Pyrolysis and Gasification Appendices

Appendix A: syngas cleaning

The purpose of syngas cleaning is to remove as far as possible all solid and gaseous contaminant matter

- that conflicts with the purposes to which it is desired to put the syngas. The contaminant matter may interfere with subsequent chemical conversion processes and / or it may damage the equipment using or converting the syngas.
- that contributes to toxic emissions when the syngas is combusted.

Syngas cleaning techniques include evolving high technologies, most of which are beyond the scope of this briefing, and which, at their most effective, are geared towards removing contaminants from syngas destined for fuel cells, chemical conversion or gas turbines.

If the syngas is to be combusted in a steam boiler, syngas cleaning may be considered unnecessary (ie if the boiler is considered able to withstand the effects of the contaminants) but, if cleaning is omitted, the level of post combustion emissions requiring capture will be greater.

The acceptable constituents of syngas are H_2, CO, and, to a lesser degree, CO_2 and CH_4.

The principle contaminants in syngas, as it leaves the gasifier, are

- soot and ash,
- tars (particularly if the gasification temperature is relatively low)
- H_2S (hydrogen sulphide) depending on the sulphur content of the feed,

And trace quantities of

- NH_3 (ammonia)
- COS (carbonyl sulphide)
- HCl (hydogen chloride)
- HCN (hydrogen cyanide)
- Heavy metals

If the gasification process has been fed with air, as opposed to pure oxygen, there will also be nitrogen present with the syngas.

In summary, a complete cleaning package will include filtration, chemical and catalytic solutions, and temperature and pressure will be critical in some cases.

Such packages will be extremely costly and it is unlikely that the operators of waste gasifiers will wish to include one, relying rather on post combustion capture of toxic emissions.

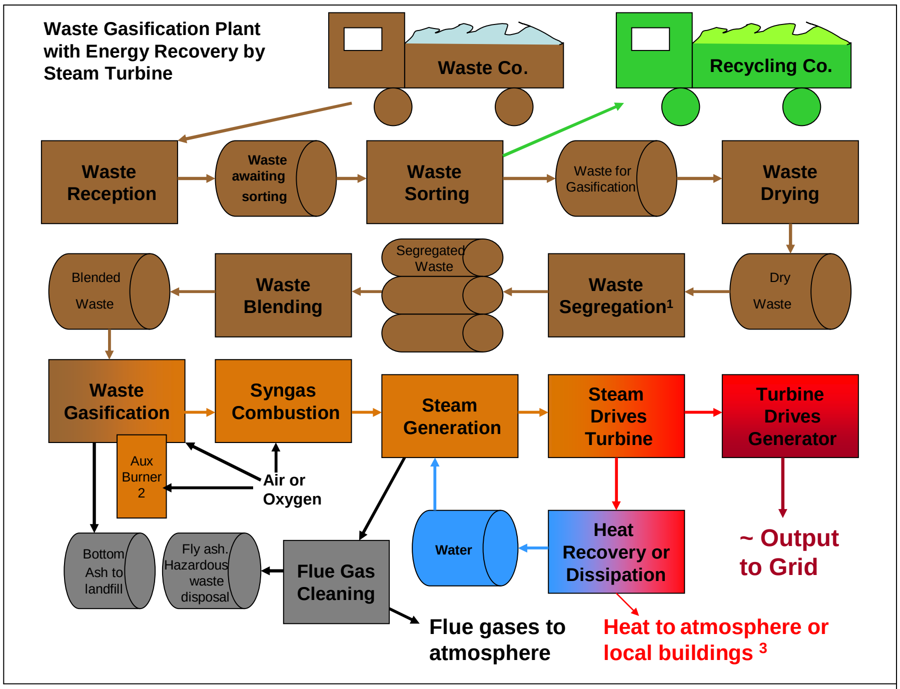
Dioxins will be reduced but not eliminated by syngas cleaning. They are formed within a specific temperature range, in the presence of chlorine and are best minimised by, within the gasifier – combustion – stack cycle, avoiding, as far as practical, that temperature range. They are destroyed by higher temperatures, but can reform once the temperature drops.

