The Viability of Advanced Thermal Treatment of MSW in the UK

Fichtner Consulting
Engineers Limited

Contact details

ESTET
154 Buckingham Palace Road
London
SW1W 9TR
Tel: 020 7824 8882

Fichtner Consulting Engineers Ltd
18 The Acorn Business Park
Heaton Lane
Stockport
Cheshire
SK4 1AS
Tel: 0161 476 0032

Published by ESTET in March 2004

The Viability of Advanced Thermal Treatment of MSW in the UK

This work was commissioned by the Environmental Services Training and Education Trust (ESTET) as a positive contribution to the debate on the role that advanced thermal treatment technologies can play in the management of MSW in the UK.

Fichtner Consulting Engineers Ltd

Management Summary

The UK government is committed to reducing the quantity of waste going to landfill to meet the requirements of the landfill directive. Practical and financial considerations limit the quantity of waste that can be re-used, recycled or composted. Thermal treatment will therefore play a role in the achievement of landfill diversion targets.

There is considerable interest in new ways to dispose of waste using alternative conversion technologies, particularly gasification and pyrolysis. Gasification and pyrolysis are established processes but are not widely deployed for the thermal treatment of residual municipal solid waste (RMSW). There is a general perception that pyrolysis and gasification technologies have many advantages over combustion, are proven and that they are widespread in Continental Europe. These perceived advantages include higher recycling rates, lower emissions, higher energy efficiencies, lower costs, smaller footprints and reduced visual impact. They are also said to be more suited to small capacity projects. Few of these perceptions are based on hard evidence. The information available on gasification and pyrolysis technologies for the thermal treatment of waste is often incomplete and based on widely varying assumptions, so comparisons between different technologies on a consistent and common basis are very difficult.

Fichtner was therefore commissioned to assess the commercial viability of gasification and pyrolysis technologies for the processing of RMSW to help those seeking to procure a commercial waste management service in the UK. The assessment starts with a review of the main steps involved in preliminary screening of technologies for a project including a review of uncertainties and their management. Different gasification and pyrolysis technologies are then compared against each other and against a benchmark modern combustion technology. Impediments to the further development of gasification and pyrolysis technologies for the treatment of RMSW in the UK are identified. Potential areas for further development are also suggested.

This review concludes that the commercial application of gasification and pyrolysis technologies for the treatment of RMSW is not widespread in the UK or in Europe. Only a few plants operate at a commercial scale. The risks associated with using less developed technologies for the treatment of waste are considered to be higher than for more established technologies.

The development of the gasification or pyrolysis technology is not the only challenge in striving for an improved thermal process. To be commercially successful, the technology must be incorporated into a complete solution that is better in overall terms than that achievable with technologies that are already mature. In comparing technologies, all components of the process (pre-treatment, thermal conversion, solid residue generation and syngas utilisation) and all factors (energy efficiency, economics and environmental performance) must be considered simultaneously.

Many of the perceived benefits of gasification and pyrolysis over combustion technology proved to be unfounded. These perceptions have arisen mainly from inconsistent comparisons in the absence of quality information:

1. Differences in recycling rates are due to the use of front-end recovery systems that can generally be employed in conjunction with any thermal treatment technology to achieve similar results;

2. All waste treatment plants based on combustion, gasification or pyrolysis technologies are classified as incineration plants under WID and are therefore required to meet the same stringent emissions limits. Incineration plants based on all three types of technologies (gasification, pyrolysis and combustion) can generally comfortably meet the required emissions limits. The benefits of incremental improvements below the WID limits at the expense of reduced energy efficiency, increased use of resources, increased residue production or higher cost must be weighed against the economic and environmental costs.

3. In terms of energy efficiency of standalone plants when optimised for power generation, existing gasification and pyrolysis technologies are less efficient than modern combustion technology. Standalone power generation plants, using gasification or pyrolysis technology to supply fuel gas to a combined cycle gas turbine for power generation, may ultimately achieve higher energy efficiencies than combustion technology using a simple steam turbine. However, this application has yet to be successfully demonstrated anywhere in the world and ensuring that such applications comply with WID is a significant obstacle to their development.

4. Meaningful comparisons of capital and operating costs for the different technologies were not possible due to the scarcity of reliable and publicly available information, but there is no reason to believe that these technologies are any less expensive than combustion and it is likely, from information available, that the more complex processes are significantly more expensive;

5. Site footprints, building heights and stack heights are generally not determined by whether the thermal conversion technology is pyrolysis, gasification or combustion, but by the quantities of waste handled and the thermal energy released;

6. Regardless of the technology employed, plants will become more economical, more efficient and use less land overall when capacity is concentrated in fewer but larger plants. These economies and benefits of scale can be substantial. Nevertheless, in some situations a small plant is the best option, for instance the Shetland plant;

7. Some gasification and pyrolysis technologies are based on modular designs. Modular technologies avoid the risks associated with scaling up but do not fully benefit from the significant economies of scale that are available to scaleable technologies when large quantities of waste need to be processed.

Due to real or perceived technology risk and the rigorous requirements of private finance, standalone plants based on those gasification and pyrolysis technologies that are not commercially proven for thermal treatment of RMSW will generally be difficult to deliver in the UK in the near future. Lenders will be deterred by the limited track record and the scarcity of meaningful guarantees from established organisations with good credit ratings. Developers and waste contractors will be deterred by the lack of support from lenders, the lack of clear commercial justification for adopting these technologies and the risk that the adoption of unproven technologies poses to the achievement of contractual waste diversion and recovery targets.

In the short to medium term at least, the real potential of gasification and pyrolysis technologies is likely to be limited to:

- situations where, because of the benefits of the Renewables Obligation Order, they are commercially competitive with conventional combustion technologies;
- situations where the host community is willing to employ gasification or pyrolysis, but does not wish to use combustion;
- the treatment of selected homogenous waste streams such as plastics and possibly refuse derived fuels (RDF); and
- the treatment of small quantities of clinical and hazardous waste where energy efficiency is less important than in high volume applications.

An ideal application for gasification would be the use of the syngas as a fossil fuel substitute in an existing power station or in other industrial processes where the application would benefit from the higher energy efficiency of the host plant. However, the treatment of this application as co-incineration under the Renewables Order and the interpretation of WID by the Environment Agency will severely inhibit this opportunity.

A number of prospective long-term technological developments (syngas liquefaction, use as chemical feedstock or in CCGT generation etc) offer potential benefits in lower costs, lower environmental impact, and lower dependency on ever decreasing fossil fuel reserves. However, the market (as currently structured) is not able to support or deliver these developments. Indeed, even the continuing development of the core technologies is not guaranteed, as evidenced by the recent withdrawal of Lurgi from this market.

In the risk averse world of government contracts and private finance, these prospective developments are unlikely to take place. If the UK Government wishes to see progress in this field, it will need to deliver a more supportive framework within which long-term development is encouraged and fostered and a degree of technical failure is anticipated. It will also need to review and, where necessary, adjust those elements of its environmental regulatory regime which undermine the ability of the market to deliver and deploy these technologies.

TABLE OF CONTENTS

MANAGEMENT SUMMARY 3

TABLE OF CONTENTS 6

1 INTRODUCTION **10**

1.1 Background 10

1.2 Objectives 11

1.3 Methodology 11

1.4 Representations from Suppliers 11

2 GUIDE TO INITIAL ASSESSMENT OF A POTENTIAL PROJECT **12**

2.1 Define Project Objectives & Constraints 12

2.2 Assess Risks 13

2.3 Assess Deliverability 13

2.3.1 Ability to Attract Finance 14

2.3.2 Planning & Regulatory Issues 15

2.3.3 Contracting Organisation 15

2.4 Assess Benefits 15

2.5 Assess Financial Costs 17

2.6 Assess Environmental Impacts 17

2.7 Examples of Specific Issues and the Consequences of Failure 18

3 PYROLYSIS, GASIFICATION, AND COMBUSTION **20**

3.1 Brief History of Advanced Thermal Waste Treatment Technologies 20

3.2 Combustion 20

3.3 Gasification 20

3.4 Pyrolysis 21

4 AVAILABLE TECHNOLOGIES AND POTENTIAL SOLUTIONS **22**

4.1 Pre-Treatment 22

4.2 Main Process 22

4.2.1 Fluidised Bed Gasifiers 23

4.2.2 Fixed (Non-Fluidising) Bed or Grate Gasifiers 23

4.2.3 Rotary Kilns for Pyrolysis 23

4.2.4 Heated Tube Pyrolysers 24

4.2.5 Fast Pyrolysis 24

4.2.6 Use of Syngas 24

5 ASSESSMENT OF TECHNOLOGIES **25**

5.1 Energy Recovery & Efficiencies 25
5.1.1 General 25
5.1.2 Generation Efficiency of Integrated Gasification Combined Cycle (IGCC) Systems 26
5.2 Alternative Uses for Syngas 26
5.3 Materials Balance 27
5.4 Economics 27
5.4.1 Capital Costs 28
5.4.2 Operating Costs 28
5.4.3 Renewable Obligation Certificates 28
5.5 Emissions 29
5.5.1 Conventional Steam Cycles 30
5.5.1.1 Comparison Against WID Limits 32
5.5.1.2 Lower Emissions Due to Improved Gas Cleaning Systems 32
5.5.1.3 Reduced Emissions to Air Due to Choice of Thermal Treatment Technology 32
5.5.2 Gas Engines & Gas Turbines 33
5.5.3 Syngas Cleaning 34
5.6 Visual Impact 34
5.6.1 Results 34
5.6.2 Footprint 34
5.6.3 Building Height 35
5.6.4 Stack Height 35
5.7 Commercial Availability 36
5.8 Risk Management 37
5.9 Effect of Scaling Up 37
5.9.1 Effect of Scaling Up on Economics 37
5.9.2 Effect of Scaling Up on Land Use 38
5.9.3 Effect of Scaling Up on Energy Efficiency 38
5.9.4 Effect of Scaling Up on Environmental Performance 38
5.9.5 Economies of Scale vs Proximity Principle 38
5.9.6 Scaling up and Risk 39
5.9.7 Small Gasification and Pyrolysis Plants 39

6 IMPEDIMENTS TO DEVELOPMENT OF ADVANCED THERMAL TECHNOLOGIES 40

7 POTENTIAL DEPLOYMENT AND AREAS FOR FURTHER DEVELOPMENT 41

8 CONCLUSIONS 42

8.1 Uncertainties 42
8.2 Emissions 42
8.3 Materials Recovery and Waste Disposal 42
8.4 Energy Efficiency 43
8.5 Plant Reliability and Utilisation 43

8.6 Economics 43
8.7 Footprint 43
8.8 Visual Impact 43
8.9 Economies of Scale 44
8.10 Impact of Scale on Choice of Technology 44
8.11 Impediments to Development of Gasification and Pyrolysis Technologies 44
8.12 Commercial Viability 44
8.13 Longer-Term Development 44

APPENDIX A ENERGY EFFICIENCY 45

A.1 Methodology and Definitions 45
A.2 Results 45
A.3 Thermal Conversion Efficiency 49
A.4 Power Generation Efficiency 49
A.4.1 Steam Turbine 49
A.4.2 Gas Engine 49
A.4.3 Combined Cycle Gas Turbine 49
A.4.4 Parasitic Load 50
A.4.5 Summary 50

APPENDIX B MATERIALS BALANCE 52

B.1 Materials Recovery 52
B.2 Solid Residues 52
B.2.1 Combustion Residues 52
B.2.2 Gasification Residues 52
B.2.3 Pyrolysis Residues 55
B.2.4 Air Pollution Control Residues & Effluents 55
B.3 Quantity of Combustion Products in Flue Gas 55

APPENDIX C RENEWABLE OBLIGATION CERTIFICATES 56

APPENDIX D GASIFICATION AND PYROLYSIS TECHNOLOGIES AND TECHNOLOGY SUPPLIERS 58

D.1 Brightstar Environmental – SWERF 58
D.2 Compact Power 60
D.3 Energos 61
D.4 Enerkem/Novera 62
D.5 FERCO 63
D.6 Foster Wheeler 64
D.7 GEM (Graveson Energy Management) 67
D.8 IET Energy / Entech 68

D.9 Lurgi 70
D.10 Mitsui Babcock 72
D.11 Techtrade/Wastegen 73
D.12 Thermoselect 74
D.13 TPS Termiska 76
D.14 Von Roll 76

APPENDIX E REPRESENTATIONS FROM TECHNOLOGY SUPPLIERS 80

E.1 Representations from WasteGen/Techtrade 80
E.1.1 Maximum Combustion Temperature 80
E.1.2 Emissions 80
E.1.3 Utilisation 81
E.1.4 Definition of Proven 82
E.1.5 Japanese Plants 82
E.1.6 Why Compare Gasification and Pyrolysis with Combustion 84
E.1.7 Unpredictability of ROCs 84
E.2 Representations by Compact Power 85
E.2.1 Capacity 85
E.2.2 Energy Efficiency 85

APPENDIX F GLOSSARY 86

1 INTRODUCTION

1.1 Background

The Government is committed to reducing the quantity of waste going to landfill to meet the requirements of the landfill directive[1]. Practical and financial considerations limit the quantity of waste that can be re-used, recycled or composted. Thermal treatment is therefore an essential element in achieving landfill diversion targets.

There is a general perception that pyrolysis and gasification technologies have many advantages over combustion, are proven and that they are widespread in Continental Europe. These perceived advantages include higher recycling rates, lower emissions, higher energy efficiencies, lower costs, smaller footprints and reduced visual impact. They are also said to be more suited to small capacity projects. The Government is currently trying to encourage the development and use of these technologies for producing electricity from waste[2].

Gasification and pyrolysis are established processes but are not currently widely deployed for the thermal treatment of residual municipal solid waste (RMSW).

Much of the information available on these technologies is based on sales and publicity material provided by the technology suppliers or interest groups. The information available is often incomplete and based on widely varying assumptions, so comparisons between different technologies on a consistent and common basis are impossible. It is usually difficult to subject the information to critical and impartial scrutiny, since the information is often sketchy, assumptions unclear and the design basis unknown. The scarcity of quality data is at least partly due to the scarcity of operating plants.

ESTET therefore commissioned this assessment of the viability of gasification and pyrolysis technologies for the treatment of MSW in the UK. The review includes a summary of the main steps in preliminary screening of technologies for a project, a review of uncertainties and their management and a comparative assessment of some gasification and pyrolysis technologies currently being marketed in the UK. The impediments to the development of gasification and pyrolysis technologies for the treatment of RMSW in the UK are identified as well as opportunities for longer-term developments.

The report is primarily aimed at local authorities and waste management companies that are looking to procure waste management services or facilities.

---

[1] Directive 1999/31/EC on the landfill of waste

[2] Renewables Obligation Order 2002 and DEFRA's Waste Implementation Programme (WIP)

1.2 Objectives

The main objectives of this technology review are as follows:

1) To establish any distinct technical and commercial benefits offered by gasification and pyrolysis technologies;

2) To identify the commercial and technical risks associated with the use of gasification and pyrolysis technologies and to indicate the options for managing those risks;

3) To provide a basic guide on how to perform an initial screening assessment of potential gasification and pyrolysis technologies for the thermal treatment of RMSW;

4) Subject to the availability of information, to produce a consistent comparison of the different technologies on a common basis against each other and against a benchmark plant based on modern combustion technology. The main areas for comparison are capital costs, operating costs, footprint, emissions, energy balances, mass balances and energy efficiency;

5) To identify the impediments to further commercial development of gasification and pyrolysis technologies for thermal treatment of MSW in the UK;

6) To identify opportunities for commercial development of gasification and pyrolysis technologies for thermal treatment of MSW in the UK.

1.3 Methodology

A number of gasification and pyrolysis technology suppliers that are marketing their technology in the UK for the thermal treatment of RMSW were approached for information.

The information requested was based on a standard questionnaire asking for details of reference plants and estimated data for a hypothetical plant of 100,000 tonnes/year capacity under standardised conditions. This approach was intended to enable direct and consistent comparisons between technologies.

The information supplied was limited and often on a different basis from that requested, making consistent comparisons difficult or impossible. The scarcity of operating plants and commercial confidentiality are likely reasons for the lack of quality information.

Other sources of information such as gas engine suppliers, gas turbine suppliers, the Environment Agency and other reports were used to supplement the information from gasification, pyrolysis and combustion technology suppliers.

1.4 Representations from Suppliers

This report was finalised with the help of many comments and suggestions from waste management contractors, technology suppliers, and independent consultants. Due to the diverse nature of the sector, it was inevitable that consensus could not be reached on all issues. In particular, it was not possible to accommodate certain representations made by some technology suppliers. To maintain the independence of the report, these views are included in Appendix E.

2 GUIDE TO INITIAL ASSESSMENT OF A POTENTIAL PROJECT

This section describes the general steps that a procurer of a waste management service or processing facility should take in assessing the viability of the project. The guide is then rounded off with examples of specific issues to be considered and the consequences of failing to adequately assess and address these issues at an early stage.

2.1 Define Project Objectives & Constraints

The first step in a project should be to define the desired outcome and the constraints that will limit the options available. A list of the main criteria that may be relevant to a waste thermal treatment project are given below:

The Waste Stream

1) How much waste is there to be treated?

2) What type of waste is to be treated? For example does it contain just MSW or does it include commercial waste, sewage sludge, tyres etc.?

3) What are the characteristics of the waste in terms of chemical composition, calorific value, particle size, moisture, quantity of ash, and properties of ash?

Energy Utilisation

4) Is there a suitable market for heat sales nearby?

5) Is there a suitable market for the syngas product nearby such as a power station or industrial plant?

6) Is it possible to connect to the local electricity distribution network or large power consumers at a reasonable cost?

Procurement and Finance

7) Is the intention to procure a waste treatment plant or a waste treatment service?

8) How will the project be financed? The required method of finance may preclude certain procurement strategies and some technologies;

9) What are the budget and other financial constraints?

Permitting

10) What are the likely planning constraints?

11) What is the likely acceptability of the project and technology to interested parties?

2.2 Assess Risks

The main risk issues to be assessed as early as possible are:

1) Will the plant perform reliably and efficiently over the project life?

   a) Are there comparable reference plants?

   b) Do the contractors and suppliers have adequate and relevant track records?

   c) For imported technology, how will the plant be delivered in the UK and supported throughout its operating life?

2) Are the estimates of plant economics, and plant performance realistic?

   a) Has the technology supplier built any similar plants to base their estimates of plant costs and plant performance on?

   b) What is the basis of the estimates?

   c) What are the consequences of estimating errors?

3) Are the contract structure, guarantees, and warranties adequate?

   a) Do the guarantees accurately reflect the performance objectives and are they provable?

   b) Are the guarantees realistic when compared with the performance of the supplier's reference plants?

   c) Can the guarantors afford to honour their guarantees in the event of claims? What are their financial strengths and credit ratings?

4) Some of the potential consequences of failure will be reduced for the purchaser if the facilities are to be built and owned by a service provider for a gate fee. However, the purchaser will still be left with the cost of alternative disposal or penalties for failing to achieve landfill diversion targets if the project fails to deliver.

2.3 Assess Deliverability

The main hurdles to delivery of a project are the ability to obtain finance, necessary permissions to build and operate the plant, and the ability of both the contractor and the technology supplier to deliver the performance required by the project. The means of overcoming these hurdles must be clear from the outset to avoid the risk of spending time and resources pursuing options that cannot be delivered.

2.3.1 Ability to Attract Finance

1) How will the project be financed?

   a) Few organisations will be able and willing to finance large projects from their own balance sheets;

   b) If debt finance is required then the risk of unproven technologies is unlikely to be accepted by lenders.

2) Is the intention to purchase the facility outright? In this case, the purchaser will procure the facility requiring significant capital expenditure.

   a) For projects that depend on debt finance, the risk of multiple contracts is unlikely be acceptable to lenders unless the technology is mature and proven, the project management team has a sound track record and a UK cost record established;

   b) Procurement by means of a lump sum design and build turnkey contract will be more acceptable to lenders but will significantly increase costs, since the main contractor will charge a fee for taking on the overall risk for the project;

   c) There are very few remaining major contractors in the UK market willing to offer contracts on a design and build lump sum basis, against firm performance guarantees, for projects based on proven technology and none for projects based on unproven technology.

3) Alternatively, is it intended to let a waste treatment contract in which the service provider finances the facility?

   a) The purchaser requires little or no capital and is not subjected to these risks;

   b) The service provider will take on the task and risks of obtaining capital. The same considerations listed in item 2) above will apply;

   c) The purchaser will still need to consider the risk and consequences of having no waste treatment facility if the service provider fails to deliver;

   d) The purchaser will pay a premium to the service provider to cover risks, financing and operation of the plant.

