(1)	2.16 – 3.81	5.42 – 6.50	1.05 – 2.88
1 (2)	-	-	3.72 – 5.05
2 (1)	1.33 – 3.11	5.96 – 7.05	4.07 – 5.55
2 (2)	20.3 – 21.0	4.66 – 5.96	-
2 (3)	1.59 – 3.37	-	-
3 (1)	2.29 – 3.87	5.96 – 8.67	0.49 – 4.49

The work on residues included a modern European mass burn grate plant fitted with a semi-dry scrubbing system and bag filter. The plant had been designed to meet the requirements of the EU directive on municipal waste incineration (89/369/EEC). Dioxin levels in bottom ash were between 7.5 – 28 ng/kg and the abatement plant residue had dioxin levels of 810 – 1821 ng/kg (*see Tabl*).

Dioxin levels

Laboratory and sample	Bottom ash	Aged bottom ash	APC residue
1 (1)	11 – 12	11 – 12	810
1 (2)	-	-	810
1 (3)	-	-	840
3 (1)	27	18 - 21	1700
3 (2)	-	-	1700
3 (3)	-	-	1800
4 (1)	25	-	1478
4 (2)	27	-	1821

Dioxin Removal

Environment Agency controls over MSW incineration processes require that combustion conditions of >850oC be maintained for at least 2 seconds in at least 6% oxygen. Such conditions, together with rapid cooling in the range from 800oC to 100oC and the use of fabric filters can reduce the levels of dioxins to much below the required levels. Further use of activated carbon in the gas stream (as a dioxin adsorbent) can reduce these levels even further.

Controls such as these have greatly reduced emissions of dioxins from incinerators and measurements in the USA (Travis and Blaylock, 1994) have shown that emissions from MSW incinerators at the national level account for less than 1% of total current input to the environment. In Sweden, Rappe (1991) has said that spontaneous fires in rubbish tips emit much more dioxin than controlled burning in incineration plants.

Gas Clean-Up

1. Wet Systems

Slaked lime or sodium hydroxide in **solution** are used to neutralise and precipitate acid gases such as HCl, SO2 and HF. The mixing of gases and alkaline reagents occurs in a range of reactors including venturi scrubbers and packed absorption towers. The rapid cooling of hot gases in an alkaline quench reduces the *de novo* formation of dioxins and furans as well as removing large particulate matter and acid gases.

Advantages:

• Captures condensed metals

• High degree of removal of acid gases

Disadvantages:

• Equipment intensive

• Requires effluent treatment

• Plume reheat necessary

• Running costs higher than dry or semi-dry systems

2. Dry Systems

In such systems the reagent (slaked lime) (Ca (OH)2/(limestone) is either mixed with the waste, introduced separately into the furnace, or is injected into the gas stream which then passes through a tortuous route within a reactor tower to ensure efficient reaction. The neutralised particulates and excess reagent are trapped on baghouse filters (See below).

Advantages:
• Little equipment needed/low cost
• No reheat necessary
• No effluent treatment required

Disadvantages:
• Degree of acid gas removal may be low compared to semi-dry or wet systems
• High limestone demand
• The reaction product is mixed with the ash (can cause problems upon landfill)

3. Semi-dry Systems

These are similar to dry systems but uses a slurry made of limestone (CaO) mixed with water and slaked lime (Ca(OH) 2 which is sprayed into the flue gas flow. The slurry is injected as a finely atomised spray into the top of a tall (15 – 25 metres) vertical reactor vessel, known as a spray dryer absorber. The acid gases adsorb onto the slurry and are neutralised through reaction. At the same time, the gases are cooled and a dry solid is formed. The residence time in the reactor vessel is typically 10 to 15 seconds and requires a slow gas velocity (1.5m/s) for this to be achieved. The dried reacted particulates are collected in the same way as dry systems using baghouse filters.

The semi-dry systems are more efficient at removal of SO2 than dry systems, and otherwise perform in similar way to dry systems towards other acid gases.

Advantages:
• Reheating not necessary
• Greatest degree of acid gas removal
• No waste water

Disadvantages
• Additional equipment required
• Reaction product not directly re-usable
• Lime surplus required

4. Electrostatic Precipitators

The electrostatic precipitator is essentially a large earthed tank through which gases from the scrubber can move at relatively low velocity. Inside, vertical wires are connected to a DC supply and the electric field created causes particles passing through to be electrostatically charged. These are then attracted to the wires to which they adhere. They are not normally as efficient as bag filters for removing fine particles. These gas control systems were, until relatively recently, the most widely used in the UK. However, tightening controls have forced a move towards the more effective bag filters (below).

5.   Bag Filters

Dry filtration systems normally comprise filters separated into banks so that one may be cleaned while another is operational. Each bank contains many filter elements made up of long cylindrical filter bags supported on a cage. The bags can be many metres in length and approximately 10 – 20 cm diameter. The exhaust gases flow into the inside of the cylinder, trapping any particulates on the woven filter fabric. An induced draught fan "pulls" the cleaned gases from the baghouse. As the amount of particulate matter collected on the inside of the bag increases, so the pore size decreases and finer particulates become trapped. Eventually, the pressure drop across the filter becomes such that the particulates must be removed. This is done after directing waste gases to another bank and using air jets to loosen the caked particulates, which fall to the base of the filter housing from where they are removed.