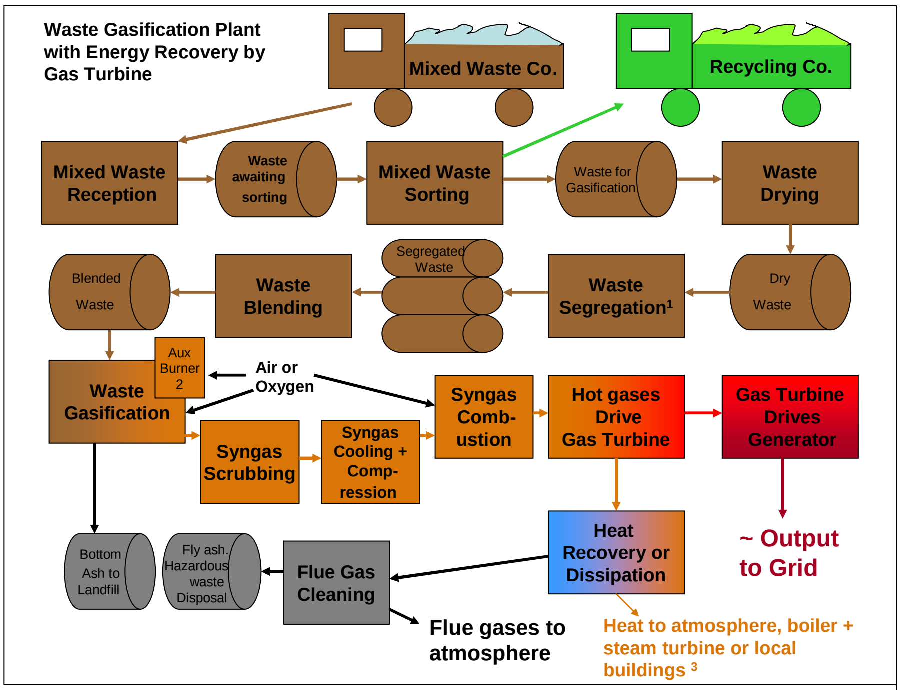
Section 10 of the briefing includes links accessing details of syngas cleaning technologies.

Appendix B: Typical Gasification and Pyrolysis Plant Layouts

The following schematic diagrams show the flow processes for a waste gasification plant with energy recovery a) via a steam turbine and b) via a gas turbine. (See note[4] below)

Gasification plants:





(Appendix B continued)

Notes:

[1] Waste grading is necessary in order to separate waste materials with different calorific values.
[2] This is the burner required for when starting the gasifier and bringing it to the operating temperature or otherwise to ensure that the correct syngas combustion temperature is maintained.
[3] Because, typically, the steam turbine will absorb only about 20% of the energy heat once the syngas has been combusted, whilst a gas turbine may absorb some 30%. In any case, some 70% of the heat energy from the syngas will be available either to:

- provide heat to neighbouring buildings, commercial or residential
- (in the case of a gas turbine) provide steam to feed a steam turbine, coupled to a generator after it has powered the gas turbine.