2.3.2 Planning & Regulatory Issues

1) What is the planning application process likely to involve and is it likely to be successful?

   a) Does the project conform to government and local waste strategies?

   b) Has a case been justified for the project as the best practicable environmental option?

   c) What is the likely acceptability of the project to local residents, local businesses, politicians, and environmental pressure groups?

   d) Is a public inquiry likely to be required?

   e) Does the political will necessary for the approval of the project exist?

2) Will the project comply with the stringent emission requirements of the Waste Incineration Directive (WID)[3]?

3) Is the environmental case for the project robust enough to achieve authorization under the PPC Regulations[4]?

2.3.3 Contracting Organisation

The size, financial position, and experience of the contractor and technology supplier are critical in determining whether a particular project will be delivered on time, to budget and to specification.

2.4 Assess Benefits

1) Assess the availability of ROCs (renewables obligation certificates)[5] and their worth:

   a) Check whether the technology will qualify for ROCs;

   b) If the technology qualifies, assess what portion of the power generated will be classed as renewable and therefore qualify for ROCs;

   c) Financial backers for the project may insist on a long-term power purchase agreement with an electricity supplier, which will reduce the value of the ROCs.

---

[3] Directive 2000/76/EC, 2000, on the incineration of waste

[4] "The PPC Regulations", SI2000/1973). As amended by SI2001/503

[5] Statutory Instrument 2002 No 914 "The Renewables Obligation Order 2002"

2) Assess materials recovery:

   a) Are the claimed materials recovery rates proven or just theoretical estimates?

   b) Is the materials recovery due to the choice of thermal treatment technology or due to pre-treatment systems that could be applied regardless of technology to obtain similar benefits?

   c) Are there adequate markets for these recovered materials or will they be classed as a waste that requires disposal?

   d) Are the recovered materials of adequate quality for the intended use?

   e) What is the net cost/revenue for disposal/sale of these recovered materials?

3) Assess energy recovery rates:

   a) Are the energy recovery efficiencies, heat and/or power, proven?

   b) Are there ready markets for heat and/or power?

   c) What is the net cost/revenue for disposal/sale of the heat and/or power?

4) Assess alternative uses for the product syngas:

   a) Are there adequate proven markets for the syngas?

   b) Is the syngas clean enough to satisfy these markets?

   c) What is the net revenue for sale of syngas?

2.5 Assess Financial Costs

1) What is the likely capital cost of the entire project? The capital cost should include:

    a) Cost of the plant;

    b) Enabling costs such as electrical connections;

    c) Land costs;

    d) Development fees and costs;

    e) Interest during construction.

2) What is the likely operating cost for each year of the project? The operating costs should include:

    a) Labour;

    b) Short-term and long-term maintenance;

    c) Consumables;

    d) Fixed costs such as rates and insurance.

3) What are the financing costs?

2.6 Assess Environmental Impacts

What is the environmental impact of the project including emissions to land, air and water? It is important to consider the overall impact of the project including the impact of processes that take place before the waste arrives on site and after the products and residues leave the plant.

2.7 Examples of Specific Issues and the Consequences of Failure

Table 1 - Specific Risk Issues for Consideration When Assessing the Viability of A Project

Factors	Issues for Consideration	Consequences of Failure
Recycling	• Are there established markets for the recovered material? It could end up as a residue if not; • Are the materials recovery techniques proven and tested on the intended waste feedstock? • What assumptions have been made about the character and composition of the intended waste feedstock? • Is recycling the BPEO (Best Practicable Environmental Option) for the material in question?	• Emergency diversion required; • Backup diversion required; • Low throughput; • Recovered materials rejected by market; • Failure to gain IPPC consent.
Residues	• Are residue figures consistent with the intended waste feedstock? • Is all inert material accounted for in the various recovery material and residue streams?	• Backup diversion required.
Efficiency	• What CV is assumed for the intended waste feedstock? • Have all energy requirements for the plant been considered, including energy required to pre-treat the waste? • Are efficiency figures dependent on novel applications of generating technologies such as gas turbines? If so, what evidence is there that such technologies will work reliably to the design specifications? • Has auxiliary fuel been accounted for?	• Reduced income/plant throughput; • Increased operating or capital costs; • Reduced or no plant throughput; • Increased operating or capital costs.
Emissions	• Are the emissions figures proven simultaneously on similar feedstock, similar equipment, similar system configurations, at design throughput and normal operating conditions?	• Increased risk of plant failure; • Increased consumables consumption; • Cost increases from retrofits.
Plant size and Capacity	• Have the basis of plant throughput estimates been proven simultaneously on similar feedstock, similar equipment and similar system configurations?	• Reduced or no plant throughput.
	• Will the technology require significant scale-up for commercial use?	• Increased risk of cost increase & performance loss.
	• Could conventional technology be scaled down to do the same?	• Low risk of cost increase & performance loss.
Costs	• Are all elements of capital costs included (e.g. development and financing costs as well as the basic turnkey cost)? • Are the costs of any essential pre-treatment included? • Are all elements of operating costs included (e.g. labour, maintenance, consumables, auxiliary fuel, insurance, rates)? • What availability has been assumed in cost calculations? Is this consistent with the technologies' track record? • What assumptions have been made about income from recovered materials? • What residue disposal costs have been assumed? Are there any contingencies for the possibility that recovered material may not find a market and thus require disposal? • Have the additional costs/more arduous financing terms been accounted for if the technology is less than established?	• Risks to contract viability: 1) Failure to reach financial close; 2) Call for contract re-negotiation; 3) Contract abrogation; 4) Maintenance & investment lower; 5) Reduced service flexibility; 6) Reversion to close textual analysis of contract documentation.
Modularity	• Will performance be sacrificed as capacity increases (i.e. would a larger plant perform better than a number of smaller units)?	• Cost increase & performance loss.

Table 1 - Specific Risk Issues for Consideration When Assessing the Viability of A Project		
Factors	**Issues for Consideration**	**Consequences of Failure**
General	• Can the technology be financed? • Will the technology get all the necessary permits? • What is the track record? • Has the technology treated the intended waste feedstock (including any waste pre-treatment)? • What guarantees will be offered? • What contingencies will be required if the plant doesn't work as planned?	• Failure to reach Financial Close • Project aborted • Service failure • 'Employer' picks up pieces

3 PYROLYSIS, GASIFICATION, AND COMBUSTION

3.1 Brief History of Advanced Thermal Waste Treatment Technologies

Gasification and pyrolysis processes have been known and used for centuries. Examples include pyrolysis and gasification of coal as early as the 18th century. Pyrolysis of coal produced coke and a coal gas. Gasification of coal or coke in a stream of air and steam produced a combustible gas referred to as producer gas.

Despite this long history, development of gasification and pyrolysis technologies for processing RMSW has only become a focus of attention in recent years stimulated by the search for more efficient energy recovery.

3.2 Combustion

Combustion is the total thermal degradation of a substance with sufficient oxygen to oxidise the fuel completely. The general characteristics of combustion of a waste stream are as follows:

1) Excess air is required to ensure complete oxidation;

2) High maximum temperatures typically above 1,000°C;

3) Fuel is completely oxidised to carbon dioxide and steam, leaving only a small amount of carbon in the ash (less than 3% by weight of ash);

4) The overall process converts almost all of the chemical energy in the fuel into thermal energy, leaving no unconverted chemical energy in the flue gas and very little unconverted chemical energy in the ash.

3.3 Gasification

Gasification is the partial thermal degradation of a substance in the presence of oxygen but with insufficient oxygen to oxidise the fuel completely (i.e. sub-stoichiometric). The general characteristics of gasification of a waste stream are as follows:

1) A gas such as air, oxygen, or steam is used as a source of oxygen and/or to act as a carrier gas to remove the reaction products from reaction sites;

2) Moderate temperatures typically above 750 °C;

3) Products are gas (main combustible components being methane, hydrogen, and carbon monoxide) and a solid residue (consisting of non-combustible material and a small amount of carbon);

4) The overall process does not convert all of the chemical energy in the fuel into thermal energy but instead leaves some of the chemical energy in the syngas and in the solid residues;

5) The typical NCV (net calorific value) of the gas from gasification using oxygen is 10 to 15 MJ/Nm^3;

6) The typical NCV of the gas from gasification using air is 4 to 10 MJ/Nm^3.

For comparison, the NCV for natural gas is about 38 MJ/Nm^3.

Gasification offers at least the theoretical potential for innovative use of the product syngas other than immediate combustion to produce heat. Examples of innovative use would be firing of the syngas in gas engines/turbines, the displacement of fossil fuel in large combustion plants or as feedstock for chemicals or liquid fuel production.

3.4 Pyrolysis

Pyrolysis is the thermal degradation of a substance in the absence of added oxygen. The general characteristics of pyrolysis of a waste stream are as follows:

1) No oxygen is present (or almost no oxygen) other than any oxygen present in the fuel;

2) Low temperatures typically from 300 °C to 800 °C;

3) Products are syngas (main combustible components being carbon monoxide, hydrogen, methane and some longer chain hydrocarbons including condensable tars, waxes and oils) and a solid residue (consisting of non-combustible material and a significant amount of carbon);

4) The general lack of oxidation, and lack of an added diluting gas, means that the NCV of syngas from a pyrolysis process is likely to be higher than that from a gasification process (provided substantial quantities of carbon are not left in the solid residues). Typical NCV for the gas produced is 10 to 20 MJ/Nm^3;

5) The overall process generally converts less of the chemical energy into thermal energy than gasification.

Pyrolysis also offers the potential option of more innovative use of the pyrolysis syngas other than immediate combustion to produce heat.

Pyrolysis generally takes place at lower temperatures than for combustion and gasification. The result is less volatilisation of carbon and certain other pollutants such as heavy metals and dioxin precursors into the gaseous stream. Ultimately, the flue gases will need less treatment to meet the emission limits of WID. Any pollutant that is not volatilised will be retained in the pyrolysis residues and need to be dealt with in an environmentally acceptable manner.

The emission benefits of low temperature processing are largely negated if the char subsequently undergoes high temperature processing such as gasification or combustion.

The solid residues from some pyrolysis processes could contain up to 40% carbon representing a significant proportion of the energy from the input waste. Recovery of the energy from the char is therefore important for energy efficiency.

4 AVAILABLE TECHNOLOGIES AND POTENTIAL SOLUTIONS

4.1 Pre-Treatment

Some gasification and pyrolysis processes have very specific limitations on the type of feedstock that can be processed. Pre-treatment of the raw waste is sometimes necessary or desirable. Pre-treatment can be used for a number of reasons:

1) To recover materials for recycling by source separation, materials recycling facilities or more sophisticated mechanical biological treatment (MBT) plants. MBT plants will typically produce a high NCV fraction that is dry and relatively free of pathogens and odours, making it easier to transport, store and handle. This fraction will contain about 35% to 50% of the original mass and its NCV will be about 11 to15 MJ/kg. The remaining mass is made up of decomposition and evaporation losses, a low NCV fraction, and a small proportion of recovered materials for recycling;

2) Removal of fractions such as bulky items or very wet materials that some combustion, gasification and pyrolysis processes cannot handle;

3) Removal of low calorific value materials to reduce thermal treatment plant capacity and to increase the calorific value of the residual waste;

4) To reduce the size of particles entering the process. In general, pyrolysis reactions are slower than gasification reactions, which are in turn slower than combustion reactions. Some pyrolysis and gasification processes will be too slow unless particle size is reduced by milling and/or shredding;

5) To dry the raw waste, since some processes are not designed to process wet waste.

Many pre-treatment processes tend to divert low NCV materials away from the thermal treatment plant. However, the main determinant of the thermal treatment plant size and capital cost is the total thermal input and not the mass throughput. Diverting 10% of the mass flow away from the thermal treatment plant may result in diversion of less than 10% of the thermal input. In this example, if the NCV of the original material is 10 MJ/kg and the NCV of the diverted material is 5 MJ/kg then only 5% of the thermal input is diverted, resulting in a capital cost reduction[6] of only about 3% for sections of the plant whose capacity is determined by waste thermal input.

Gasification and pyrolysis plants are generally able to cope with higher NCV feedstocks and in fact would prefer to have high NCV feedstocks in order to produce higher heat content in the NCV syngas. Conventional grate combustion systems are not able to accept very high NCV feedstocks without special modifications.

4.2 Main Process

A range of equipment can be employed for pyrolysis and gasification systems. Descriptions of the main categories of gasifiers and pyrolysers and potential uses for the product syngas are given below whilst information on individual technology suppliers and their specific technologies are given in Appendix D.

[6] Assumes that capital cost is proportional to thermal input to the power 0.6 – a crude but common assumption

4.2.1 Fluidised Bed Gasifiers

In a fluidised bed the waste is suspended in a swirling mass of hot particles (such as sand) kept fluidised by hot gases. This system gives very good mixing and hence good heat and mass transfer. The exit gases carry off some particulates of ash, carbon, and bed material.

Bed material and ash are periodically extracted and fresh bed material (normally inert sand) is simultaneously supplied. The consumption of bed material is fuel dependent, as more difficult fuels require more frequent extraction of residues. Sometimes the bed material can be separated from the residues for re-use.

All fluidised bed systems will require pre-treatment of the waste to remove coarse dense material and to reduce particle size.

Aside from potential problems with fuels that have low melting point ash or large quantities of large dense particles, a fluidised bed system is very flexible in terms of feed moisture, feed size, calorific value, density, and sulphur content. The main reason for the flexibility is that the fuel is mixed in and retained in the fluidised bed for as long as necessary until reactions are complete. An alkaline material, such as limestone, can also be added to the bed material to help retain acidic impurities in the solid residues.

Fluidised bed technology is mature and well proven in other applications such as combustion of biomass and pulverised coal. Fluidised bed plants are most suited to treating RDF (refuse derived fuel) rather than raw MSW.

Examples of fluidised bed gasification systems include those offered by Enerkem/Novera, Foster Wheeler, FERCO and TPS Termiska.

4.2.2 Fixed (Non-Fluidising) Bed or Grate Gasifiers

There are many variations on this theme. The main reactor can be horizontal or vertical. The flow of gasification medium (generally air) through the bed can be upwards (updraft) or downwards (downdraft). There are also different mechanisms for discharging the ash.

One common configuration is the grate gasification system. This system is similar to grate combustion systems but insufficient air is supplied for complete combustion. In a grate system, waste is fed in at one end and goes through the process of drying and gasification as it travels along the grate to the discharge end. By the time the solid mass reaches the end of the grate only, ash and unreacted carbon should remain for discharge. The movement of waste along the grate is helped along by the grate incline and the action of the grate. Combustion air can be supplied through slots in the grate.

Grate systems are mature and well proven for other applications such as RMSW combustion. However, gasification reactions are slower than combustion reactions due to lower temperatures and lower ratios of oxygen to fuel. Higher levels of unreacted carbon may remain in the residues.

Examples of grate gasification systems are offered by Entech/IET. An example of a fixed bed updraft gasifier was developed by British Gas-Lurgi.

4.2.3 Rotary Kilns for Pyrolysis

In rotary kilns, waste is fed into one end of a rotating drum. As the waste progresses through the drum, it is dried and thermally decomposed into volatiles and char. The slowly rotating drum tumbles the waste to promote mixing, and to expose different parts of the waste to contact with gases and with heating surfaces. Heat is supplied indirectly. An alkaline material can also be added to the rotary kiln to help retain acidic impurities in the solid residues.

Techtrade and Mitsui Babcock offer examples of rotary kiln pyrolysers for the treatment of RMSW. Examples of other existing applications of indirectly heated rotary kilns include reactivation of spent activated carbon, drying and partial calcination of dolomite and thermal treatment of various materials such as oil sludge, contaminated soil and sewage sludge.

4.2.4 Heated Tube Pyrolysers

Waste is moved through a tube that is heated externally. Movement can be achieved by screw action or by ramming. Indirect heating is usually supplied by hot gases from the combustion of part of the product syngas or char.

These pyrolysis systems are usually used as the first stage with a second stage gasification step to convert more of the combustible solids into syngas.

Examples of heated tube pyrolysis systems are those offered by Thermoselect and Compact Power.

4.2.5 Fast Pyrolysis

Pyrolysis reactions are generally slower than gasification and combustion reactions. To help speed up the reaction, high temperatures, low moistures and very small particle sizes are used. Feed preparation is therefore critical but the advantage is a faster reaction and smaller reactor than would otherwise be required.

An example of fast pyrolysis is offered by GEM. In this system, the fine dry feed is pyrolysed on contact with the hot metal surface of the reaction chamber.

4.2.6 Use of Syngas

Possible applications for the syngas produced include:

1) Direct combustion of the untreated syngas in a second chamber followed by heat recovery in a steam boiler. Flue gas cleaning is then required prior to discharge to atmosphere;

2) Cleaning and cooling of the syngas ready for use in a gas engine or a gas turbine. Whether the flue gas from the gas engine or gas turbine requires further cleaning will depend on the effectiveness of the syngas cleaning and the regulator's interpretation of the requirements of WID;

3) Use of clean or untreated syngas in other fossil fuel combustion processes. The attractiveness or otherwise of this option will again depend on the regulator's interpretation and application of WID to the industrial process;

4) Use of the syngas as a chemical feedstock and production of transport fuels.

Option 1 is the most common configuration currently being offered to the UK market.

5 ASSESSMENT OF TECHNOLOGIES

For ease of assessment, the comparisons have been standardised on a common set of conditions including a defined waste composition, a plant capacity of 100,000 tpa, and restricting the use of energy to power generation only. Standardisation has been only partially achieved due to limited and inconsistent responses from technology suppliers.

5.1 Energy Recovery & Efficiencies

5.1.1 General

A summary of energy recovery and efficiency issues is given below with a more detailed analysis in Appendix A. Sufficient data was only available from a limited number of technology suppliers regarding energy efficiencies.

The efficiencies given in the table below are for the conversion of waste energy, based on NCV, to net exported power for plants currently offered by technology suppliers.

Table 2 – Overall Net Electrical Efficiencies Claimed by Technology Suppliers

Thermal Treatment	Combustion	Gasification and Pyrolysis			
Power Generation	**Steam Cycle**	**Steam Cycle**	**Gas Engine**	**CCGT** **See 5.1.2**	**Co-fired with fossil fuel**
Overall Net Electrical Efficiency - Claimed		14% - 20%	13%-24%	34%	33%-35%[7]
Realistic	19 - 27%	9% - 20%	13% - 24%	23% - 26%	27 – 35%

The claimed efficiency figures are based on the technology suppliers' own assumptions and claims including those regarding char utilisation.

The realistic figures are calculated by applying anticipated efficiency of conversion of the energy in the fuel to energy in the syngas and then applying known efficiencies to the power generation cycles.

One of the proposed benefits of gasification and pyrolysis is that the use of gas engines or gas turbines will lead to higher electrical efficiencies.

The available data show that the use of gas engines is not enough to increase the net electrical efficiency above that currently achievable by modern combustion technology coupled to a steam cycle.

[7] The efficiency of the co-firing application depends on the efficiency of the process in which the syngas is used.

5.1.2 Generation Efficiency of Integrated Gasification Combined Cycle (IGCC) Systems

The use of a combined cycle gas turbine plant might increase the net electrical efficiency above that currently achievable by modern combustion technology coupled to a steam cycle.

It is essential to clean the syngas for use in a gas turbine due to the presence of tars, higher temperatures and other contaminants along with the associated risks of corrosion and fouling. These difficulties are not insurmountable, but they inevitably lead to further processing stages and give rise to additional inefficiencies, unavailability and costs. The use of a combined cycle gas turbine coupled to gasification and pyrolysis of RMSW is currently unproven anywhere in the world.

Attempts to develop commercial scale IGCC systems for firing of coal began over two decades ago and firing of biomass more recently. Neither of these two applications using easier fuels (higher NCV and/or more homogeneous) compared to RMSW has yet achieved commercial success. Combustion technologies remain the preferred choice for new coal and biomass fueled power stations.

An overall net electrical efficiency of 34% is estimated by one technology supplier, based on a gross (excluding site power use) power generation efficiency of 54% for the CCGT part of the plant alone. The following analysis puts these efficiency figures into perspective.

A 15MW output CCGT system using natural gas has a gross efficiency of about 41%[8]. Using a CCGT efficiency of 41% would give an overall net electrical efficiency of about 26% assuming the same fuel conversion efficiency and site power use claimed by the same technology supplier.

Use of waste heat recovery from the gasification process could increase the net electrical efficiency above 26%, but such improvements require additional equipment and lead to increased complexity. The actual efficiency will only be confirmed once a relevant demonstration plant is built.

5.2 Alternative Uses for Syngas

An option that is open to gasification and pyrolysis, but not to combustion technologies, is the alternative use of the product syngas other than for power generation.

One alternative use for syngas is as feedstock for chemical production. An example of this is the British Gas-Lurgi plant at Schwarze Pumpe, Germany with syngas used as a chemical feedstock to produce methanol.