Solid Wastes

Combustion of 1 tonne of MSW with above composition produces 270 kg ash (230 kg grate ash and 40kg flyash from gas cleaning) i.e. a mass reduction of 73% (volume reduction of approx 90%). In the UK this ash is currently sent to landfill but elsewhere is used for construction and road making (e.g. in USA Netherlands and France). In the UK the use of bottom ash has been investigated by WRC (Blakey, 1996).

There are essentially two types of ash; bottom ash discharged from the grate and fly ash from the bag filters (plus air pollution control (APC) residues. The bottom ash usually amounts to 25% by weight of input MSW from which ferrous metal is recovered by a magnetic extractor. The fly ash (4%w/w input MSW) can contain fine particles, alkaline salts from gas clean up, other soluble salts, and volatile trace metals. The importance of these in relation to dioxin levels in the environment is shown in Table 8 (above).

New developments in ash management are further reducing the environmental impact of EfW incineration. In Cleveland, a new plant will process approximately 70,000 tonnes per year of bottom ash. 60,000 tonnes will be processed into aggregates for use in masonry blocks, cement-bound products and asphalt for use in road building and other construction products, with the remaining10,000 tonnes being made up of scrap metal (ferrous and nonferrous which is recycled).

Municipal solid waste incinerators (MSWIs) produce on average (per tonne MSW):

- 225kg bottom ash

- 23kg ferrous metals

- 20kg fly ash from the flue gas cleaning equipment

- 1kg non-ferrous metals (mainly copper and aluminium)

- 15kg air pollution control (APC) residues

Fly Ash

Fly ash is designated under Dutch law to be a hazardous waste, although its use as a filler replacing part of the lime in asphalt (the current route for around 20 per cent of fly ash in The Netherlands) is acceptable. This is because bitumen encapsulates the fly ash particles, and because fly ash constitutes only a small component of the asphalt. Novem believes that fly ash can be used as an additive to concrete. From 1998, untreated MSWI fly ash will be banned from landfills.

Novem has view on the two main fly ash treatment systems:

Cold solidification, fixation of heavy metals to reduce leachability at temperatures below 200°C. This would promote the disposal status of the material from C2 to C3 landfills (see box). Additionally, washing to remove soluble salts (such as chlorides and bromides) would also improve quality;

Thermal treatment process such as sintering are held to offer insufficient improvements in fly ash quality. Novem notes that the high temperatures required (greater than 1300°C) consume a great deal of expensive energy from fossil fuels.

The UK's newest EfW plant
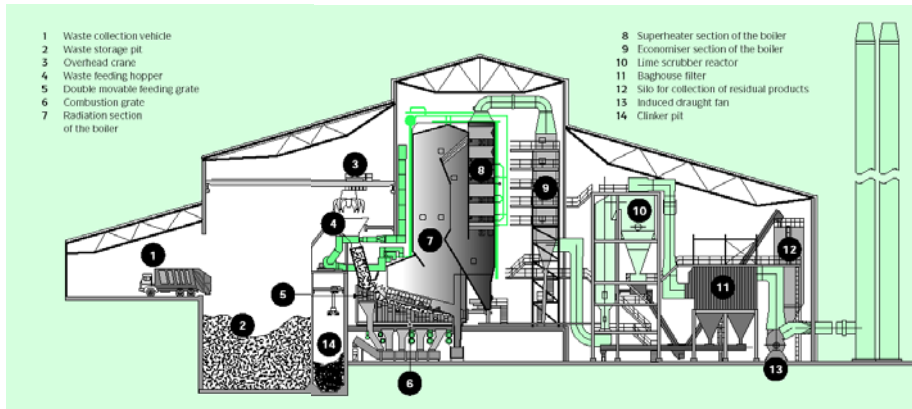
by the CADDET UK National Team

Built at a cost of £40 million, one of the latest in the new generation of energy-from-waste (EfW) plants in the UK is now up and running at Teesside in north-east England.

Characteristics

➢ Power capacity : 20 Mwe

➢ Waste capacity : > 180.000 t/year

➢ Bottom ash : 65.000 t/year

➢ Two incinerators with 16 t/h each

➢ Boiler to 400 °C

➢ Waste reduction 90% in volume with ash and clinker as by-products

➢ Cost of the EfW plant : £40 million

➢ Gas cleaning techniques include:

- acid neutralization with lime treatment

- dioxin elimination with activated carbon

- removal of large particulates with bag filters

Schematic of the Teeside plant

1 Waste collection vehicle
2 Waste storage pit
3 Overhead crane
4 Waste feeding hopper
5 Double movable feeding grate
6 Combustion grate
7 Radiation section of the boiler

8 Superheater section of the boiler
9 Economiser section of the boiler
10 Lime scrubber reactor
11 Baghouse filter
12 Silo for collection of residual products
13 Induced draught fan
14 Clinker pit

Other M.S.W Management Options

- **Recycling and Treatment for Levulinic Acid and other Chemicals production**
- **Recycling and Composting**
- **Plasmolysis**