Or, as will usually be the case with waste gasification,

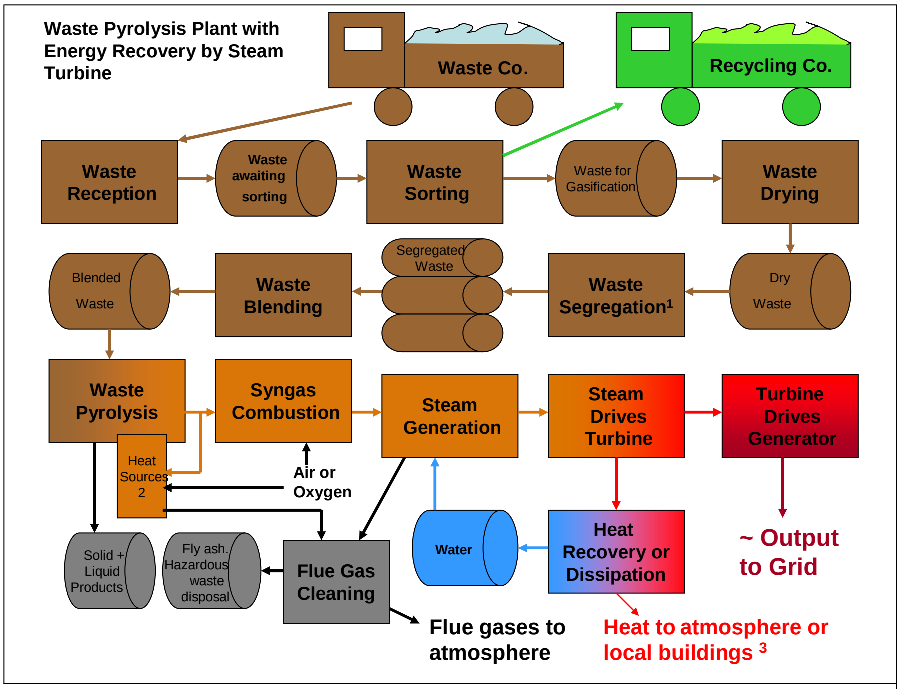
- be dissipated to atmosphere.

[4] The detailed designs of gasification plants vary greatly depending on the supplier as well as on the fuel and the objectives.

These variations relate to the feedstock flow arrangements, the gasifier itself (in which gasification takes place) and the gas cleaning arrangements.

See **section 10** for links to the layouts of gasification plants currently awaiting planning consent.

Pyrolysis Plants



(Appendix B continued)

The Pyrolysis schematic diagram differs from those for gasification because (note [2] on the diagram) the waste material, rather than being partially combusted as in gasification, is heated, in the absence of air, by an external heat source which, other than for starting purposes, will normally be supplied by the syngas from the pyrolysis process. The diversion for this purpose of a proportion of the syngas means that the quantity of syngas available for power generation, or other purposes, will generally, and for a similar waste input, be lower than for gasification.

See **section 10** for a link to details of the Mitcham EPi plant.

[1] As for gasification, [3] As for gasification.

Types of gasifier extracted from:

http://www.oregon.gov/ENERGY/RENEW/Biomass/bioenergy.shtml

There are three principal types of gasifier: updraft, downdraft and fluidized-bed. In an updraft (or "counterflow") gasifier, the biomass fuel enters the top of the reaction chamber while steam and air (or oxygen) enter from below a grate. The fuel flows downward, and upflowing hot gases pyrolyze it. Some of the resulting charcoal residue falls to the grate, where it burns, producing heat and giving off carbon dioxide (CO2) and water vapour (H2O). The CO2 and H2O react with other charcoal particles, producing carbon monoxide (CO) and hydrogen (H2) gases. The gases exit from the top of the chamber. Ashes fall through the grate.

The updraft design is relatively simple and can handle biomass fuels with high ash and moisture content. However, the producer gas contains 10% to 20 %t volatile oils (tar), making the gas unsuitable for use in engines or gas turbines.

Successful operation of a downdraft (or "co-flow") gasifier requires drying the biomass fuel to a moisture content of less than 20%. Fuel and air (or oxygen) enter the top of the reaction chamber. Downflowing fuel particles ignite, burning intensely and leaving a charcoal residue. The charcoal (which is about 5 to 15% of the original fuel mass) then reacts with the combustion gases, producing CO and H2 gases. These gases flow down and exit from the chamber below a grate. The producer gas leaving the gasifier is at a high temperature (around 700°C). Combustion ash falls through the grate. The advantage of the downdraft design is the very low tar content of the producer gas.

A fluidized-bed gasifier typically contains a bed of inert granular particles (usually silica or ceramic). Biomass fuel, reduced to particle size, enters at the bottom of the gasification chamber. A high velocity flow of air from below forces the fuel upward through the bed of heated particles. The heated bed is at a temperature sufficient to partially burn and gasify the fuel. The processes of pyrolysis and char conversion occur throughout the bed. Although fluidized-bed gasifiers can handle a wider range of biomass fuels, the fuel particles must be less than 10 centimetres in length and must have no more than 65-percent moisture content. The fluidized-bed design produces a gas with low tar content but a higher level of particulate compared with fixed-bed designs.