Another alternative is the use of syngas as a substitute fuel in conventional power stations, industrial processes or CHP plants using gas. This possibility may be the most promising development opportunity for gasification and pyrolysis technologies. The impact of fuel substitution on the host plant output, reliability, performance and product quality would need to be assessed for each individual case. For very large host plants such as conventional power stations, the smaller gasification or pyrolysis plant would benefit from the high efficiency of the power generation stage.

[8] The figure of 41% supplied by Siemens Industrial Turbines Division

Some examples of MSW gasification and pyrolysis plants producing syngas as a fuel substitute are:

1) Lurgi plant at Rudersdorf, Germany feeding syngas into a cement kiln;
2) Foster Wheeler plant using syngas in a power station in Lahti, Finland;
3) Techtrade plant using syngas in a power station in Hamm, Germany.

The use of syngas as a substitute fuel in the above examples has a number of potential advantages:

1) The syngas does not need to be as clean as for use in gas engines or gas turbines;
2) The hot syngas may not need to be cooled down, so will not lose significant quantities of sensible heat;
3) No additional equipment is required for syngas utilization;
4) The waste treatment plants are either large or are attached to large host plants to benefit from the substantial economies of scale to make the facilities more economical and more energy efficient.

Whether such applications can be implemented in the UK will depend on the interpretation of WID by the regulator. If the consequence of using waste derived syngas in a fossil fuel fired process is that the process becomes subject to WID, it is unlikely that any of these applications will be developed.

5.3 Materials Balance

The materials balance information received from different technology suppliers is shown in Appendix B, Table 8. No direct comparisons can be made because of the varying assumptions between suppliers. However, some inferences can be drawn from the comparison:

1) Some technologies such as Brightstar's SWERF require pre-treatment of the waste before it can be fed into the thermal treatment process. This pre-treatment is usually associated with some additional recycling, particularly of ferrous and non-ferrous metals. It is important to ensure that the advantages (lower thermal treatment costs and increased recycling) and disadvantages (additional cost of pre-treatment and energy consumption) are fully accounted for when comparing different solutions;
2) Technologies such as that offered by Thermoselect, which is striving to produce a clean syngas, consume significantly more resources in terms of energy, water, and chemicals than those processes that are simply passing the hot untreated gas on to a combustion stage;
3) Pure pyrolysis technologies produce a carbon rich residue that has to be landfilled. Combustion and some gasification technologies produce a bottom ash that can be recovered for use as secondary aggregate in the construction industry.

5.4 Economics

It has not been possible to make detailed comparisons between different technologies from the limited information supplied. Cost breakdowns were generally either not given or not detailed enough to be scrutinised or verified. The assumptions used were also often not clear.

5.4.1 Capital Costs

The total capital cost (including buildings and civils) quoted for a 100,000 tonnes/year gasification and pyrolysis plant ranged between £23.5M and £30M. The cost for such a plant based on grate combustion technology is likely to be over £30M. Capital costs required for the complete operating facility with cost breakdowns were requested from the technology suppliers. Land costs, demolition and ground preparation costs, permitting costs, transport and other off-site costs, and disposal costs were to be excluded.

The limited information provided by the technology suppliers was not adequate to produce meaningful comparisons between different gasification and pyrolysis technologies or against combustion technology.

Reasonably accurate costs are only likely to come from real quotations to detailed specifications. Even costs obtained from tenders must be treated with a degree of caution since tender prices can vary dramatically from one supplier to the next even for almost identical technologies.

5.4.2 Operating Costs

Operating costs (excluding the cost of capital) quoted for the 100,000 tonnes/year gasification and pyrolysis plant generally ranged from £1.8M/year to £2.2M/year (about £20/tonne). Lower operating costs were quoted but these were only for part of the facility. The operating cost estimates requested were for the complete operating plant but excluding transport, disposal and other off-site costs. The information supplied was again often incomplete.

Operating costs can only be estimated with accuracy when derived from similar operating plants. As the costs quoted are generally not based on real data, they should not be considered as being accurate.

5.4.3 Renewable Obligation Certificates

In the UK, the Government is promoting the development of gasification and pyrolysis technologies by allowing them to qualify for Renewable Obligation Certificates (ROCs)[9]. ROCs increase the electricity revenue significantly and are considered a major incentive for those investing in gasification and pyrolysis technologies, although their unpredictable future value makes it difficult to finance a project on the basis of ROCs.

Modern energy from waste plants based on combustion technology do not qualify for ROCs in the UK as they are considered to be commercially mature. From a practical and environmental point of view, it is the source of the raw energy that determines whether it is renewable and not the technology that is used to refine the raw energy. The European Renewables Directive[10] takes this view and defines the biodegradable fraction of MSW as a renewable source regardless of the technology used.

---

[9] Statutory Instrument 2002 No. 914, "The Renewables Obligation Order 2002"

[10] Directive 2001/77/EC on promotion of electricity produced from renewable energy sources in the internal electricity market

To date, the only facility using gasification or pyrolysis technology for the thermal treatment of waste accredited for ROCs is the small Compact Power plant at Avonmouth which handles high gate fee waste such as clinical waste. This does not necessarily mean that other gasification and pyrolysis technologies cannot become accredited but simply that deployment of gasification or pyrolysis projects for RMSW in the UK is not yet in sight.

A brief review of what types of technologies are likely to qualify for ROCs and their impact is given in Appendix C.

About 60% of the power generated from an accredited gasification or pyrolysis plant running on MSW would qualify for ROCs. The remaining 40% of the power is assumed to be generated from fossil fuel based waste.

Electricity suppliers that fail to meet their renewable obligations targets will need to buy-out their unfulfilled obligations at the rate of £30/MWh. The money obtained from buy-outs is then shared out equally (for each ROC surrendered) amongst the electricity suppliers that are able to surrender ROCs.

If total renewable generating capacity exceeds total obligations then excess ROCs held by smaller independent generators that cannot be matched with obligations will be worthless. If total renewable generating capacity is lower than total obligations then ROCs will be worth more than £30/MWh due to the buy-outs.

A developer requiring finance needs a long-term power contract (for a minimum of fifteen years) at a predictable price. The value of ROCs is discounted in such arrangements reflecting the risk to the electricity supply company of committing to a firm future price.

The value of ROCs is unpredictable but is nonetheless a significant bonus for those projects that do not rely on a guaranteed high income stream from ROCs to make the project financially viable.

5.5 Emissions

This section focuses on emissions to air. Emissions to land and water are already covered under section 5.3 “Materials Balance”. The European Waste Incineration Directive (WID) sets the same emissions limits to air for gasification, pyrolysis, and combustion plants processing waste.

As part of the authorisation process, the developer must demonstrate that the plant has minimal impact on human health and the environment, regardless of the technology employed. Once this criterion has been achieved, different technologies may be compared on the basis of all of their impacts including emissions to air, water and land and taking into account their efficiency in displacing fossil fuelled power generation. If reductions in emissions to air are at the expense of reduced efficiency, increased use of other resources such as water, increased impact to land or water or higher cost then it will be necessary to weigh the benefits against the economic and environmental costs.

The emissions performance required under WID for thermal treatment of waste are more stringent than the requirements for other combustion processes. A major obstacle to the use of syngas in, for example, a coal fired power station is that the station would then come under WID which may have major economic, operational and image consequences for the process.

Note that the emissions from the plant, in isolation, are not the only measure of environmental performance. Improved energy efficiency of the plant increases the displacement of electricity generation from other generation plants. Given that conventional power generation plants operate under less stringent emissions regulations than those using RMSW, the displacement of power generation from fossil fuel fired plants can result in a substantial reduction in total emissions.

5.5.1 Conventional Steam Cycles

Few of the gasification and pyrolysis technology suppliers approached in this study provided comprehensive emissions data for this review. In the following table, the emissions to air for gasification and pyrolysis plants are compared against those from a plant based on modern combustion technology:

1) All pollution concentrations were corrected to WID reference conditions of dry gas and 11% oxygen;

2) Emissions data was based on the actual waste composition relevant to each plant so the comparisons are only indicative rather than on a strictly common basis.

Table 3 - Emissions to Air – Power Generation Using Steam Cycle								
	Units	**WID Limits**	**Lurgi**	**Thermo-select**	**Compact Power**	**WasteGen**	**Energos**	**Averaging Period**
Process			Grate combustion	Pyrolysis & gasification	Pyrolysis & gasification	Pyrolysis	Gasification	
Power generation			Steam cycle	Steam cycle	Steam cycle	Steam cycle	Steam cycle	
NO_x Control			SNCR	SNCR/SCR	SCR	SNCR	FGR	
Flue gas treatment			Spray absorber, fabric filter (with lime and activated carbon)	Wet scrubbing (4 stages), fabric filter (with sodium bicarbonate)	Fabric filter (with sodium bicarbonate)	Lime with feed, fabric filter (with sodium bicarbonate and activated carbon)		
Particulates	mg/Nm^3	10	<1	<2	2	1	0.01	Daily average
Sulphur dioxide	mg/Nm^3	50	20	<6	<1	20	17	Daily average
Oxides of nitrogen	mg/Nm^3	200	<200	<45	<37	167	128	Daily average
Carbon monoxide	mg/Nm^3	50	<5	<6	<2	<10	0.1	Daily average
Hydrogen chloride	mg/Nm^3	10	7	<1.5	2	5	1.2	Daily average
Hydrogen fluoride	mg/Nm^3	1	<0.2	<0.15	<0.1	Below detect	0.0082	Daily average
Total organic carbon	mg/Nm^3	10	<3	<1.5	<1	1.6	1	0.5 to 8 hour sample
Mercury	mg/Nm^3	0.05	0.004	<0.01	0.006	0.011	0.0001	0.5 to 8 hour sample
Cadmium, Thallium	mg/Nm^3	0.05	<0.001	0.0002	0.006	0.006	0.001	0.5 to 8 hour sample
Metals[11]	mg/Nm^3	0.5	<0.2	0.01	0.006	0.054	0.024	0.5 to 8 hour sample
Dioxins & furans	$ng ITEQ/Nm^3$	0.1	0.03	0.0005	<0.003	0.001	0.0009	6 to 8 hour sample

[11] Antimony, Arsenic, lead, chromium, cobalt, copper, manganese, Nickel, Vanadium and compounds associated with these metals

5.5.1.1 Comparison Against WID Limits

All three types of technologies (combustion, gasification, and pyrolysis) can achieve emissions significantly lower than the WID limits.

5.5.1.2 Lower Emissions Due to Improved Gas Cleaning Systems

Acid gas emissions such as sulphur dioxide and hydrogen chloride depend on:

a) The design of the flue gas treatment system;

b) The type, quantity and state of any neutralising agent used;

c) The type, quantity and condition of any scrubbing media used;

d) The chemical composition of the waste feed.

Differences in acid gas emissions are due to the flue gas treatment system and the input waste composition. The choice of thermal treatment process (gasification, pyrolysis, or combustion) is **not** a significant factor in determining acid gas emissions. At least one of the pyrolysis processes uses lime mixed with the waste to retain some of the acid gases. A similar technique is sometimes used in fluidised bed combustion. The relative merits of using lime in the thermal treatment as opposed to the flue gas treatment are not clear.

5.5.1.3 Reduced Emissions to Air Due to Choice of Thermal Treatment Technology

Generally, combustion processes operate at higher temperatures than gasification processes, which in turn operate at higher temperatures than pyrolysis processes. There are some exceptions to this general rule. Lower operating temperatures and less vigorous chemical reactions mean that lower quantities of pollutants such as heavy metals are likely to be volatilised into the gaseous stream. Table 3 indicates that gasification and pyrolysis plants generally emit lower levels of dioxins and certain metals to air compared to combustion plants.

The result is higher levels of pollutants in the char residue and lower levels of pollutants in the flue gas requiring removal in the flue gas treatment system. If the char from a low temperature treatment process is subsequently treated in a high temperature process such as gasification or combustion, then the benefits of the initially low temperature treatment may be reduced or entirely negated.

5.5.2 Gas Engines & Gas Turbines

The following table shows emissions test data from gas engines running on syngas derived from RMSW.

Table 4 - Emissions to Air – Power Generation Using Gas Engines

		WID Limits	Thermoselect	GEM
Plant			Chiba	Bridgend[12]
Process			Pyrolysis & gasification	Pyrolysis
Power generation			Gas Engine	Gas Engine
Particulates	mg/Nm^3	10	0.2	
SO_2	mg/Nm^3	50	2	55
NO_x	mg/Nm^3	200	13	250
CO	mg/Nm^3	50	1799[13]	1000
Dioxins & furans	ng $ITEQ/Nm^3$	0.1	0.0011	

Note that these emissions figures are based on limited test data. Actual emissions figures may be different when optimised for long term operation. Typical emissions figures[14] reported for gas engines running on landfill gas are 300 mg/Nm^3 for NO_x and 875 mg/Nm^3 for CO.

Control of NO_x, CO, and volatile organic compounds (VOCs) from gas engines and gas turbines can be difficult. It is particularly difficult to simultaneously control CO and NO_x emissions from gas engines. Increasing combustion air can reduce CO emissions, but this will increase NO_x levels and also reduce energy efficiency. Conversely, reducing NO_x is likely to result in increased CO emissions.

Expensive catalytic converters or thermal oxidisers are likely to be required for flue gas treatment to remove CO from gas engine exhausts. A recent report[15] published by the Environment Agency suggested that even with catalytic converters, CO emissions from gas engines might still struggle to achieve WID limits.

Although no data is available for VOCs, high CO is an indicator of incomplete combustion and likely to be equated with high levels of VOCs. Gas engines running on landfill gas report VOC emissions of about 600 mg/Nm^3.

---

[12] IPPC data supplied by Environment Agency

[13] This result based on not using catalytic converter

[14] All corrected to the same reference conditions as for WID for ease of comparison

[15] EA Technical Report P4-100/TR "Review of BAT for New Waste Incineration Issues, part 1: Waste Pyrolysis & Gasification Activities"

No emissions data for gas turbines running on syngas derived from RMSW is available because no commercial example of such a configuration exists.

Neither gas turbines nor gas engines can comply with the WID requirement for a minimum of 2 seconds residence time at a temperature of at least 850 ^{o}C after the last point of air injection. There is flexibility for the Environment Agency to waive this requirement if it can be demonstrated that doing so would not compromise emissions control.

5.5.3 Syngas Cleaning

The cost of gas cleaning may be reduced by cleaning the much smaller quantity of syngas, rather than cleaning the larger quantity of flue gas after combustion. However, due to the presence of tars, syngas cleaning is demanding. The cleaning of syngas derived from RMSW to the point where flue gas from gas engines or gas turbines do not require further treatment to meet WID has yet to be demonstrated. Also there are no defined criteria to enable the regulator to determine whether the cleaning is sufficient to waive the requirements of WID in the subsequent combustion process.

Syngas cleaning normally necessitates cooling, resulting in the loss of sensible heat from the syngas that cannot be fully recovered.

5.6 Visual Impact

5.6.1 Results

Table 5 - Estimated Footprints and Building Heights

Technology	Thermal Treatment	Power Generation	Footprint	Building Height
			m^2	m
Lurgi	Grate Combustion	Steam Cycle	15,000	30
Novera/Enerkem	BFB Gasification	Gas Engine		17
GEM	Fast Pyrolysis	Gas Engine	15,600	11
Compact Power	Tube Pyrolysis	Steam Cycle	15,300	10
Brightstar	Tube Pyrolysis	Gas Engine	20,000	15

5.6.2 Footprint

The footprint requested was for the complete site (length x width of site boundary). Layout sketches were also requested to enable confirmation that this definition had been interpreted correctly. Many suppliers were unable to supply the footprint for the entire site and instead excluded important items such as roads, parking, offices, waste pre-treatment, and power generation.

Only the suppliers that provided the footprint for a complete site are included in the table above.

5.6.3 Building Height

For plants using a steam cycle, the building height is likely to be determined by the size of the boiler.

If syngas is to be used in gas engines, then building heights should be lower due to the absence of the boiler. For plants using gas engines, other structures such as the gasifier may then be the tallest on site.

Modular designs with many lines will result in lower buildings at the cost of spreading out over a larger area.

Smaller and less efficient boilers may also result in lower building heights.

5.6.4 Stack Height

Stack heights are influenced by many factors that have little to do with the thermal treatment technology employed. These factors include local topography, local weather, local background pollution concentrations, local air quality targets and safety margins.

Assuming comparison of different technologies on a common basis, the main factors in determining stack height are the height of the tallest building, the quantity of flue gas discharged and the concentration of pollutants at the point of discharge. It is assumed that the temperature and velocity of discharge will be similar for the different technologies.

The quantity of flue gas discharged will be similar for the different technologies. Gasification and pyrolysis followed by combustion of the syngas will result in exactly the same quantity of flue gases as direct combustion provided the quantity of excess air in the flue gases are the same. The quantity of excess air will generally be similar to ensure complete oxidation in a boiler. Excess air in gas engines can be lower but this will produce high levels of CO. Excess air for gas turbines can be higher than for boilers, producing over 50% more flue gas than boilers.

One reason for gasification or pyrolysis resulting in lower quantities of flue gas would be if a significant quantity of carbon remains in the char residue. In this case, the impact of carbon in char and reduced energy efficiency must be weighed against the impact of more combustion products and a taller stack.

Note that excess air affects the volume of flue gas but not the quantity of CO_2 emitted. The quantity of CO_2 is purely dependent on the quantity of carbon combusted.

Stack height is almost invariably dictated by NO_x emissions. A process for which guarantees can be given that NO_x emission levels would be significantly below those in WID would not need as tall a stack.

The height of the tallest building has an influence on the stack height since the stack must be tall enough to ensure that tall buildings do not interfere with dispersion of pollutants. The stacks for plants using gas engines or modular designs may therefore be slightly lower than for those using steam boilers.

All energy from waste plants emitting flue gases to the atmosphere will require a discharge stack, regardless of technology employed.

5.7 Commercial Availability

Development, demonstration and commercialisation of large-scale capital-intensive technologies such as gasification and pyrolysis are generally slow, costly and without guarantee of success. The following examples illustrate some of the difficulties that have been encountered by gasification and pyrolysis projects:

1) The Furth plant, based on Siemens technology, struggled to achieve satisfactory operation and was eventually closed. Siemens have withdrawn from this market although other developers, notably in Japan, have continued to develop this technology;

2) The ARBRE project in the UK, based on TPS technology and intended to gasify short rotation coppice, failed to get past the commissioning phase and has been abandoned;

3) The Wollongong demonstration plant, based on Brightstar's SWERF technology, has not lived up to expectations. Energy Developments Limited, the majority owner of the SWERF process, has stopped all development funding to the demonstration plant.

Arguably, one of the best commercial examples of a gasification and pyrolysis plant for MSW derived fuel is the Rudersdorf plant based on Lurgi technology. The plant has been working well and supplying syngas to a cement kiln. In spite of this good track record, Lurgi has recently decided to withdraw from the gasification pyrolysis market for waste and issued the following statement[16]:

> *" …can confirm that a decision has been taken within Lurgi to discontinue marketing gasification and pyrolysis technologies for waste conversion applications. This decision has come after a rigorous analysis of the market requirements, technical feasibility and economic sensitivities of gasification and pyrolysis of waste, as applied by Lurgi and our competitors. We recognise that there is a positive bias towards gasification/pyrolysis amongst politicians and environmentalists. However, we are in no doubt that in the short to medium term neither technology will be developed and commercially proven to the point where it can compete."*

The track records of individual gasification and pyrolysis suppliers are described in Appendix D. Some of the technologies listed have a credible track record in that there are one or more commercially operational examples of the technology treating either RMSW or RDF. There is an opportunity for these technologies to be employed in the UK where they can establish a commercial benefit or in communities that have specifically ruled out combustion (but not gasification or pyrolysis).

Some gasification and pyrolysis technologies are being marketed based on using gas engines or gas turbines for power generation. However, the only examples where high power generation efficiency has been achieved are those in which syngas is delivered to a fossil fuel Power station with high power generation efficiencies.

Technology suppliers have yet to develop any track record of operating gasification or pyrolysis plants coupled to a CCGT system for power generation on a commercial scale and using RMSW as a feedstock. The problems associated with engine emissions and authorisation under IPPC as described in 5.5.2 remain to be resolved.

There have been many attempts to realise the benefits of high power generation efficiency using pyrolysis and/or gasification combined with gas engines or gas turbines. However, these attempts have yet to be successful. More time, effort and resources as well as the political will to resolve the legislative difficulties will be required if these high efficiency aspirations are to stand any chance of becoming commercial reality.

[16] In letter to Fichtner dated 08-09-2003

5.8 Risk Management

Purchasers of, and lenders for, thermal waste treatment facilities are reluctant to invest in technologies with a limited track record.

Possibilities for risk management include:

1) Use of efficacy insurance to reduce risks to the technology supplier, purchaser and lender. Such insurance is intended to cover against the risk of the installed facility not meeting certain specified performance criteria. The availability of such insurance for unproven technologies at an affordable cost should not be assumed;

2) Technology suppliers with adequate financial strength, faith and inclination can finance initial commercial projects from their own balance sheet and take on all of the risks of failure. The number of technology suppliers able to take this approach is very limited and even these companies would not be able to progress more than one or two such projects at a time;

3) Technology suppliers may try to convince their customers to share the risks of failure, in some form of partnership. This approach may be suited to power stations using syngas;

4) To progress gasification and pyrolysis technology development, it may be necessary for the government to engage more positively in the market, for example, by providing capital grant support or by underwriting the value of ROCs to selected technologies;

5) PFI (private finance initiative) procurement rules are designed to transfer the risk from the public to the private sector. Public procurement rules need to change if emerging technologies are to be deployed in the UK. Technical development is in the interests of all stakeholders and the risks cannot necessarily be born by private developers alone.

5.9 Effect of Scaling Up

Scaling up plant size can offer substantial benefits in terms of reduced unit costs, more efficient use of land and increased plant efficiency.

5.9.1 Effect of Scaling Up on Economics

Plant capital costs do not increase linearly with plant capacity. A crude but very common method of estimating the capital cost of process equipment[17] is by assuming that capital cost is proportional to capacity raised to a power n. The index n is often assumed to be about 0.6 but will vary depending on the type of equipment. This means that if the plant capacity is doubled then the capital cost will only increase by about 50%.

There are a number of reasons why capital costs do not increase by as much as plant capacity:

1) Many costs such as roads, weighbridges, offices, development fees and engineering design remain similar irrespective of plant capacity;

2) The capacity of equipment such as waste bunkers, boilers and vessels depend on their volume but their cost depends on the quantity of construction material (approximately equating to surface area).

[17] For example as described in Coulson J M, Richardson J F, & Sinnott R K ,“Chemical Engineering”, 1991, volume 6, page 185

Increasing plant capacity will similarly also reduce the unit cost of operation. Maintenance costs are linked to plant capital costs. The number of operators required to run a plant will normally depend on plant complexity rather than on the size of the equipment. Many other functions remain essentially fixed regardless of plant capacity.

5.9.2 Effect of Scaling Up on Land Use

Doubling the plant capacity does not require a doubling of the footprint area. The footprint from roads, parking, offices etc would only increase marginally. Even the footprint from the main processing equipment would not scale linearly since most of the equipment will be volumetric devices. For example, to double the volume of a cube it is only necessary to increase its footprint by about 60%. Therefore increasing plant capacity will reduce the specific area (m^2/tonne of waste processed).

5.9.3 Effect of Scaling Up on Energy Efficiency

Boilers, turbines, pumps and fans tend to be more efficient at higher capacities, although the effect is more marked with some types of equipment than with others.

Percentage heat losses via hot surfaces to atmosphere crudely depend on the ratio of surface area to volume. The ratio of surface area to volume will decrease with increasing plant capacity.

Leakage paths in rotating machinery are more significant in smaller machines than in larger. Larger turbines, pumps and compressors have more accurately shaped blades and impellers and can accommodate more stages than smaller machines.

Larger capacity plants will therefore generally be more efficient than smaller plants.

5.9.4 Effect of Scaling Up on Environmental Performance

Energy efficiency increases with increasing plant capacity as does the efficiency of emission abatement equipment. Environmental performance (per unit waste processed) will therefore improve as a direct result of improved energy efficiency.

5.9.5 Economies of Scale vs Proximity Principle

The proximity principle is enshrined in the government's waste strategy[18]. The proximity principle is based on the premise that waste management facilities should be sited locally to the waste producers so that waste problems are not exported to others. The proximity principle attempts to give local waste producers ownership of their own waste problems, to create waste awareness, to encourage waste minimisation and recycling, and to give a sense of fairness.

[18] For example in Waste Strategy 2000

Strict application of the proximity principle would result in many small local waste management facilities rather than fewer larger centralized facilities. The main practical benefit of small and localized waste management facilities is a reduction in transportation from the waste producers to the local waste management facility. However, recovered materials still need to be transported very long distances to reprocessing facilities. Reject materials and residues still need to be transported long distances to landfill sites.

From previous sections it is clear that, in all cases, increasing plant size whilst keeping all other factors constant offers substantial economies of scale in terms of capital costs, operating costs, land use, plant efficiency and plant performance including environmental performance.

The proximity principle should therefore be applied in a pragmatic manner with due consideration for the substantial economies and benefits that can be gained from larger, more centralised facilities.

The proximity principle can be an obstacle to technology development and utilisation if it prevents economies of scale. Some gasification and pyrolysis suppliers have indicated that their technologies would only be economical at relatively large capacities although others claim that their technologies are more competitive at smaller capacities.

5.9.6 Scaling up and Risk

The consequences of failure increase with the size and capital cost of the project. It is therefore unlikely that any solution other than well proven technology will be used in a large-scale application in the short to medium term.

5.9.7 Small Gasification and Pyrolysis Plants

With some notable exceptions, thermal treatment plants based on gasification and pyrolysis technology have tended to be small whilst those based on combustion technology have tended to be larger. Plants become more efficient and more economical as they become larger regardless of technology employed.

The suppliers of commercially unproven technologies will not have the necessary knowledge, experience, confidence, financial backing and willing customers for large installations. Larger plants will be installed as these technologies mature.

Some gasification and pyrolysis technologies are based on modular designs. Modular technologies avoid the risks associated with scaling up but do not fully benefit from the significant economies of scale that are available to scaleable technologies when large quantities of waste need to be processed.

6 IMPEDIMENTS TO DEVELOPMENT OF ADVANCED THERMAL TECHNOLOGIES

There are few plants for treating RMSW based on gasification and pyrolysis technology in commercial operation or under construction in Europe and none at all in the UK.

The main impediments to development are:

1) A mismatch between the risk bearing capabilities of suppliers, consumers and lenders. The parties involved are generally unable or unwilling to accept an adequate portion of the risks in a project if the technology involved is unproven;

2) Difficulties in securing funding for those technologies with limited operating experience and track record;

3) Proximity principle deterring larger scale developments regardless of type of technology employed;

4) Low gate fees for waste treatment and disposal is a deterrent for all types of waste projects but more so for those utilising capital intensive plant and equipment;

5) ROCs are often cited as an incentive from the UK government for development of gasification and pyrolysis technologies. As detailed in Appendix C, ROCs do not appear to be the ideal way to drive development of gasification and pyrolysis technologies for waste and in some instances serve to inhibit efficient design and to discourage innovative developments. Projects depending on a high revenue from power sales need this revenue to be predictable for the finance life of the project;

6) Expenditure of scarce resources and effort on perceived benefits that do not exist rather than focusing on developments that may result in real benefits.

Unless some of these obstacles are addressed, commercially successful standalone plants based on gasification or pyrolysis technologies for the thermal treatment of RMSW will be difficult to deliver in the UK in the near future.

7 POTENTIAL DEPLOYMENT AND AREAS FOR FURTHER DEVELOPMENT

Although there are many barriers to the general implementation of gasification and pyrolysis technologies for treatment of RMSW in the UK, there are also strong incentives to encourage further efforts to bring about their deployment.

The energy efficiency (i.e. resource utilisation) of stand alone small scale pyrolysis and gasification plant generating electricity is likely to be significantly less than a combustion plant. Development of gasification or pyrolysis merely as a way to dispose of municipal waste with low efficiency electricity generation appears to be an insufficient ambition.

Potential developments of gasification and pyrolysis in the UK in the near to medium term are:

1) Use of the syngas as a fossil fuel substitute in power stations, industrial processes or CHP schemes. These configurations can potentially benefit from using existing higher efficiency energy conversion equipment and also, if the host plant is large, significant economies of scale. The quality requirements and demand pattern of the host plant must match that of the syngas produced. The negative image associated with incineration and the more stringent emissions limits of WID that are invariably associated with waste treatment are significant barriers to the acceptance of waste derived fuels in traditionally fossil fuel fired applications;

2) Use of proven gasification or pyrolysis technologies in standalone power generation with a conventional steam turbine cycle if the application is commercially competitive or the local authority has precluded the use of combustion;

3) These systems can also be used for treatment of selected waste streams such as homogeneous and high NCV waste fuels or high gate fee wastes. Examples of these wastes would be plastics, RDF and clinical wastes.

Longer term potential areas for development are:

1) Cleaning the syngas for use in a combined cycle gas turbine plant to give higher net electrical efficiencies;

2) Further processing of the syngas for use in producing valuable transport fuels;

3) Use of syngas as a chemical feedstock.

These applications are at various stages of research, development and demonstration which may require considerable time, effort and political will.

However, if technically and commercially successful, they may ultimately offer substantial benefits. The potential benefits would be lower costs, lower environmental impact, and lower dependency on ever decreasing fossil fuel reserves.

8 CONCLUSIONS

The conclusions of the assessment of commercial and technical viability of gasification and pyrolysis for treatment of RMSW in the UK are summarised below.

8.1 Uncertainties

Many of the gasification and pyrolysis technologies for the thermal treatment of RMSW are still generally commercially unproven. There are few relevant operational plants and therefore little data upon which developers and lenders can rely. The uncertainties (regarding performance, reliability and economics) associated with using those technologies that are unproven for the treatment of waste is generally considered to be high.

8.2 Emissions

Plants based on all three types of technologies in connection with a conventional steam boiler and steam turbine cycle can generally comfortably meet the WID emissions limits. In the application for authorisation, the operator has to demonstrate that the impact on human health and the environment is minimal and the plant, regardless of technology, has to be designed to meet this criterion. A plant that can guarantee lower emissions of a critical parameter, such as $NO_{x,}$ will be able to benefit from a shorter stack height.

The real value of differences in emissions to air between technologies has to be carefully weighed against any increased use of resources, increased residue generation or reduced generation efficiency. There is currently insufficient reliable data on which to base this complex comparison.

Plants based on the use of syngas from gasification or pyrolysis in gas engines or gas turbines will be unable to meet the WID requirements concerning the residence time of the products of combustion and will also need additional and expensive final treatment to reduce CO and NO_x emissions.

There is no commercially operating gas turbine running on syngas derived from RMSW, so no reliable emissions data can be given for such a configuration.

Generally, emissions performance can be improved for any thermal treatment process (combustion, gasification or pyrolysis) with additional capital and operational expenditure.

8.3 Materials Recovery and Waste Disposal

Processes which require waste preparation and are not already being supplied with a prepared waste may recover some additional materials for recycling, particularly metals.

Pyrolysis plants will produce a residue that contains significant quantities of carbon and most of the original pollutants present in the incoming RMSW. This residue will have to be landfilled or undergo further treatment. Most of the bottom ash from combustion and some gasification processes can be re-used as secondary aggregate in the construction industry.

Processes with complex syngas cleaning systems aimed at the production of a clean syngas generally require significantly more energy and resources such as water and chemicals than other processes.

8.4 Energy Efficiency

In terms of fuel conversion efficiency, the complete combustion of the fuel is more efficient than any other thermal process. Therefore neither gasification nor pyrolysis can have higher thermal efficiencies[19] than combustion. In most practical cases, the thermal efficiencies for gasification and pyrolysis technologies will be lower than for combustion technologies.

In terms of the efficiency of standalone plants optimised for power generation, all existing gasification and pyrolysis technologies have lower efficiencies than that currently achieved by modern combustion technology. The only standalone gasification or pyrolysis configuration that might result in a higher overall electrical efficiency[20] than combustion technology is one based on the use of a combined cycle gas turbine for power generation, but this configuration is currently unproven on RMSW.

The overall efficiency of gasification and pyrolysis processes may be improved by co-firing of the syngas, and possibly also the char, with other fuels in a large conventional power station. However, this application in the UK may be inhibited by the Environment Agency's interpretation of WID.

8.5 Plant Reliability and Utilisation

Only a few of the gasification and pyrolysis technology suppliers have adequate operating experience to accurately estimate long-term plant reliability and utilisation in a complete and commercially viable facility.

8.6 Economics

Meaningful comparisons of capital and operating costs for the different technologies were not possible from the limited information supplied. There is little evidence to support the view that gasification and pyrolysis plants will be significantly cheaper than combustion plants when compared at similar plant capacities.

8.7 Footprint

The footprints of gasification and pyrolysis plants appear to be generally similar to each other and also to combustion plants. Modular technologies are increasingly disadvantaged as the waste processing capacity increases.

8.8 Visual Impact

Building heights for thermal treatment plants using gas engines for power generation should be lower than those needing to use a steam boiler. Modular designs that increase capacity by duplication of modules rather than scaling up can reduce building height at the expense of a larger footprint.

Stack height is determined by a combination of factors including the ground level impact of emissions, topography and building heights and proximity.

---

[19] For conversion of waste and auxiliary fuel energy to syngas energy (for systems using gas engines or gas turbines for subsequent power generation) or steam energy (for systems using steam turbines for subsequent power generation).

[20] For overall conversion of waste and auxiliary fuel energy to net exported electricity.

8.9 Economies of Scale

Regardless of technology employed, plants will become more economical, more energy efficient and use less land when capacity is concentrated in fewer but larger plants. These economies of scale can be substantial.

8.10 Impact of Scale on Choice of Technology

Some gasification and pyrolysis technologies are based on modular designs. Modular technologies avoid the risks associated with scaling up but do not fully benefit from the significant economies of scale that are available to scaleable technologies when large quantities of waste need to be processed.

8.11 Impediments to Development of Gasification and Pyrolysis Technologies

The main impediments to progress in the implementation of gasification and pyrolysis technologies are the lack of track record for many of the technologies (particularly in the UK), difficulties in securing funding, uncertainty in the value of electricity generated and the limited progress which has been made toward the achievement of high power generation efficiency.

8.12 Commercial Viability

Some of the technologies listed in Appendix D have a credible track record in that there are one or more commercially operational examples of the technology treating either RMSW or RDF. There is an opportunity for these technologies to be employed in the UK where they can establish a commercial benefit or where combustion technology (but not gasification or pyrolysis) has specifically been ruled out by the local authority.

Potential developments of gasification and pyrolysis in the UK in the near to medium term are:

1) Use of the syngas as a fossil fuel substitute in power stations, industrial processes or CHP schemes;

2) Use of proven gasification or pyrolysis technologies in standalone power generation configurations where a commercial benefit can be demonstrated.

8.13 Longer-Term Development

Longer-term potential developments include:

1) Cleaning the syngas for use in a combined gas cycle;

2) Further processing of the syngas for use in producing transport fuels;

3) Use of syngas as a chemical feedstock.

If technically and commercially successful, such developments may ultimately offer substantial benefits including lower costs, lower environmental impact, and lower dependency on ever decreasing fossil fuel reserves.

Appendix A Energy Efficiency

One of the major claims for gasification and pyrolysis technologies is that they offer higher energy efficiencies compared to combustion technology. This appendix reviews the evidence behind these claims.

A.1 Methodology and Definitions

The energy efficiencies of the different technologies are compared based on assuming that the only form of energy output will be electricity.

The "Net Electrical Efficiency" is defined as the electrical energy exported from the site divided by the total fuel energy input to the site. The total fuel input to the site will include the waste and any significant auxiliary fuel. All fuel energies and efficiencies in this report are based on net calorific values rather than gross.

The net electrical efficiency (E) is defined as: $E = E_{th}\, E_g\,(1-P_p)$

E_{th} = Thermal conversion efficiency – defined as efficiency of conversion from fuel to steam or syngas expressed as a % of the total thermal input. For processes that utilise a simple steam cycle, the thermal efficiency is that for converting waste energy to steam energy. For processes utilising gas engines or gas turbines, the efficiency is that for converting waste energy to syngas energy after any cooling and cleaning but before compression;

E_g = Electrical generation efficiency – defined as gross efficiency of converting syngas to power expressed as a % of the syngas energy;

P_p = Parasitic load for the whole site including any pre-treatment, oxygen enrichment of air etc expressed as a % of the gross power generated.

A.2 Results

The following tables compare the overall net generation efficiencies claimed by different technology suppliers for their processes. Whilst some effort has been made to screen out obvious errors in the data supplied by the technology suppliers, it has not been possible to subject the efficiency claims to detailed scrutiny. Inclusion in this table does not necessarily mean that these efficiencies have been proven and in some cases it was not possible to reconcile the claimed efficiencies with the data provided.

As can be seen from the wide range of thermal inputs, each supplier has chosen to use a different waste flow and NCV into the plant even though data was requested for a plant capacity of 100,000 tonnes/year with a waste NCV of 8.48 MJ/kg. In many cases the deviations from the defined plant capacity were due to assuming some form of pre-treatment to divert some material away from the thermal treatment process. Waste flows and compositions after pre-treatment were simply assumed.

Many of the processes did not include for the loss of chemical energy associated with materials that have been diverted away during the pre-treatment process, or for the power that would be consumed by the pre-treatment process. To include these losses would make the relevant technologies significantly less energy efficient than shown in the table. Energy efficiency tends to increase with increasing plant capacity. To compare the larger plants against the smaller plants on a more similar basis, the efficiencies for the larger plants should be reduced.

Table 6 - Overall Net Power Generation Efficiencies for Thermal Treatment Coupled to Steam Cycles

		Lurgi	Novera/Enerkem	Compact Power	IET/Entech	Energos	WasteGen
Thermal treatment		**Combustion**	**BFB Gasification**	**Tube Pyrolysis**	**Grate Gasification**	**Grate Gasification**	**Rot-Kiln Pyrolysis**
Power generation		**Steam Cycle**	**Steam Cycle**	**Steam Cycle**	**Steam Cycle**	**Steam Cycle**	**Steam Cycle**
Thermal input	MWth	42.5	35.4	40.0	34.4	32.1	31.6
Syngas energy	MWth	N/A	19.4	30.1	No data	26.8	
Power generated	MWe	11.1	6.0	6.5	7.3	6.0	
Site power use	MWe	1.4	0.7	0.9	0.4	1.5	
Export power	MWe	9.7	5.3	5.6	6.8	4.5	
Conversion efficiency	%	83%	55%	75%	No data	84%	
Generation efficiency	%	31%	31%	22%	No data	22%	
Overall gross efficiency	%	26%	17%	16%	21%	19%	
Site power use	%	12%	11%	14%	6%	25%	
Overall net efficiency	**%**	**23%**	**15%**	**14%**	**20%**	**14%**	**20%-25%**
Include power consumed in pre-treatment?	Yes/No	Yes	No	Yes	No	Yes	
Include chemical energy loss in pre-treatment?	Yes/No	Yes	No	No	No	No	

Table 7 - Overall Net Power Generation Efficiencies for Thermal Treatment Coupled to Gas Engines & CCGTs							
	Units	**Novera/Enerkem**	**GEM**	**Thermoselect**	**Brightstar**	**FERCO**	**Theoretical**
Thermal treatment		**BFB Gasification**	**Fast Pyrolysis**	**Tube Pyrolysis**	**Tube Pyrolysis**	**CFB Gasification**	**Gasification**
Power generation		**Gas Engine**	**Gas Engine**	**Gas Engine**	**Gas Engine**	**CCGT**	**CCGT**
Thermal input	MWth	35.4	27.2	91.9	29.9	66.0	-
Syngas energy	MWth	25.8	20.2	53.3	No data	49.5	-
Power generated	MWe	8.8	6.9	21.7	6.2	26.6	-
Site power use	MWe	1.0	0.5	9.4	0.6	4.0	-
Export power	MWe	7.8	6.4	12.4	5.6	22.6	-
Conversion efficiency	%	[21]73%	74%	58%	60%	75%	75%
Generation efficiency	%	34%	34%	41%[22]	35%	54%	41%
Overall gross efficiency	%	25%	25%	24%	21%	40%	31%
Site power use	%	11%	7%	43%	10%	15%	15%
Overall net efficiency	**%**	**22%**	**24%**	**13%**	**19%**	**34%**	**26%**
Include power consumed in pre-treatment?	Yes/No	No	Yes	Yes	Yes	No	No
Include chemical energy loss in pre-treatment?	Yes/No	No	No	Yes	Yes	No	No

[21] The conversion efficiency given for use in a steam cycle is lower since it includes losses associated with steam generation that are not applicable if syngas is fired in a gas engine

[22] Bulk of Thermoselect experience is with Jenbacher engines rated at 37% efficiency but Thermoselect are looking to use larger (8.6MWe) Pielstick Engines believed to able to achieve an efficiency of 40.8%.

A.3 Thermal Conversion Efficiency

The thermal conversion efficiencies for gasification and pyrolysis processes tend to range from about 55% to 75%. If the hot syngas is used directly in a steam boiler without cooling then the sensible heat in the syngas will not be lost, but there will be losses associated with the steam generation process.

The conversion efficiencies for the gasification and pyrolysis technologies reviewed were generally lower than that achievable by a modern combustion process. In terms of fuel conversion efficiency, the complete combustion of the fuel is more efficient than any other thermal process. Therefore neither gasification nor pyrolysis can have higher thermal efficiencies than combustion at similar excess air levels.