Appendix C: Fuel cells

Syngas can, in addition to being burnt to provide heat for a boiler or fed to a gas engine or gas turbine, be used in either a hydrogen fuel cell to generate energy. In Eunomia‟s study, scenarios involving hydrogen fuel cell technologies (export of syngas for conversion to H2 for use in vehicles and plastics reprocessing) performed better than CHP, in terms of their greenhouse gas impact. This is because of greater conversion efficiencies of fuel cells when compared to other energy generation technologies.
Although this suggests that there is potential for fuel cells to generate energy from hydrogen converted from syngas, in reality very little research has been carried out on the use of syngas derived from municipal solid waste in hydrogen applications and they are presently unlikely to attract commercial finance, not least because fuel cells are very costly.
Given the current uncertainties about this technology, claims should be treated with extreme caution.

Note also that fuel cells processing syngas will emit CO_2 in quantities comparable to an incinerator or ATT plant.

See also the **Fuel Cell** briefing.

Appendix D: Juniper report extracts with comments

Links to the full report appear in section 10.

(1) On Energy Efficiency and Reliability

A report by consultancy company Juniper states that "*the recovery routes that have the highest energy recovery efficiencies are the least proven.*" It explains the complications of assessing the energy recovery potential of these technologies: "*unlike incineration, gasification can be used in conjunction with higher efficiency energy recovery technologies … but, because the higher efficiency modes of energy recovery are less proven, the financial and environmental benefits are offset by the increased risk.*

Partly because of this greater risk, many projects actually choose to use less efficient technologies for energy recovery. So it is important to judge each project on its own merits, when assessing the actual performance. Proponents … may „talk-up‟ the energy efficiency, based on theoretical capabilities of this family of technology. Yet, because the specific project uses more conventional, low efficiency energy recovery it may actually have a lower net recovery than equivalent incinerators."

The report goes on to explain "*Most commercial processes use combinations of technologies. It is important to note that nearly all of the commercial "gasification" systems actually follow the gasification with combustion. In doing so many of the key theoretical differences between pyrolysis, gasification and incineration become blurred.*

(Appendix D continued)

While gasification is not the same as incineration, the actual practical differences between some commercial gasification systems (that incorporate combustion to produce electricity) with incineration are relatively modest. Similarly, if pyrolysis is followed by combustion, there is relatively little difference from incineration."

[Be it noted that other evidence to date suggests that gasifier plants are <u>no more efficient at electricity generation than are incinerator plants).</u>See **Appendix F.**

It should also be noted that proponents of these technologies, when submitting planning applications and elsewhere, 'talk up' the potential for utilising the waste heat (ie that heat energy that is not converted into electrical power) for community or industrial park heating systems. This implies that they will be CHP plants.

The actual provision of these heating systems is not covered in the planning applications and is at best aspirational. There is only two such systems operational in the UK (in Sheffield and Nottingham) at this point in time. (See below under **Climate Change and appendix F**).

Juniper go on to warn that:

"*technology risks for many P&G processes targeting municipal solid waste (MSW) can be significant. One reason for this is that P&G processes do not yet have an established track record in the UK. This is compounded by the fact that variants that are being widely marketed here (close-coupled, gasification to gas engines and plasma gasification) have limited relevant track record anywhere else in the world. The lack of relevant track record means that the robustness of guarantees given on factors that may include process availability, maintenance costs and energy output, all of which are necessary to underpin financial models and contract terms, are often called into question in technical due diligence.*"

Juniper still see the integration of gasification with gas engines as very risky. Their report also says "*integration issues will have an impact on factors that include project deliverability, performance guarantees and costs and therefore are seen as having a significant risk potential for P&G projects. The main issue is syngas cleaning. Gas engines and turbines typically have low-tolerances to impurities in the syngas and therefore cleanup of this gas product when processing a heterogenous input such as MSW is challenging. Thus, the cleaning of syngas from this type of feedstock to within narrow tolerances is seen as difficult to achieve and considered a major technical risk factor in integrating MSW gasification with high efficiency energy recovery.*"