A.4 Power Generation Efficiency

A.4.1 Steam Turbine

All combustion technologies and almost all gasification and pyrolysis technologies processing RMSW currently utilize steam turbines for power generation. The hot exhaust gas, from combustion of the solid, liquid, or gaseous fuel, is used to generate steam in a boiler. The steam is used to drive a steam turbine for electricity generation.

Modern steam turbine systems, of the size and temperature/pressure normally associated with waste fired plants, can typically achieve electrical generation efficiencies (power output divided by steam energy) of about 31%.

A.4.2 Gas Engine

The gas engine electrical generation efficiencies derived from data provided by GEM, and Novera lie in the range 34% to 37%. These efficiencies are similar to those obtained from landfill gas engines. The bulk of Thermoselect experience is with Jenbacher engines rated at 37% efficiency but Thermoselect are looking to use larger (8.6 MWe) Pielstick Engines claimed, by Thermoselect, to able to achieve an efficiency of 40.8%.

A.4.3 Combined Cycle Gas Turbine

The efficiencies of large-scale combined gas cycles using natural gas as fuel are very high. A 560 MWe output (SF107FB) combined cycle offered by GE Power would have a maximum electrical generation efficiency of about 58%. This efficiency is the result of years of development on large gas turbines for major power plants using specifically natural gas and very high combustion temperatures. This performance is not representative of smaller scale industrial gas turbines and could not be achieved on a fuel gas with a lower and less predictable NCV.

A typical small-scale industrial CCGT plant has a net generation efficiency of around 41%[23] on natural gas.

[23] The figure of 41% for 15MW output CCGT running on natural gas supplied by Siemens Industrial Turbines Division

The overall net electrical efficiency of 34% is estimated by FERCO based on a gross (i.e. excluding parasitic loads) power generation efficiency of 54% for the CCGT part of the plant alone. If the above figure of 41% is used instead of 54%, the net generation efficiency of the facility will be approximately 26% (as shown in the last column of Table 7).

A.4.4 Parasitic Load

Power is consumed in the operation of the complete facility by equipment such as fans, pumps, compressors, other machinery and lighting. A significant portion of power generated will not be available for export. It is important to account for all site power use. The power consumed in generating utilities such as compressed air, nitrogen and oxygen are sometimes forgotten. Similarly the power consumed by pre and post treatment processes must also be accounted for.

Site power use varies significantly from one process to the next. Processes that utilise oxygen for gasification will consume a lot of power to produce the oxygen.

A.4.5 Summary

A.4.5.1 Net Electrical Efficiency Using Steam Cycles for Power Generation

For a modern plant based combustion technology, the net electrical efficiency is in the range 19 to 27%.

For gasification and pyrolysis technologies the net electrical efficiency is about 14%-20%.

If power is generated by means of a steam cycle, then the direct combustion process will generally have a higher generation efficiency than pyrolysis or gasification technologies.

A.4.5.2 Net Electrical Efficiency Using Gas Engines for Power Generation

For gasification and pyrolysis technologies the net electrical efficiency is about 13%-24%.

Even the use of more efficient gas engines for power generation is not enough to give overall efficiencies higher than for modern direct combustion processes coupled to steam cycles.

A.4.5.3 Net Electrical Efficiency Using CCGT for Power Generation

The successful use of a combined cycle gas turbine plant might give a higher net electrical efficiency. However, the use of gas turbines has yet to be demonstrated on a commercial plant using RMSW as the starting point.

A.4.5.4 Net Electrical Efficiency by Co-firing of Syngas in Conventional Power Station

One reason for the relatively low electrical efficiency of standalone plants using RMSW is their relatively small scale. The electrical output of conventional power plants can be over 30 times[24] higher than from standalone plants using RMSW.

One way of capitalising on the very significant benefits of scale is to co-fire the syngas from gasification or pyrolysis plants processing RMSW in much larger existing conventional power stations. The implications of this configuration are as follows:

1) The smaller gasification or pyrolysis plant benefits from the much higher energy efficiency of the larger boiler and power island:
   - The net electrical efficiency attributable to the gasification portion (rather than the fossil fuel portion) of the Lahti plant is estimated by Foster Wheeler to be about 33%. This estimate is based on a net efficiency of about 36% for the boiler and power island portions of the plant;
   - The net electrical efficiency attributable to the gasification portion (rather than the fossil fuel portion) of the Hamm plant is estimated by Techtrade to be over 35%. This estimate is based on a net efficiency of over 40% for the boiler and power island portions of the plant;
2) The use of a boiler means that difficulties and inefficiencies associated with syngas cleaning required for use in a gas engine or gas turbine can be avoided;
3) The energy in the char can be recovered by firing in the conventional boiler also;
4) The boiler, power island and much of the site infrastructure of the host plant helps to reduce the additional capital costs;
5) This configuration means replacement of fossil fuel with waste fuel. Standalone configurations represent additional power generation capacity.

[24] 600MW conventional power stations compared to 20MW plants using MSW derived fuel.

Appendix B Materials Balance

The intention of the review was to ensure that comparisons between technologies were consistent. Each supplier was asked to provide a mass balance for a 100,000 tonnes/year plant[25] based on a design waste composition and specifically asked to ensure that total inputs balanced exactly with total outputs. Mass balances with obvious gaps or which did not balance have been omitted from the table.

The majority of the mass balance information supplied, even that shown in the table below, was based on the suppliers' understanding of a typical waste or RDF composition rather than the design waste composition. The data in the table is therefore indicative only, rather than strictly comparable on a common basis.

B.1 Materials Recovery

Some technologies require pre-treatment of the RMSW in order to reduce particle size and remove unwanted material. There will then be additional benefit from the recovery of recyclable materials, particularly metals.

Front-end processing requires additional land, capital expenditure, operating expenditure and energy consumption. These factors need to be considered when comparing technologies.

B.2 Solid Residues

Combustion, pyrolysis, and gasification all typically produce two grades of solid residues:

1) Bottom ash – from the bottom of the combustor, pyrolyser, or gasifier;

2) Flue gas treatment (FGT) residues - containing fly ash, flue gas treatment chemicals, and chemicals produced in the flue gas treatment process.

B.2.1 Combustion Residues

The Environment Agency recently concluded[26] that bottom ash produced by energy from waste plants based on combustion technology is suitable for re-use in certain building and construction applications. A pyrolysis process that produces a carbon rich residue would have difficulty providing an ash suitable for these applications.

B.2.2 Gasification Residues

Some gasification processes claim to produce better quality residue compared to that from combustion. For example, the Thermoselect process produces a smelted granular material segregated into metal and non-metal. The non-metal granules are said to be more physically and chemically stable than mass burn bottom ash. However, if there is no significant risk from the re-use of bottom ash, the justification for additional capital cost and lower energy efficiencies is questionable.

Furthermore, the production of slag rather than ash is due to high temperature treatment of the ash rather than the gasification and pyrolysis process. A slagging system can also be combined with other thermal treatment processes.

[25] One supplier has objected to the choice of 100,000 tpa as their technology specifically targets smaller applications. However, there are other suppliers whose applications are specifically for larger installations and it was necessary to strike some reasonable compromise.

[26] "Solid Residues from Municipal Waste Incinerators in England and Wales" May 2002

Table 8 – Materials Balance Comparison								
Technology Supplier	**Lurgi**	**Compact Power No Pretreat**	**Compact Power With Pretreat**	**Brightstar**	**WasteGen**	**Foster Wheeler**	**Thermo-select**	**Energos**
Process	Combustion	Pyrolysis	Pyrolysis	Pyrolysis	Pyrolysis	Gasification	Pyrolysis - gasification	Gasification
Power generation	Steam cycle	Steam cycle	Steam cycle	Gas engine	Steam Cycle	Syngas only	Syngas only	Steam only
Input								
Waste	100,000	100,000	100,000	100,000	100,000	100,000	240,000	100,000
Bed material						7,027		
Natural gas							6,858	
Air	569,000	604,485	402,990		436,686	186,216		478,303
Oxygen							127,808	
Steam		9,990	6,660					
Water				14,700			17,528	13,414
Ammonia/Urea	182	113	75		733			
Gas cleaning consumables	1,194	1,350	900		1,100		13,032	2,365
Total input	670,699	715,938	510,625	114,700	538,819	293,243	405,226	594,083

Table 8 – Materials Balance Comparison								
Technology Supplier	**Lurgi**	**Compact Power No Pretreat**	**Compact Power With Pretreat**	**Brightstar**	**WasteGen**	**Foster Wheeler**	**Thermo-select**	**Energos**
Output								
Ash/char/slag	21,353	19,598	13,065	23,400	27,090	30,351	56,136	34,526
Gas cleaning residues	2,265	945	630	500	2,257		8,600	3,823
Syngas						261,189	201,352	
Flue gas	646,588	685,418	456,945	26,600[27]	485,075			547,862
Water				43,100	24,097		139,136	3,866
Diverted materials		10,000	40,000	19,100				3,997
Metals				2,000				
Total output	670,206	715,960	510,640	114,700	538,519	291,541	405,224	594,074

[27] Excludes combustion air that has been included by the other suppliers

B.2.3 Pyrolysis Residues

The pyrolysis processes on the market produce a dry residue but with high carbon content of up to 40%. Char combustion or gasification in a further step represents additional equipment, complications and costs. High temperature treatment of char may also remove some of the potential reduction in heavy metals due to low temperature pyrolysis. Char combustion for the purposes of power generation would also disqualify the entire generating station from ROCs.

Landfilling of the char represents a waste of useful energy that could be recovered.

Pyrolysis technology suppliers have generally indicated that even where the carbon content in the solid residue is high this carbon is elemental carbon rather than organic carbon. In this event, the WID limits relating to solid residues would be complied with.

B.2.4 Air Pollution Control Residues & Effluents

The nature and quantity of air pollution control residues and effluents will tend to depend on the flue gas treatment system rather than on the thermal treatment technology.

B.3 Quantity of Combustion Products in Flue Gas

If the end use of the energy recovered by thermal treatment is for heat or electricity production, then the ultimate quantity of carbon dioxide in the flue gas will be exactly the same regardless of whether the thermal treatment process is gasification, pyrolysis or combustion. A few exceptions to this general rule exist and some examples are given below:

1) Pyrolysis processes that dispose of large quantities of carbon with the char will result in less CO_2 in the flue gas at the expense of loss of useful energy;

2) Gasification and pyrolysis processes that use significant quantities of fossil fuel to support the process will result in more CO_2 in the flue gas.

Appendix C Renewable Obligation Certificates

In the UK, the Government has tried to assist the development of gasification and pyrolysis technologies by allowing them to qualify for Renewable Obligation Certificates (ROCs)[28]. Modern energy from waste plants based on combustion technology do not qualify as these are considered to be commercially mature. The Renewables Obligation Certificate increases the electricity revenue and is a significant incentive for those investing in gasification and pyrolysis technologies.

To qualify for ROCs, the electricity must come from an accredited generating station. To be an accredited generating station, the waste fuel must be biomass or **all** of the waste fuel must have first been converted into gaseous or liquid form by gasification or pyrolysis. The definition of biomass is that the fossil fuel energy content of the material must be less than 2% calculated on a gross CV basis.

The following proposed changes to the Renewables Obligation Order 2002 have been under consultation[29].

"2.25 Under the Obligation, a generating station is eligible or ineligible for ROCs according to the fuel used at the station as a whole. Ofgem[30] have asked us to consider changing this so that ***a station is classified only in terms of the fuel used in the combustion chamber to generate electricity****. This would have the effect of allowing fossil fuels to be used, possibly extensively, at an accredited generating station provided the fuel used in the combustion chamber to generate electricity was either wholly renewable, or complied with the requirements for co-firing of biomass with fossil fuels. It would also mean that generators could use char, a residue produced from pyrolysis and gasification, for example to heat the combustion chamber, without the generating station being considered co-fired."*

A few practical examples will serve to illustrate the impact of the above paragraph:

1) Any process that does not use fossil fuels (except for minimal fossil fuel use such as during start-up or to control emissions) and does not combust char would qualify for ROCs under present and proposed rules;
2) Any process that generates electricity using **only** gas engines or gas turbines would also qualify for ROCs after the proposed changes to the rules regardless of whether char is combusted or not;
3) Using the heat from char combustion purely for heating the gasification and pyrolysis vessel rather than for power generation would not disqualify the generating station from ROCs after the proposed changes to the rules;
4) The energy from the hot flue gases can be used for waste drying, for sale to district heating schemes, or simply dumped without disqualifying the generating station from ROCs;
5) Any process that uses the heat from char combustion for power generation in a steam cycle would be disqualified from ROCs under present and proposed rules.

Even the proposed change in rules would still mean that generating stations based on a number of gasification and pyrolysis technologies would fail to become accredited for ROCs. Penalising the recovery of heat from char for power generation means penalising efficient operation and can lead to dumping of the energy from the char.

---

[28] Statutory Instrument 2002 No. 914, "The Renewables Obligation Order 2002"

[29] The Renewables Obligation (Amendment) Order 2003 Statutory Consultation. The consultation is now closed. Decisions have yet to be announced. New rules to come into force in April 2004.

[30] Office of Gas and Electricity Markets – responsible for assessing qualification for ROCs

Only the power generated from the non-fossil fuel (renewable) portion of the waste will qualify for ROCs even if the generating station is accredited for ROCs. Typically about 60% of MSW energy is assumed to be renewable, but this can change with pre-treatment. For example a pre-treatment process that removes paper for recycling and putrescibles for composting would leave behind mainly plastics. Power generated from gasification and pyrolysis of plastics would not qualify for ROCs since plastics are generally manufactured from fossil fuels.

ROCs only apply if the syngas is used to generate power. Use of syngas for other purposes such as chemical production, heat production, and as substitute fuel in a cement kiln would not produce ROCs.

Any project requiring debt finance with a significant dependence on revenue from electricity produced will be required by their lenders to obtain long-term power purchase agreements, of up to 15 years, with electricity suppliers. In such cases, the price obtained for ROCs over the life of the project will be significantly lower than the average trading price of the ROCs over the same period. This is because the risk in the price of ROCs is taken by the public electricity supplier rather than the generator.

ROCs are often cited as an incentive from the UK government for development of gasification and pyrolysis technologies. However, ROCs do not appear to be the ideal way to drive development of gasification and pyrolysis technologies for waste:

1) ROCs only apply to biodegradable waste;
2) ROCs can encourage inefficient practices such as dumping of energy from char;
3) ROCs are not applicable if the syngas is used for anything other than power generation so will discourage innovative uses of syngas;
4) Small generators, such as those processing waste, are unlikely to be able to obtain good long-term prices for ROCs as they are likely to need long-term power supply contracts from electricity suppliers;
5) ROCSs do not provide a predictable income over the finance life of the project.

Better incentives for the development of gasification and pyrolysis technologies for waste may be capital grants or risk insurance.

Appendix D Gasification and Pyrolysis Technologies and Technology Suppliers

Information on individual technology suppliers and their technology are given below. A table of the main reference plants is available at the end of this appendix. The majority of the plants in the table are either very small, operating on RDF rather than RMSW, incomplete, or closed down.

D.1 Brightstar Environmental – SWERF

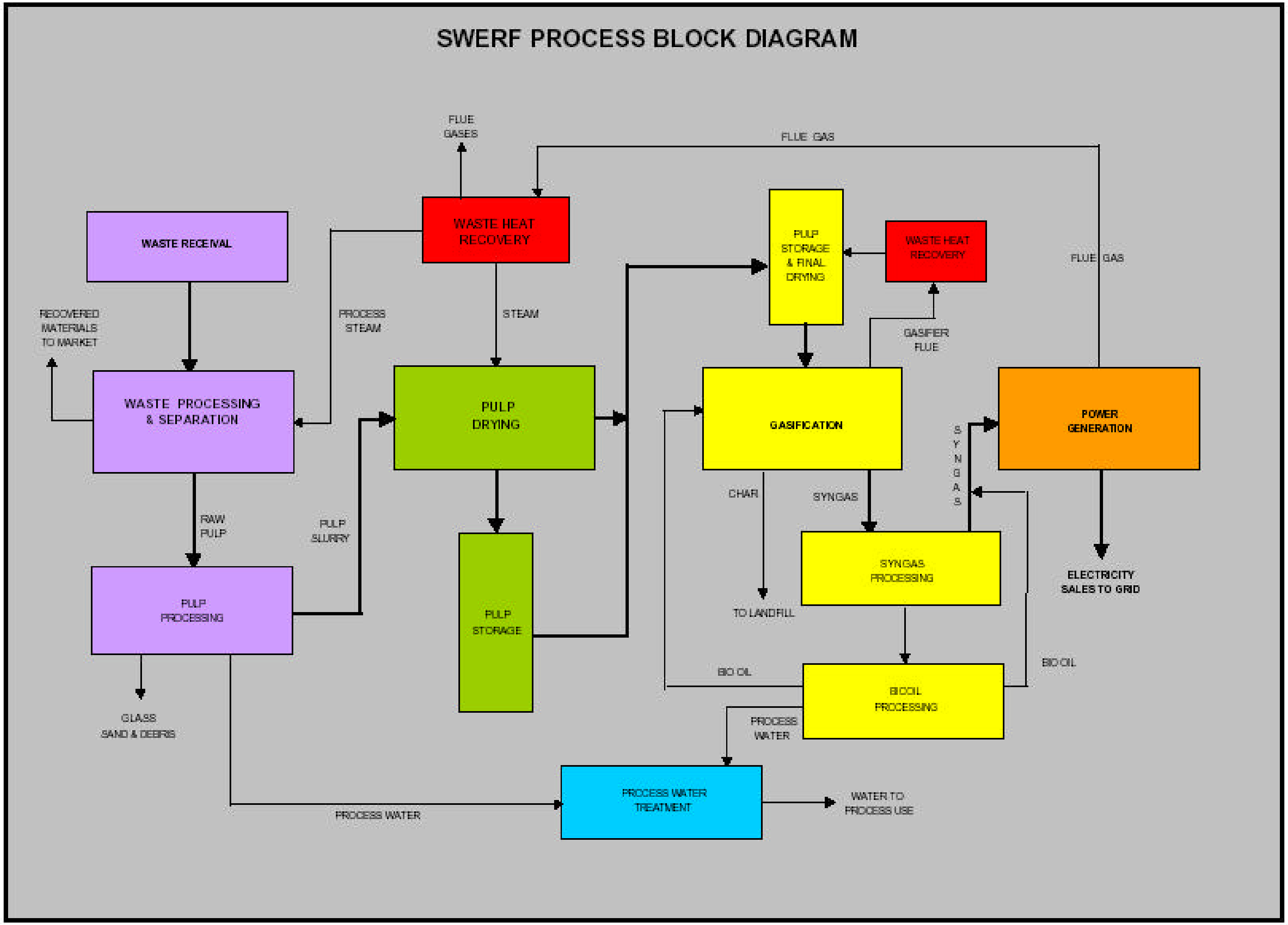
Process

1) Waste sterilisation in rotating steam autoclave at temperatures between 130^{o}C to 150^{o}C;
2) Recovery of recyclables from cooked waste in materials separation plant;
3) Drying of residual waste using steam;
4) Fuel storage;
5) Pyrolysis in series of externally heated pipe coils to produce syngas and liquid fuel;
6) Syngas cooling and cleaning;
7) Power generation using gas engines;
8) Char (containing 35% to 40% carbon) is intended to be landfilled;
9) Liquid fuel used for steam production and heating of pyrolyser.

Comments

1) Single demonstration plant commissioned in 2001 in Australia but still operating intermittently and at an output of 25,000 tonnes/year compared to the design capacity of 100,000 tonnes/year;
2) Gas engines are employed for power generation at the demonstration plant but the exhaust gases do not meet WID limits. WID does not apply in Australia;
3) For the UK market, Brightstar Environmental intends to treat the engine exhaust gases to meet WID limits but this treatment has yet to be demonstrated by the company;
4) Energy Developments Limited, owner of about 88% of the SWERF business, announced its intention to cease all funding of the company’s share of development at the demonstration plant;
5) Marketing of the technology in the UK is still continuing.

SWERF Process – diagram supplied by Brightstar



D.2 Compact Power

Process

1) Materials recovery facility for taking out bulky materials and recyclables;

2) Pyrolysis at 800°C in externally heated screw tube pyrolysers;

3) Gasification of residues with air & steam;

4) Thermal oxidation (combustion) of syngas at 1250 °C. Fuel and air is introduced tangentially into the combustion chamber to create swirling flow to promote mixing;

5) Power generation via steam turbine;

6) Flue gas cleaning via bag filter with sodium bicarbonate injection, and selective catalytic reduction (SCR) with ammonia for NO_x reduction.