(2) On Emissions and Human Health

Juniper"s report states "*it is possible, due to certain technical features of P&G, that their emissions performance can be considered to be better than incineration. However, in practice, the project specific nature of process implementation means that it is inappropriate to generalise and not correct to say that gasification is better than incineration in terms of its emissions performance of vice versa…Though some developers of plasma gasification technologies have claimed that their process does not produce dioxins, solid commercial data is not yet available to back-up such claims.*

(Appendix D continued)

(3) On Greenhouse Gases

. Juniper‟s report says "*where pyrolysis and gasification (P&G) processes are integrated with more efficient energy recovery, significant greenhouse gas savings per kW of electricity generated relative to incineration are possible*", however pyrolysis and gasification plants that directly combust the raw syngas to produce electricity in a steam boiler (called "close-coupled‟) "*are quite similar to incineration in the way energy can be recovered and in greenhouse gas terms this type of P&G is arguably little different from incineration.*"

Appendix E: Efficiency and the EU approach to measuring it

Gasifiers and Efficiency

Expressed simply, the energy recovery efficiency of a thermal waste plant is the ratio:

$$\frac{\text{energy output}}{\text{energy consumed.}}$$

It can also be expressed as a percentage.

Where energy consumed is the energy contained in the feedstock + energy required from external sources to operate the plant. A gasification plant will require energy from external sources to feed the auxiliary burner(s) and run pumps and fans etc. Any energy taken from the output and used to run the plant should not be included in the gainfully utilised output.

Incineration and Gasification plants are inefficient in energy terms normally running at less than 25% and often less than 20%. They represent an inefficient means of recovering energy from waste because

- the electrical energy recovered is obtained via a steam turbine
- if they recover electrical energy alone the heat in the steam not used for driving the steam turbine is wasted.
- Steam turbines have inherent inefficiencies

The efficiency could be improved if

- The syngas and steam temperature and steam pressure were increased
- The heat not used in the steam turbine was used for community or other space or process heating purposes
- (alternatively) the syngas could be cleaned and used to power a gas engine or gas turbine.

However, these plants exist because of the (perceived) need to dispose of waste rather than the need to generate power. Inherently and for commercial reasons, their design is geared to reducing waste volumes rather than energy recovery efficiency.

(Appendix E continued)

The EU approach

The EU Commission (21st December 2005) in the Waste Framework Directive (WFD) COM 2005/667 – Annexe II proposed the following methodology for the purposes of comparing the efficiency of waste recovery installations and defining a minimum acceptable efficiency.

It should be noted that this methodology does not reflect the true energy recovery efficiency of such an installation, thermal (eg an Incinerator or Gasifier) or otherwise (eg Anaerobic Digestion) and simply produces a ratio that can be used for comparison purposes.

For the EU Methodology see also:

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0667:FIN:EN:PDF

In Chapter II, Recovery and Disposal, SECTION 1, GENERAL, Article 5, it is stated that:

Recovery

1. Member States shall take the necessary measures to ensure that all waste undergoes operations that result in it serving a useful purpose in replacing, whether in the plant or in the wider economy, other resources which would have been used to fulfil that function, or in it being prepared for such a use, hereinafter “recovery operations”.
They shall regard as recovery operations at least the operations listed in Annex II.

2. The Commission may, in accordance with the procedure referred to in Article 36(2), adopt implementing measures in order to set efficiency criteria on the basis of which operations listed in Annex II may be considered to have resulted in a useful purpose, as referred to in paragraph 1.

In Annex II, Recovery Operations Type R1:

Use principally as a fuel or other means to generate energy.