Comments

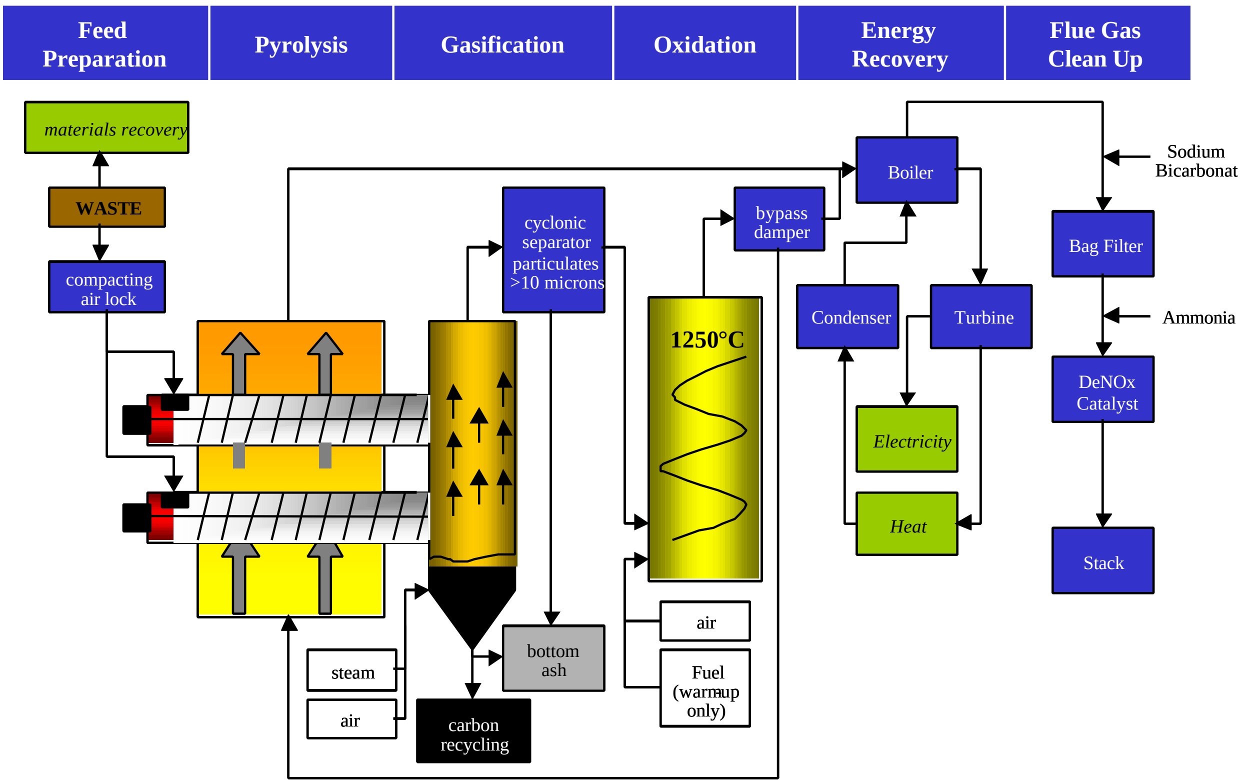
1) Single reference plant operating commercially at Avonmouth but only at very small scale for high gate fee material such as clinical waste;

2) The reference plant was initially commissioned on MSW for several months prior to processing clinical waste;

3) Modular technology less able to benefit from economies of scale but reduces scale up risks;

4) This technology is marketed for treatment of small quantities of RMSW was a component of an integrated waste management facility rather than a high volume treatment process.

Compact Power process – flow diagram supplied by Compact Power



D.3 Energos

Process

1) Feed preparation (shredding) required to increase surface area of waste;
2) Static grate gasifier with combustion chamber directly above grate;
3) Each module can process 35,000 tonnes/year. Additional capacity is achieved with multiple modules;
4) Steam generation in boiler;
5) Flue gas cleaning by fabric filter with lime and carbon injection.

Comments

1) Established track record with five operating plants in Norway and one in Germany;
2) OFGEM has communicated the following view[31] to Energos regarding qualification of the Energos process for ROCs, "*From the information you have provided regarding the advanced thermal treatment process it appears that the electricity generated would be from an advanced conversion technology (gasification) as defined in the 'Order'*";
3) Energos estimates a capital cost of about £25M (35 million Euros) and operating cost of about £2.2M (3.1 million Euros) for a double line plant (about 75,000 tonnes/year). These costs include pre-treatment of waste and power generation.

[31] Information supplied by Energos containing email exchanges between OFGEM and Energos. The extract came from an email dated 24th October 2003.

D.4 Enerkem/Novera

Process

1) Feedstock reception, pelletisation and storage;

2) Gasification in bubbling fluidised bed with silica alumina as the fluidising medium. The quantity of air, or optionally oxygen, fed into the fluidised bed represents about 30% of the stoichiometric amount required for complete combustion of the organics in the feedstock;

3) Removal and disposal of coarse char particles from hot syngas via cyclones;

4) Gas cleaning and cooling with gas quench tower, venturi scrubber, demister, electrostatic precipitator and dehumidification to produce a clean syngas suitable for use in gas engines;

5) Power generation using gas engines or steam boiler and turbine. The reference plant in Castellon, Spain uses gas engines for power generation. The feedstock for the reference plant was plastics with a high CV in the order of 38MJ/kg.

Comments

1) The technology was developed by Enerkem and marketed in Europe by Novera;

2) Technology is marketed for high NCV plastics or RDF;

3) Novera is offering the gasification and power generation systems on a build, own, and operate basis tied to a gate fee rather than as a contractor installing plants for others. Novera intend to look to others for RDF preparation.

D.5 FERCO

Process

1) Fuel drying;

2) Gasification in circulating fluidised bed;

3) Steam is supplied as a medium to carry the syngas away from the reaction sites. Char takes combustion takes place in a second fluidised bed to provide heat to the sand carried over from the gasifier. This hot sand is then recycled back into the gasifier to provide heat for the chemical reactions;

4) Syngas from demonstration plant used in power station but FERCO intends to offer CCGT for power generation. Some testing of syngas in a small (200kW) Solar Spartan gas turbine has been undertaken at the pilot plant.

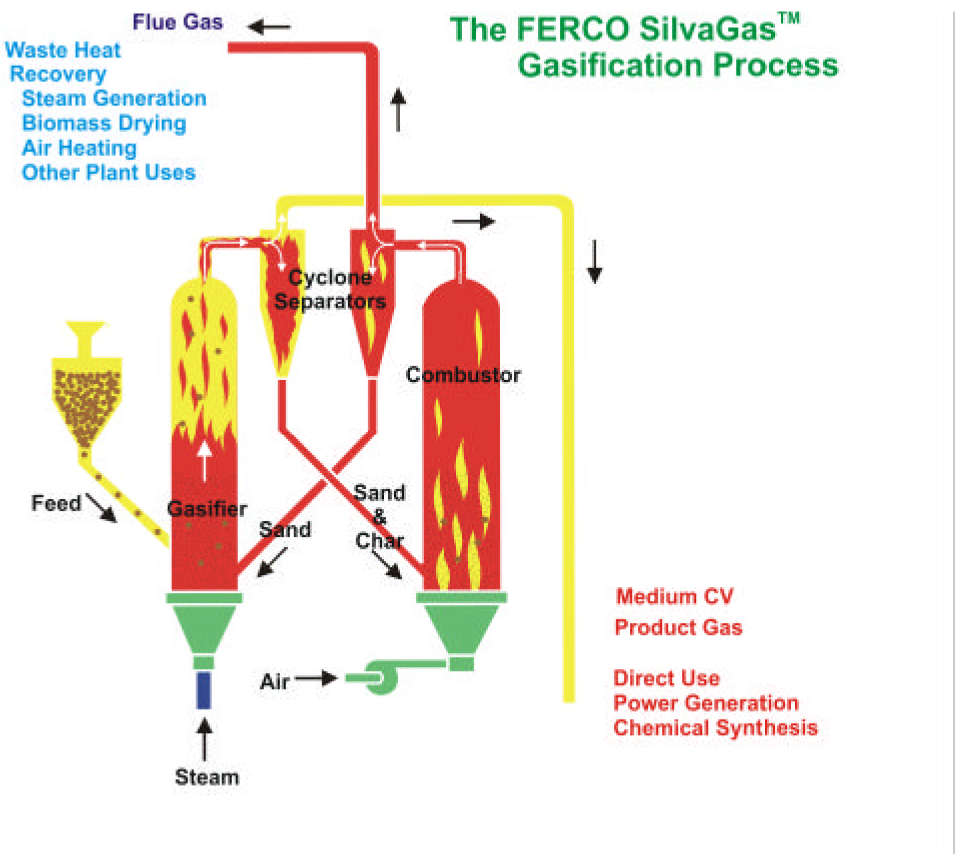
Comments

1) Single demonstration plant in Vermont (USA). The demonstration plant consists of the gasifier island processing biomass and exporting the product syngas to an adjacent conventional power plant;

2) MSW has not been tested at the demonstration plant but RDF has been tested on a small pilot plant;

3) If the flue gas heat from char combustion is used for power generation then the plant will not qualify for ROCs.

FERCO process – illustration supplied by FERCO



D.6 Foster Wheeler

Process

1) Gasification of prepared RDF in a circulating fluidised bed at atmospheric pressure using air;

2) Use of syngas in a power station or industrial process.

Comments

1) The main reference plant is demonstration plant at Lahti, Finland processes a recycled fuel containing plastics, paper, cardboard, and wood. Syngas is co-fired in conventional power station;

2) Four other atmospheric gasifiers using bark and wood waste as the main feedstock delivered between 1983 and 1986. The capacities of these gasifiers ranged from 15 MWth to 35 MWth and the syngas is typically used as a fuel for lime kilns or paper pulp mills;

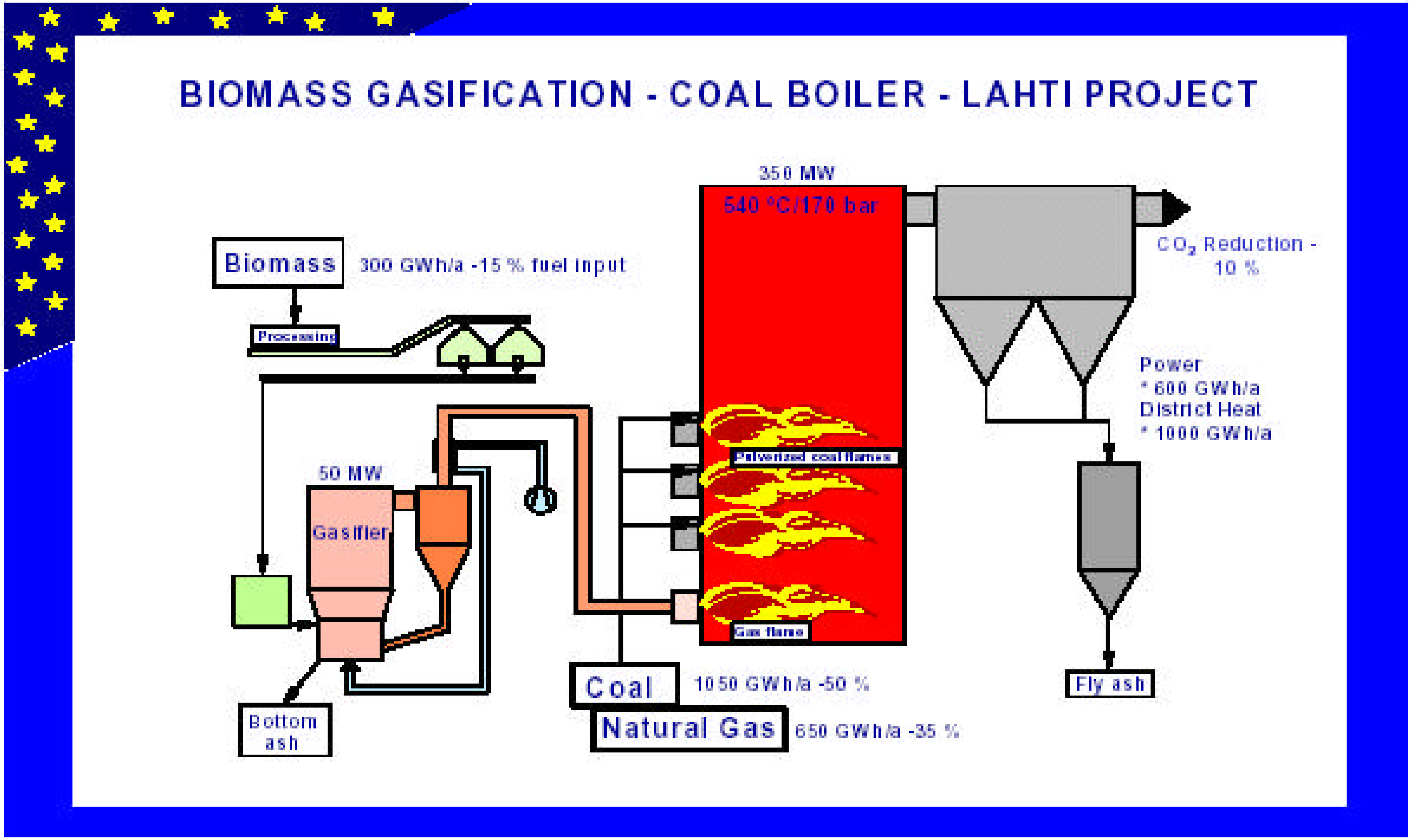
3) More recent 40 MW plant delivered to Corenso United Ltd, Finland in 2000 processes aluminous plastics waste to produce syngas for a boiler;

4) Avoids technical difficulties and energy losses associated with syngas cleaning, syngas cooling, use of syngas in gas engines and use of syngas in gas turbines;

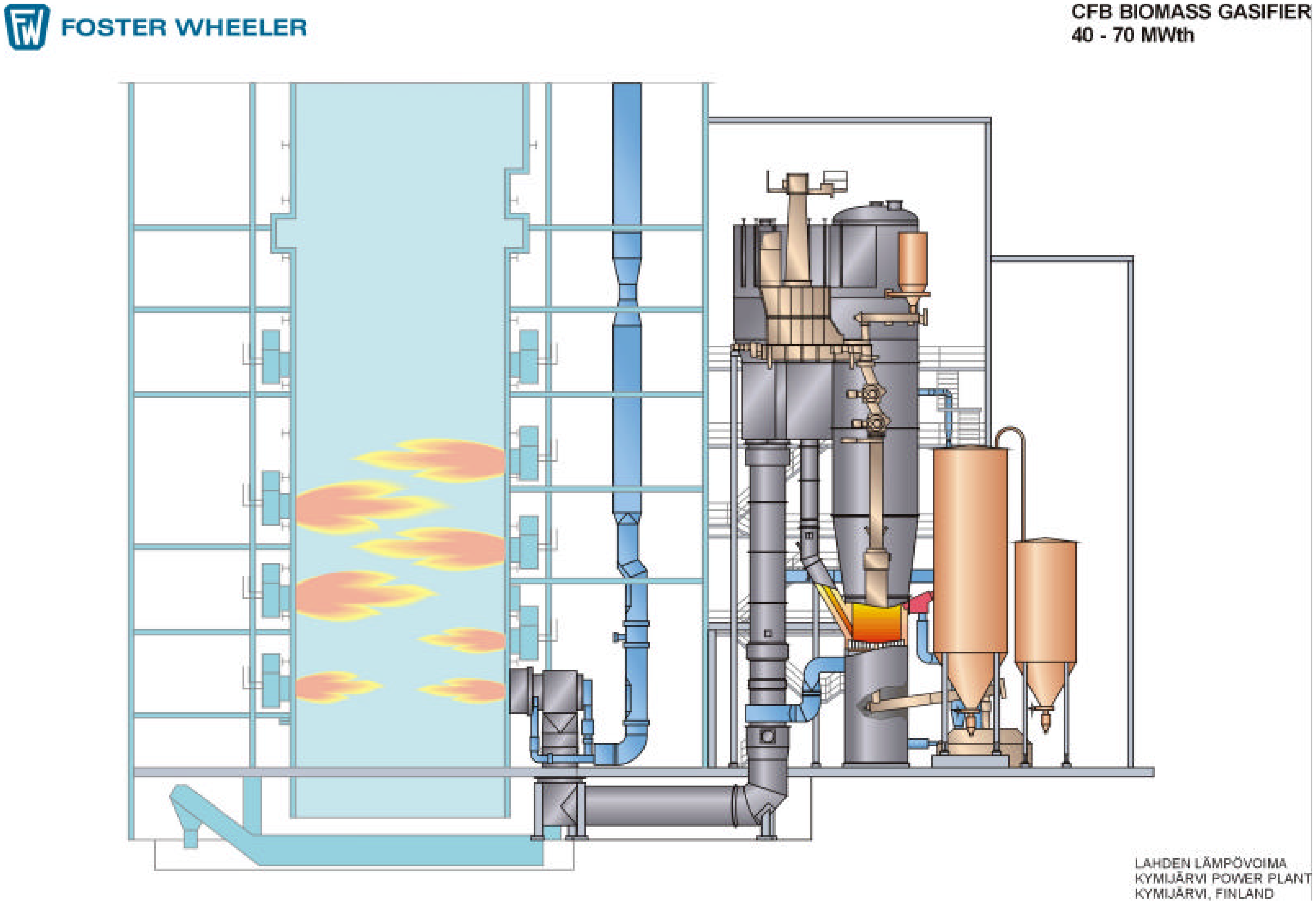
5) Foster Wheeler is targeting the gasifier for processing of RDF to produce syngas for use in power stations;

6) This system is at a more advanced stage of demonstration than most gasification and pyrolysis systems.

Lahti Demonstration Project – illustration supplied by Foster Wheeler



Lahti Plant – illustration supplied by Foster Wheeler



D.7 GEM (Graveson Energy Management)

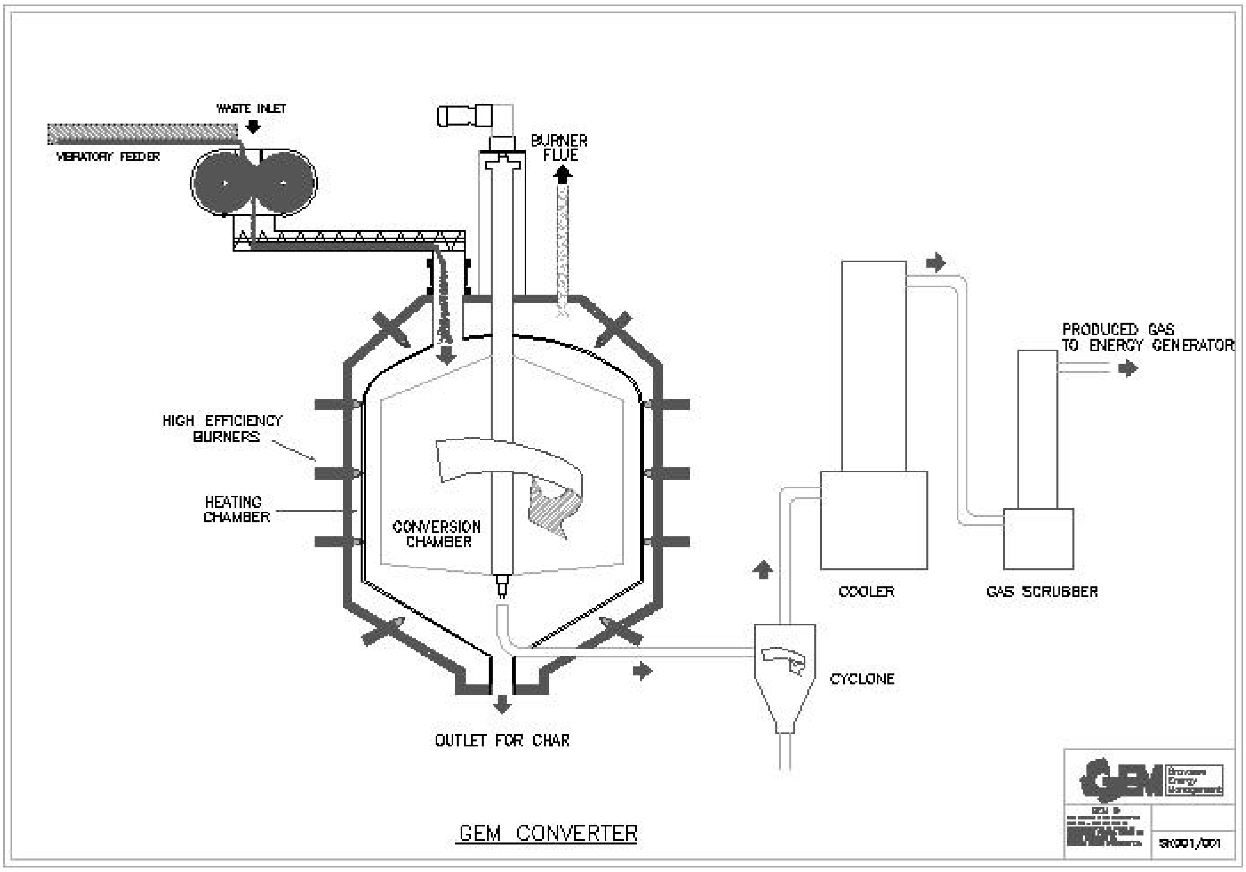
Process

1) Pre-treatment for size reduction;
2) Thermal drying down to 5%-8% moisture;
3) Continuous feed and fast pyrolysis in an externally heated stirred reactor;
4) Hot gas filtration;
5) Syngas cooling in heat exchanger cooled with atomised mineral oil coolant;
6) Syngas compression and after-cooling;
7) Syngas from the test plant is normally flared. A gas engine was on site for about 4 weeks for trials but it is not clear how many operating hours were actually clocked up by the gas engine during this period.