This includes incineration facilities dedicated to the processing of municipal solid waste only where their energy efficiency is equal to or above:
– 0.60 for installations in operation and permitted in accordance with applicable Community legislation before 1 January 2009, – 0.65 for installations permitted after 31 December 2008, using the following formula:

Energy efficiency = (Ep - (Ef + Ei)) / (0.97 x (Ew + Ef)). In which:

(Appendix E continued)

Ep means annual energy produced as heat or electricity. It is calculated with energy in the form of electricity being multiplied by 2.6 (to reflect the the unavoidable losses of electrical energy production and the implied electrical conversion efficiency of 38%) and heat produced for commercial use multiplied by 1.1 (to reflect the assumed 91 % efficiency for external heat generation)

0.97 is a factor accounting for energy losses due to bottom ash and radiation.

Ef means annual energy input to the system from fuels contributing to the production of steam (GJ/year)

Ew means annual energy contained in the treated waste calculated using the lower net calorific value of the waste (GJ/year)

Ei means annual energy imported excluding Ew and Ef (GJ/year)

(Recovery Operations types R2 to R10 relate to other forms of waste recycling / recovery.)

These details have been extracted from:

http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2005:0667:FIN:EN:PDF

Notes on the EU approach to efficiency:

The design of the formula attempts to overcome the negative perception that poor efficiency figures create. As a result, this formula may produce an efficiency figure greater than unity (or 100%), particularly if the heat not used in generating electricity is used for community or business heating.

In the context of a plant being classified as energy recovery rather than waste disposal, but not supplying heat in addition to electricity, and has a true efficiency of 20%, its efficiency as calculated using the WFD formula could be of the order of 0.5 or 50%

On no account should figures derived from this formula be used to compare the efficiencies of Energy from Waste plants with those of ‘bona fide’ power stations.

Cases have occurred wherein a company proposing the installation of an incinerator have used an incorrect version of the EU formula, possibly in order to enhance the actual performance of their equipment.

This formula forms a part of consultation by DEFRA currently in progress in the UK.

Formal implementation is due in December 2010.

Appendix F Gasification and pyrolysis disadvantages

These fall under several categories:

Impact on Recycling

- Unless they only deal with truly residual waste (what is left once maximum recycling and composting has happened) the processes will undermine recycling and composting.
- They are unlikely to be able to deal with truly residual waste, as plants need a certain amount of high calorific value materials in order to work effectively e.g. plastic, paper, and food waste. However this requirement conflicts with recycling and composting as these materials are often the most valuable parts of the waste stream.

Impact on LA finances and Council Taxes

- As with conventional incinerators, commercial success will depend in part on long term contracts that, given steadily increasing recycling levels, can only become financial burdens on their customers.

Reliability

- Whilst these technologies have been successfully used on consistent feedstocks (including industrial wastes), in reliability terms, waste gasifiers are likely to suffer compared to incinerators because they will be more sensitive to variations in feedstock content.
- Although these technologies have received a lot of attention as a possible alternative to municipal waste incineration, "*many of the most actively promoted processes have never been operated on a commercial basis on MSW at a significant scale*."[3]
- There are a handful of commercial-scale waste gasification facilities operating within Europe, but those apparently operating successfully do not treat mixed waste.
- Performance data for these technologies in the mixed waste context are likely therefore to be less reliable than that for incineration. Companies suggest that it makes sense to extrapolate the data obtained from pilot scale plants to full scale facilities; but of course the results cannot be guaranteed and they are more likely than conventional incinerators to be sensitive to variations in the content of the feedstock. Concerns about operational reliability have been raised by recent problems at various projects worldwide, particularly in the USA.

(Appendix F continued)

Toxic Emissions

- Disposal of ash and other by-products will be required, though some companies claim that their process makes this easier than for incineration ash.

- There is, currently at least, no reason to suppose that toxic emissions will be significantly different to those of a conventional incinerator. The emission levels will, in principle at least, be equally sensitive to the accidental inclusion of items of hazardous waste.

- It is often unclear exactly what emissions will be involved in practice, and what sort of ash or other residue will be produced (again, in most cases this information comes from the company). It is clear, however, that these will be of concern, in part because whilst emission limits are set out in the Waste Incineration Directive (WID), these do not apply to all operating conditions. See section 10 for further information sources.

Climate / GHG and Energy Efficiency

- Pyrolysis and gasification of municipal waste are not 100 per cent renewable energy technologies, and analysis has shown that it will be much better in climate terms to landfill stabilised waste than to burn it, particularly given the dubious claimed efficiencies of these technologies.

- Gasification plants produce large quantities of CO_2, and, if the syngas output is used for electricity generation only, many times greater, on a power for power comparison basis, than a conventional power station. Their performance in efficiency and GHG terms would be greatly improved if the waste heat was captured for community heating systems.

  In practice, and for gasification plants proposed or installed to date in the UK, because of the low efficiency the CO_2 output per unit of electrical power will be near 4 times that of a conventional, fossil fuel, power station. The basis for this statement is (a) the relevant CO_2 emission figure used by the Environment Agency in respect of conventional power stations and (b) the fact that for every 12 grams of carbon fully combusted in air, 44 grams of CO_2 will result.

  However, where the energy recovery process relies on a feedstock consisting in whole or in part of recyclables, to its directly related GHG emissions should be added those avoidable emissions resulting from the manufacture, from ‘virgin materials’, of replacement recyclables (see below under REPRISE).

- Evidence to date suggests that the efficiency of advanced thermal EFW plants (conventional incineration or gasification), as measured by comparing the electrical energy produced with the energy content of the waste feedstock, is likely to be of the order of 20%. In simple terms, this means that for every 5 units of energy in the feedstock, only 1 will emerge as electric power. This represents an appalling waste of resources.

- ATT plants will be inefficient, in energy conversion terms, unless the energy not used for electricity generation is used for local community or business premises heating ie the plant can be considered CHP. There are only two instances in the UK where a waste incineration plant provides community and business heating. These are in Sheffield and Nottingham. This instance apart, there is little evidence within the UK of any enthusiasm for this type of heating whatever its energy source despite attempts to 'talk up' the potential for utilising the waste heat (ie that heat energy that is not converted into electrical power) for community or industrial park heating systems. It is oftenimplied that they will be CHP plants when in reality that will not be the case.

Findings from an environmental impact assessment conducted by **REPRISE** clearly demonstrate that the total energy requirement to recycle plastic bottles in the UK scheme studied (i.e. from placing a bottle in a collection bank or kerbside container to the production of plastic flake) is 4.39 MJ/kg (1.2kWh/kg). This compares to, on average, 36.16 MJ/kg (10.0kWh/kg) (source: APME) necessary to produce equivalent virgin material.

1 kg of plastic burnt in a gasifier can be expected, based on its carbon content, to produce between 2kg and 3kg of CO_2 and, taking account of the plant efficiency of 25% at best, produce around 2.5 kWh of electrical power. Note, again and as above, that, for every kilogram of carbon burnt, 3.67kg of CO2 will be produced.

<u>The additional electrical power required to produce 1 kg of plastic from the virgin materials, whilst the recyclable plastic is incinerated, will involve a net additional 6.4 kg of CO_2 and 6.2kWh of electrical power.</u>

Plastic options	Gasifier CO_2 /kg	CO_2 /kg from Manufacturer	Electrical Power used kWh	Net Power used kWh
Recycle	-	+ 0.6	1.2	+1.2
Incinerate + New Manufacture	2.5	+ 5.0 + 2.5 = 7.5	10.0 (Mfr) -2.6 (incin)	+7.4

The REPRISE study further confirms this by stating that the energy used to recycle plastic bottles is about **one eighth** of the energy required for manufacturing from virgin material. The energy saving equates to powering a 60W lightbulb for six hours, for each bottle recycled! Even if one allows for the recovery of energy by incineration, recycling saves 5kWh in every 6kWh.

http://www.recoup.org/shop/product_documents/33.pdf

In addition to $CO_{2,}$ nitrogen oxides are also produced by waste gasification.

<u>Pyrolysis</u> may have a part to play in the sequestration of carbon from waste and, thereby reduce the level of global greenhouse gases. This aspect is addressed in detail in associated briefing **Carbon sequestration.**