Comments

1) Test plant at Bridgend not in operation;
2) The gas engine exhaust from the tests showed high levels of CO and NOx and special dispensation was given by the EA for these trials.

GEM Converter – illustration supplied by GEM



D.8 IET Energy / Entech

Process

1) Minimal or no waste pre-treatment is necessary but pre-treatment to recover recyclables is not precluded;

2) Continuous feeding of waste into stepped hearth;

3) Syngas combustion in a thermal reactor with flue gas recirculation (FGR) and SNCR for NO_x reduction;

4) Power generation using boiler and steam turbine;

5) Flue gas cleaning system consisting of bag filter with reagent injection for VOC control and packed tower for acid control. IET/Entech will offer to guarantee compliance with WID;

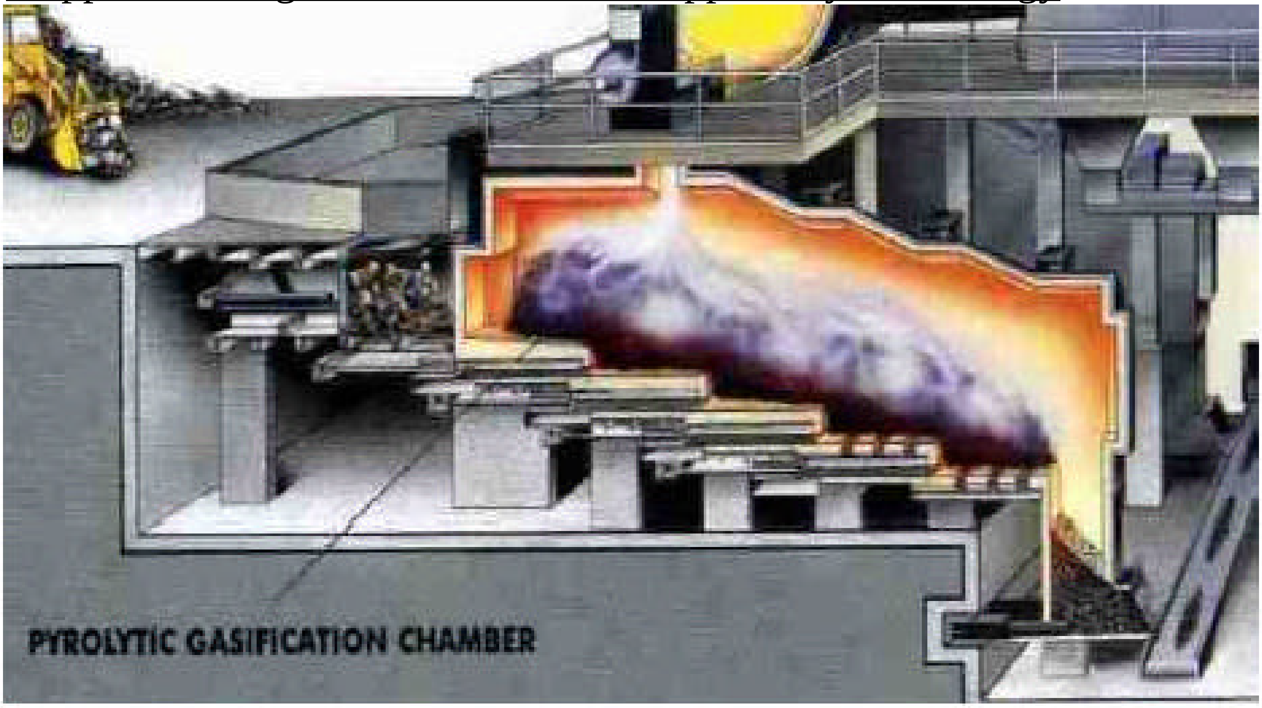
6) Recovery of ferrous and non-ferrous metals and glass from the gasifier residues.

Comments

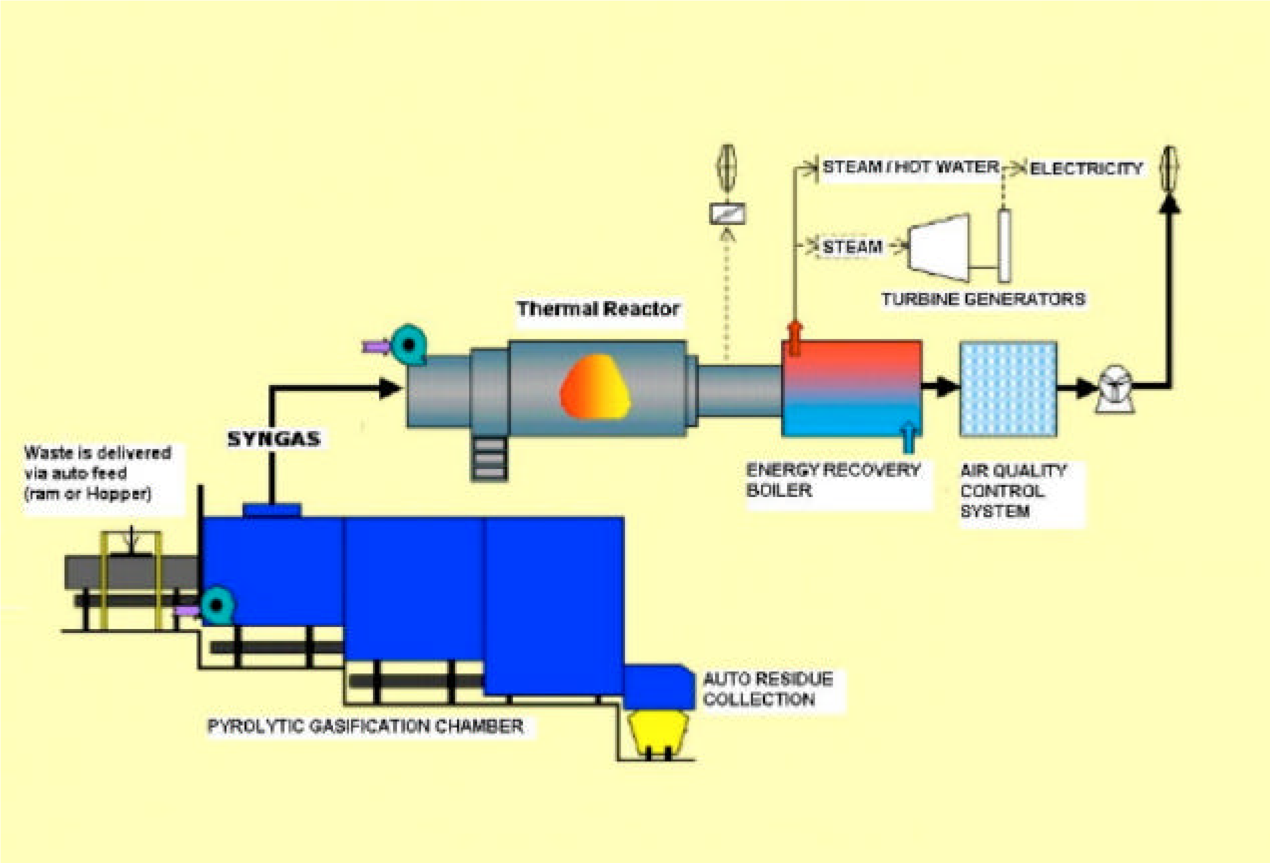
1) The Entech system is marketed by IET Energy in the UK;

2) About 145 reference plants processing a variety of waste. About 8 plants processing at least some MSW derived fuel. Largest operating plant has a capacity of less than 25,000 tonnes/year.

Stepped hearth gasifier – illustration supplied by IET Energy



IET/Entech Process - illustration supplied by IET Energy



D.9 Lurgi

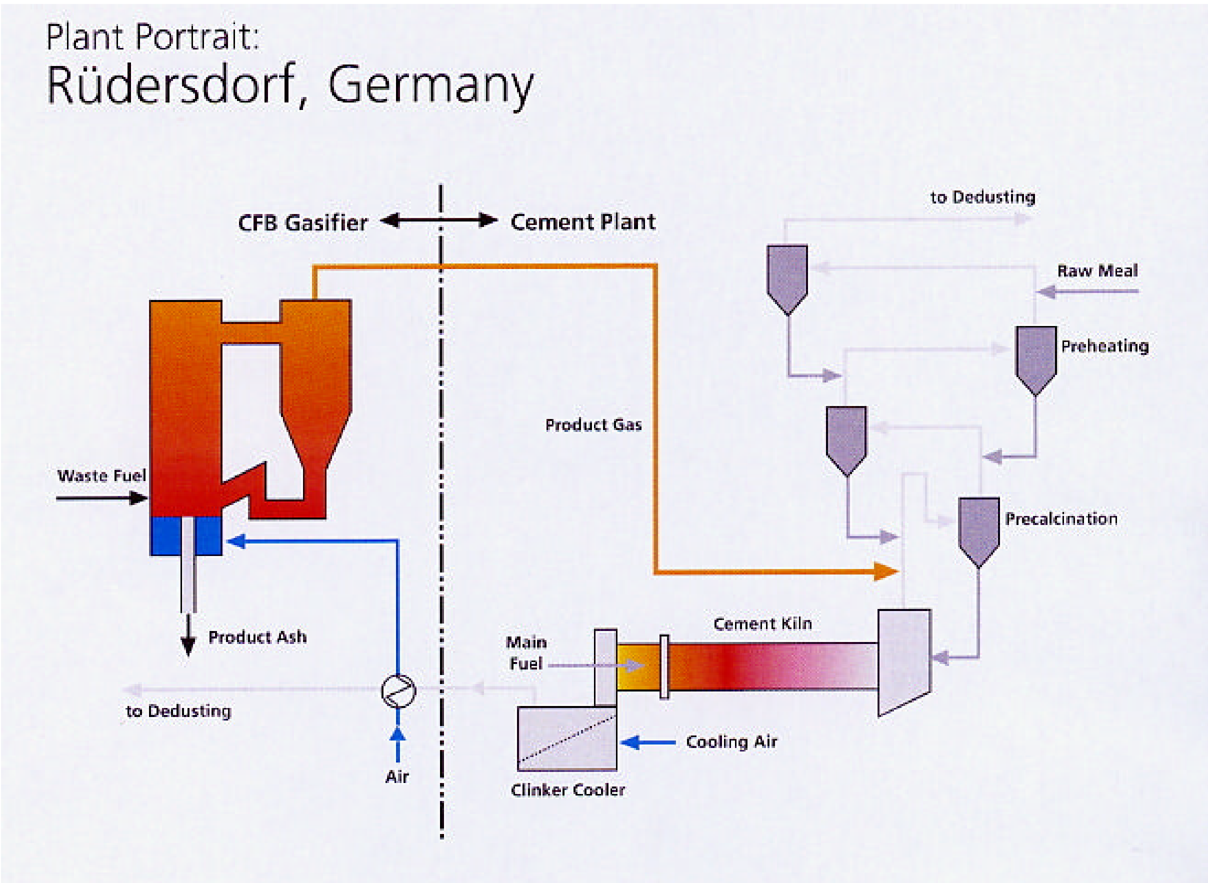
Process – Rudersdorf Plant

1) Up to 19 types of RDF used;
2) Feed systems can cope with maximum of 4 different fuels simultaneously using air blowing or mechanical means depending on type of fuel;
3) Gasification in circulating fluidised bed;
4) Ash discharge, cooling, and transportation to raw mill on cement manufacturing plant;
5) Syngas fired in calciner of cement plant.

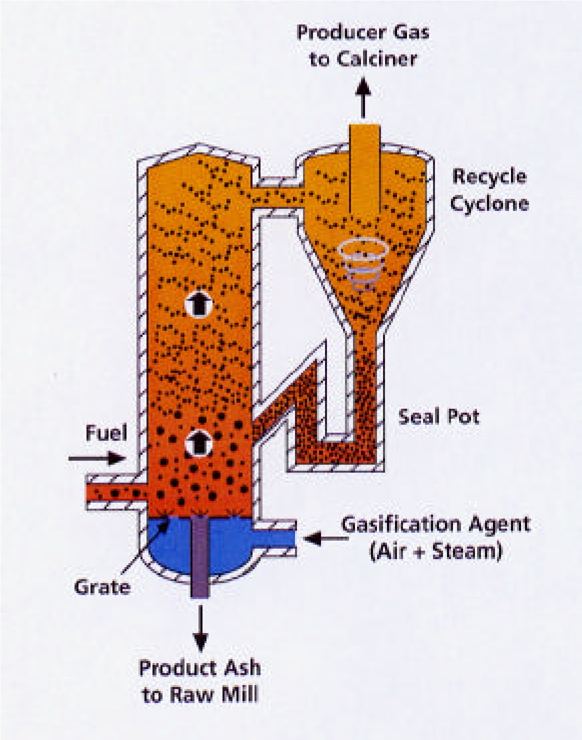
Comments

1) One reference plant producing syngas and char for use in a cement kiln. This plant is based on fluidised bed technology;
2) Another reference plant, based on British Gas – Lurgi gasifier, processing a mixture of coal and wastes to produce syngas for use as chemical feedstock. This plant is based on a fixed bed updraft gasifier using oxygen and steam as the gasification medium. This plant also turns the solid residues into a slag;
3) Despite the many years of experience from these plants, recently decided to withdraw from the gasification and pyrolysis market for waste.

<u>Rudersdorf Plant – Block Flow Diagram Supplied by Lurgi</u>



Lurgi Fluidised Bed Gasifier - Diagram Supplied by Lurgi



D.10 Mitsui Babcock

Process

1) Waste shredding at less than 450 °C in rotary kiln that is indirectly heated;
2) Metals recovery from char;
3) Combustion of syngas and char in same second chamber at over 1300 °C to melt ash into a slag;
4) Power generation via a steam cycle;
5) Fly ash collection in bag filter for melting into slag in main combustion chamber;
6) Flue gas treatment residues sent to landfill.

Comments

1) R21 technology originally developed by Siemens;
2) At least two plants built by Mitsui Babcock in Japan based on R21 technology;
3) Process involves char combustion so would not qualify for ROCs;
4) Mitsui Babcock was either unable or unwilling to supply information for this review.

D.11 Techtrade/Wastegen

Process

1) Pyrolysis in rotary kiln with lime addition;
2) Syngas combustion;
3) Generation of electricity via steam cycle;
4) SNCR for NO_x control;
5) Flue gas cleaning by fabric filter with sodium bicarbonate and activated carbon injection.

Comments

1) The Techtrade technology is marketed in the UK by Wastegen;
2) One reference plant operating in Burgau, Germany, since 1984 based on a standalone configuration;
3) Residues contain 26% carbon. A carbon recovery unit (probably based on rotary kiln or fluidised bed technology) is being considered for future standalone configurations. The efficiency claimed in Table 7 is based on implementation of char gasification;
4) More recent reference plant at Hamm-Uentrop, Germany is based on firing of syngas and char in a conventional power station.

D.12 Thermoselect

Process

1) Pyrolysis in externally heated tubes with waste feeding by ramming;

2) High temperature (2000^{o}C) gasification using oxygen as the gasification medium;

3) High temperatures melt the ash into a slag;

4) Metals and minerals solidify separately when quenched with water;

5) Magnetic separation of metals from the mixed slag;

6) Syngas held at over 1100 ^{o}C for at least 2 seconds before quenching down to 90^{o}C;

7) Water condensed from syngas cooling is treated for re-use as cooling water.

Comments

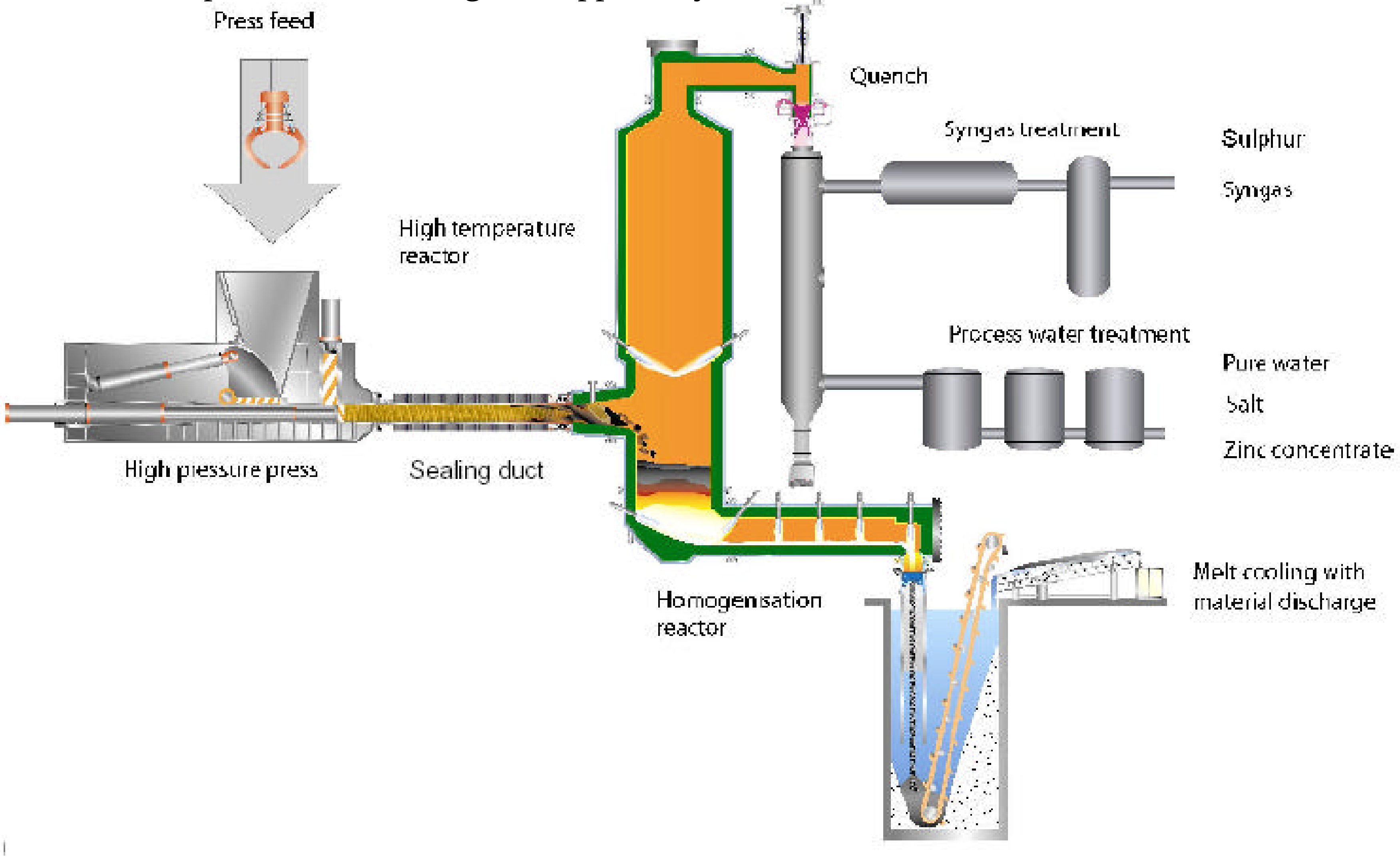
1) Two commercial reference plants in Japan and one in Germany;

2) The new reference plant in Mutsu features power generation via a mixture of steam turbine and gas engines but no operating data is yet available;

3) Approximately 3,000 hours of operating experience at Chiba of gas engine consuming syngas at a rate of 1,700 Nm^3/h;

4) Total annual costs (operating costs and cost of capital) for the 100,000 /year plant at Chiba supplied by Thermoselect was about 21,480 Japanese Yen/tonne (about £114/tonne) equating to about £11.4M/year. Note that this is an exceptionally complex plant with sophisticated syngas cleaning equipment and pure oxygen in the gasification process. Thermoselect states that this plant is profitable in Japan.

Thermoselect process – flow diagram supplied by Thermoselect



D.13 TPS Termiska

Process

1) RDF receiving, storage, and feeding;
2) Gasification using circulating fluidised;
3) Syngas combustion;
4) Power generation via steam cycle;
5) Flue gas treatment.

Comments

1) One reference plant processing RDF in Italy;
2) The ARBRE project in the UK processed biomass fuel as the feedstock intended power generation using a CCGT. The project failed to get past the commissioning phase due to problems with cleaning the syngas and has been abandoned;
3) TPS was either unable or unwilling to supply information for this review.

D.14 Von Roll

Von Roll is in the process of developing two new processes for the thermal treatment of waste. The RCP process is described by Von Roll as “incineration plus vitrification of slag and fly ash” and the pyrolysis process is described as “staged incineration” since the pyrolysis step is followed immediately by combustion further along the grate;

Von Roll does not intend to market these technologies until they are sufficiently developed and declined to take part in this review.

Table 9 - Main Gasification and pyrolysis Reference Plants							
Technology Supplier	**Plant Location**	**Feed Rate (tpa)**	**Operational Since**	**Feedstock**	**Products**	**Power Generation**	**Comments**
Brightstar Environmental	Wollongong, Australia	25,000	2001	Sorted MSW	Electricity	Gas engine	Demonstration plant not operating continuously or at full capacity
British Gas - Lurgi	Schwarze Pumpe, Germany	500,000	1993 rotating grate gasifier. 2000 slagging gasifier	Plastics, RDF, wood, sewage sludge, lubricants, coal	120,000tonnes/year methanol, 35 MWe, low grade heat, surplus fuel gas		Chemical plant operating on mix of fuels
Compact Power	Avonmouth, UK	8,000	2001	Clinical waste	Electricity & steam for heating and sterilisation	Steam cycle	Clinical waste only
Entech/IET	About 8 plants processing at least some separated MSW-biomass. All plants under 25,000 tonnes/year						
Energos	Ranheim, Norway	10,000	1998	Commercial and industrial waste	Saturated steam to adjacent factory	N/A	
Energos	Averoy, Norway	30,000	2000	MSW	Electricity & saturated steam	Steam cycle	
Energos	Hurum, Norway	35,000	2001	MSW and industrial waste	Saturated steam to adjacent factory	N/A	
Energos	Sarpsborg, Norway	70,000	2002	MSW and industrial waste	Electricity & steam	Steam cycle	
Energos	Forus, Norway	37,000	2002	MSW	Steam	N/A	
Energos	Minden, Germany	37,000	2002	MSW and commercial waste	Steam	N/A	

Table 9 - Main Gasification and pyrolysis Reference Plants							
Technology Supplier	**Plant Location**	**Feed Rate (tpa)**	**Operational Since**	**Feedstock**	**Products**	**Power Generation**	**Comments**
Enerkem/ Novera	Castellon, Spain	25,000	2002	Plastics	Electricity	Gas engine	Plastics only
FERCO	Vermont, USA	165,000	1997	Biomass, tree chips, wood pellets	Syngas	Co-fired in neighbouring power station	Biomass only
Foster Wheeler	Lahti, Finland	80,000	1998	Mix containing plastics, paper, cardboard, wood waste, shredded tyres	Syngas	Co-firing in coal fired boiler	In demonstration phase
GEM	Bridgend, UK	60,000	Not yet fully operational	MSW	Syngas	Syngas normally flared. Limited testing on gas engine	Not operational
Lurgi	Rudersdorf, Germany	100MWth	1996	RDF	Syngas	N/A	Syngas and char used in cement kiln
Mitsui Babcock	Yame Seibu, Japan	70,000	2000	MSW	Electricity	Steam cycle	.
Mitsui Babcock	Toyoashi City, Japan	120,000	2002	MSW			
Siemens	Furth, Germany		1995	MSW			Plant failure leading to gas escape to atmosphere. Project abandoned. Siemens has withdrawn from market

Table 9 - Main Gasification and pyrolysis Reference Plants							
Technology Supplier	**Plant Location**	**Feed Rate (tpa)**	**Operational Since**	**Feedstock**	**Products**	**Power Generation**	**Comments**
Thermoselect	Karlsruhe, Germany	225,000	2002	Range of domestic and industrial wastes	Syngas, sulphur, metallic slag, glassy slag	Steam cycle & syngas export	
Thermoselect	Chiba, Japan	100,000	1999	Range of domestic and industrial wastes	Synthetic gas, sulphur, metallic slag, glassy slag	Co-firing in power station. Gas engine for testing and demonstration.	
Thermoselect	Mutsu, Japan	50,000	April 2003	Industrial waste	Synthetic gas, sulphur, metallic slag, glassy slag	Steam cycle & gas engine	
TPS Termiska	Greve -in-Chianti, Italy	67,000	1992	Pelletised RDF	3.5MWe	Steam cycle	
Techtrade/ WasteGen	Burgau, Germany	35,000	1984	Mixed domestic and industrial waste	Electricity	Steam cycle	
Techtrade/ WasteGen	Hamm, Germany	100,000	2002	Mixed domestic and industrial waste	Electricity	Syngas firing in coal fired power plant	

Appendix E Representations from Technology Suppliers

This report incorporates many helpful comments and suggestions from waste management contractors, technology suppliers and independent consultants. Due to the diverse nature of the sector, consensus could not be reached on all issues. In particular, it was not possible to accommodate certain representations made by some technology suppliers.

To maintain the independence and flow of the report and at the same time to recognise that other views do exist, the representations are listed below along with a brief explanation of why they were not accommodated in the body of the report.

E.1 Representations from WasteGen/Techtrade

E.1.1 Maximum Combustion Temperature

Comment

It is mentioned, that "High maximum temperatures [are] typical above 1,000 °C"

Even in the Juniper Study "Incineration Sites in Europe" we cannot trace one plant doing that.

The comment disputes the statement that maximum temperatures for energy from waste plants based on combustion technology can exceed 1,000 ^{o}C.

Response

The **maximum** temperature referred to, is the temperature in the hottest part of the furnace and not the average temperature after mixing with all of the combustion air. This temperature is one of the main factors in helping to ensure that virtually all of the carbon is combusted rather than left in the ash and unfortunately also in determining how much of certain pollutants are volatilised into the flue gases.

Actual measurements were recently made on an existing waste combustion plant and temperatures consistently in excess of 1000 ^{o}C were recorded.

E.1.2 Emissions

Comment

Further you should be informed, that the type of process as well as other reasons are responsible for the destruction or forming of certain pollutants. With the type of process you can for instance influence the amount of dioxins in the raw gas. That you can filter these elements out again does not make incineration equal to pyrolysis, where we enjoy dioxin levels as low as [32]0,01, but without additional activated carbon filter and without producing hazardous wastes (such as ashes from the boiler which are highly dioxin contaminated).

Response

The emissions to air, claimed by Wastegen/Techtrade, is based on their reference plant at Burgau. The report does not dispute the claim that the plant may have lower dioxin emissions than a conventional combustion plant. For this to be considered a benefit, the environmental performance of the plant as a whole must be assessed.

[32] It is assumed that this is a typing error. Other information from WasteGen/Techtrade suggests the number should read 0.001 and not 0.01.

A recent Entec report to DEFRA[33] stated, "Dioxin emissions from waste incineration, cremation, public services combustion and refinery combustion were re-evaluated and found to be negligible." The value of reducing an emission that is already negligible must therefore be questioned.

It is true that low temperature pyrolysis plants will tend to volatilise less of certain pollutants into the flue gas resulting in lower emissions. This benefit should be weighed against more pollutants in the pyrolysis residues that have to be landfilled and significantly lower energy efficiency due to the unconverted carbon in the residue.

In this context, WasteGen/Techtrade are claiming energy efficiency figures of 20% to 25% based on recovering energy from the carbon in the char. A number of points should be noted regarding these claims:

- It is true that energy efficiency can be improved by recovery of carbon from the char. However, high temperature treatment of char will negate some if not all of the earlier benefits of low temperature pyrolysis;
- It is not correct to simultaneously claim the benefits of carbon recovery and low temperature operation. The plant at Burgau benefits from low temperature operation but has no carbon recovery unit;
- Bottom ash from combustion plants does not contain high levels of pollutants. In fact they contain less pollutants than pyrolysis residues since more of the pollutants have already been volatilised into the flue gases and will end up in the flue gas treatment residues. As explained in section B.2.1. The bottom ash from combustion plants and possibly some gasification plants are deemed to be suitable for use as an aggregate whereas pyrolysis char will need to be landfilled or undergo further treatment. The relative merits of having the pollutants in the reactor residues or in the flue gas treatment residues is unclear;

E.1.3 Utilisation

Comment

For instance our reference plant at Burgau (near Furth) with a commercial availability of more then 92 % for the last three years, aiming at 95 % this year. This plant operates since 1984 and has replaced the boiler last year to enable 15 years further operation. It was proven the least expensive waste to energy plant in Bavaria with the lowest emissions of dioxin.

---

[33] Developments of UK Cost Curves for Abatement of Dioxin Emissions to Air – Draft report by Entec UK Ltd to DEFRA, November 2003.

Response

There many terms used to measure the reliability of a plant. To avoid ambiguity it is preferable to measure plant reliability in terms of utilisation defined as:

$$\frac{\text{Actual annual throughput}}{\text{Maximum hourly throughput x 8760 hours}}$$

expressed as a percentage, where annual throughput is measured in tonnes/year or MJ/year thermal input and hourly throughput is measured in tonnes/hour or MJ/hour. To gain an understanding of a plant's long-term availability, the calculated annual availability should be averaged over many years.

This definition of utilisation accounts for periods when the plant is not operating due to emergency repairs, routine planned maintenance, and major refurbishments or any other reason. The definition also accounts for periods when plant is operating but not at full capacity for any reason.

Suppliers' availability data have not been quoted in this report because suppliers use widely varying definitions of availability and the basis is generally not declared.

As a general principle, any energy from waste plant that was able, on the basis of the above definition, to maintain an average utilisation in excess of 88% can be considered to be doing very well.

It is not possible to comment on the claim that the Burgau facility is the least expensive EfW plant in Bavaria since neither the basis for the comparison nor the nature and age of the plants with which Burgau is compared are known.

E.1.4 Definition of Proven

Comment

There should be a clear delineation between the comments made on research and development technology compared with those operating at full scale. Junipe'rs arbitrary 2 commercial-scale operating examples seems a not unreasonable delineation.

Response

The report does not state that WasteGen/Techtrade technology is not proven and it is agreed that the definition of two plants in commercial scale operation for a number of years is not unreasonable.

However, if a plant offered contains elements such as gasification of char or the use of syngas in a gas turbine or gas engine and these elements have not been proven against the same criteria, then the plant as a whole cannot be considered to be proven.

Similar reservations exist concerning scaling up. A significant change in size from the 'proven' reference plants would lessen the relevance of the reference plants.

E.1.5 Japanese Plants

Comment

Why do Fichtner totally ignore the 22 Japanese projects in progress since 1997? They should either explain why they consider this to be irrelevant or include the evidence to demonstrate that 22 projects somehow are only viable in a Japanese context. It may be concluded that the Japanese have actually discovered that they obtain both technical and environmental benefits to confound the last paragraph.

Table 10 – Pyrolysis Projects in Japan					
Prefecture	**Origin of Technology**	**Capacity**	**Number of Furnace**	**Receipt of Order**	**Kind of Waste**
		(tons/day)		(year)	
Fukuoka	Siemens	220	2	1997	MSW
Aichi	Siemens	400	2	1998	MSW
Hokkaido	Siemens	70	2	2000	MSW
Hokkaido	Siemens	105	2	2000	MSW
Aomori	Siemens	70	2	2000	MSW
Niigata	Thide (France)	35	2	2000	MSW
Yamanashi	Siemens	80	2	2000	MSW
Aichi		65	2	2000	MSW
Mie		80	3	2000	MSW
Shimane	Thide (France)	109	2	2000	MSW
Fukuoka	Siemens	130	2	2000	MSW
Hokkaido	Siemens	63	2	2001	MSW
Okayama	Thermoselect	185	3	2001	MSW
Kagoshima		40	2	2001	MSW
Tokushima	Thermoselect	60	2	2002	MSW
Nagasaki	Thermoselect	150	2	2002	MSW
Shizuoka	Siemens	70	2	2003	MSW
Okayama	Thermoselect			2003	MSW
Osaka	Thermoselect		1	2002	Construction Waste
Saitama	Thermoselect		1	2002	Industrial waste

Response

1) This report is based on the UK market and intended for the use of local authorities and waste management companies in the UK. Therefore, only those technologies and their associated reference plants (including the ones in Japan) that are being marketed in the UK have been specifically mentioned.

2) It is noted that the date given in the above table is for placement of order and not for start of operation. Many of the recent orders listed in the above table are unlikely to relate to operational plants. This report only covers operational reference plants from which operational experience has been gained.

3) It is understood that in addition to the 20 plants listed in the above table, there are also two other small test plants supplied by Techtrade operating in Japan but neither are processing RMSW.

4) WasteGen/Techtrade are suggesting that the report should explain why the Japanese plants are irrelevant. In fact, a UK investor will want to know why they are relevant to the UK. Technology suppliers have been given ample opportunity to submit operating data for all of their reference plants wherever they are located.

5) Where details of relevant reference plants have been supplied they have been included in Appendix D. It is not correct to say that Japanese reference plants have been ignored.

E.1.6 Why Compare Gasification and Pyrolysis with Combustion

Comment

Surely it should be stated that many local authorities specifically exclude incineration from their current contracts which makes [a comparison with combustion technology] *invalid.*

The comment questions why it is necessary to compare gasification and pyrolysis against combustion plants.

Response

If any new technology is to become established it must demonstrate an **overall** advantage when compared to the established technologies, otherwise, why adopt a new technology? Comparisons with the established technologies are therefore essential.

It is agreed that, where a local authority has ruled out combustion, then pyrolysis and gasification will be assessed on its own merits against other options such as the use of MBT to manufacture RDF.

E.1.7 Unpredictability of ROCs

Comment

It is true that ROCs are unpredictable looking forward, but the deployment of capacity relative to targets strongly suggests that prices will rise at least to 2010. This is borne out in any objective analysis. Since the start of the RO, ROCs for 2002/03 have traded at values between £41 and £53 per MWh, with prices generally increasing with time as greater certainty was gained as to the level of the shortfall for the year. It would take unprecedented levels of investment in ALL of landfill gas, small hydro, wind, biomass and waste to reach a point where supply began to approach demand. Also, there is no discounting for ROCs on long-term deals, the discounting is on the base energy price. This can reduce the total contract by £7-8 per MWh, not as drastic as is inferred.

Response

The fact is that the value of ROCs depends on the size of the deficit between the number available and the target. If more certificates have to be purchased at the buy-out rate, then more money is returned to the suppliers of ROCs and the value of ROCs will increase. Therefore, uncertainty in the future supply of ROCs means that the future price of ROCs is also uncertain. It is not therefore possible to enjoy a long-term contract for ROCs at today's market prices of £41 to £53.

Clearly the Government is expecting unprecedented levels of investment in renewables. However, it is not necessary for the supply to approach the target in order for the value of ROCs to diminish. Progress towards the target will automatically result in a reduction in the value of ROCs.

The reduction is uncertain and therefore any electricity supplier offering a long-term contract will substantially discount compared with today's market value.

E.2 Representations by Compact Power

E.2.1 Capacity

Comment

The comparison of a Compact Power plant at 100K tpa (and probably some other advanced thermal technologies) with a "stand alone" conventional incineration plant of that scale is not really valid as we specifically market plants at smaller scale as a component of an integrated waste management facility. Deployment in the way suggested is not realistic or as is rightly suggested economic. We would like to see comment that clearly points this out.

Response

To make direct comparisons it was decided to standardize on a plant capacity of 100,000 tonnes/year. It is recognized that some of the technologies reviewed are marketed for capacities higher than this standard size and some are marketed at lower capacities but a compromise was necessary.

As described in the report, plants will tend to become less economic as capacity is reduced.

E.2.2 Energy Efficiency

Comment

Section 5.1.1 - The table shows the efficiency of a combustion steam cycle is nearly twice that of a pyrolysis & gasification steam cycle. This does not seem correct.

The range of 9% to 20% for pyrolysis & gasification steam cycles seems realistic. (Compact Power is given as 14% in the appendices, which is conservatively realistic). However the range of 19%-27% for incinerator steam cycles seems very optimistic when compared to published information. (The European Commission IPPC Draft Reference Document on BAT for Waste Incineration, Section 14.5.1.1, gives the exported electricity efficiency for 8 incinerators in 2001 as 9% minimum, 18% maximum, 13% average).

We would expect conventional incinerators to be slightly more efficient than pyrolysis and gasification processes for a number of reasons as stated in this report. But only ***SLIGHTLY!***

Response

The energy efficiencies quoted in the report for gasification and pyrolysis processes (including 14% for the Compact Power process) were the efficiencies claimed by the different technology suppliers.

A survey of 8 waste combustion plants out of hundreds in existence cannot be regarded as being representative. The source does not mention the age of the plants. Some existing plants are decades old.

New plants based on gasification and pyrolysis technologies will not be competing against poor or even average plants of different ages based on combustion technology. Energy efficiency was not the main driver at the time the majority of existing combustion plants were built. The real competition for new plants is likely to be combustion plants based on modern combustion technology designed for high energy efficiency.

An overall electrical efficiency of 27% for a waste combustion plant is achievable for new plants.

Appendix F Glossary

Term	Abbreviation	Description
Biomass integrated gasification combined cycle	BIGCC	As for IGCC but specifically using biomass as the feedstock.
Calorific value	CV	The quantity of energy that can be released by complete combustion of a material typically measured in units of MJ/kg. To be unambiguous it is always necessary to state whether the value is net (NCV) or gross (GCV).
Combined cycle gas turbine	CCGT	Power generation using a gas turbine operating in combination with a steam cycle. The hot exhaust from the gas turbine is used to generate steam for use in the steam turbine.
Flue Gas Recirculation	FGR	Recirculation of some flue gas for use as part of the secondary or tertiary combustion air intended to help reduce the oxygen concentration in the flue gas whilst maintaining high gas velocities, high turbulence and good mixing thus helping to ensure complete combustion. FGR can in theory help to reduce NO_x emissions.
Gross calorific value	GCV	As for CV but assumes that all water vapour in the combustion gases are condensed so that the latent heat of condensation of water is recovered. NCV is always a smaller value than GCV if any water or hydrogen is present in the material.
Integrated gasification combined cycle	IGCC	Combination of a gasification plant with a CCGT plant.
Integrated Pollution Prevention and Control	IPPC	Refers to Statutory Instrument 2000 No. 1973 "The Pollution Prevention and Control (England and Wales) Regulations 2000". All significant industrial installations in England and Wales require a license to operate under IPPC from the Environment Agency. Similar requirements exist throughout other parts of the UK and also the EC.
Municipal solid waste	MSW	Solid waste collected from households, municipal gardens, parks, street cleaning and commercial waste similar to household waste. In this report MSW, is taken to mean residual MSW after intensive efforts to remove as much materials as possible for reuse, recycling, and composting.
Net calorific value	NCV	As for CV but assumes that all water in the combustion gases remains in the vapour phase so that the latent heat of condensation of water is not recovered. NCV is always a smaller value than GCV if any water or hydrogen is present in the material.
Office of Gas and Electricity Markets	OFGEM	UK government department responsible for assessing qualification for ROCs.
Refuse derived fuel	RDF	A fuel that has been derived from MSW. The RDF will be more homogenous and also have a higher NCV than MSW.
Residual municipal solid waste	RMSW	The residual portion of MSW, after all reasonable steps have been taken to recover materials for recycling and composting.
Renewable Obligation Certificates	ROCs	Certificates obtained under Statutory Instrument 2002 N0. 914 "The Renewables Obligation Order 2002". Each electricity supplier in Great Britain is obligated to supply a certain amount of electricity that has been generated from renewable sources to customers in Great Britain. This obligation can be met by actually generating power from renewable sources that qualify for ROCs or by buying ROCs from other generators at market value. Failure to meet the obligation will result in financial penalties.

Term	Abbreviation	Description
Selective Catalytic Reduction	SCR	Technique for reducing NO_x emissions in flue gas by injection of a reducing agent such as ammonia or urea into the hot flue gas stream in the presence of a catalyst.
Selective Non-Catalytic Reduction	SNCR	Same as SCR but with the presence of a catalyst.
Syngas		A generic term to describe a combustible synthetic gas produced by gasification or pyrolysis of hydrocarbon materials.
Waste Incineration Directive	WID	Refers to European Directive 2000/76/EC on the Incineration of Waste. Gasification and pyrolysis is also covered by WID provided the syngas is subsequently burned. WID touches on emissions to water and land but its main focus is stringent limits on emissions to air.

This page is left intentionally blank.

This page is left intentionally blank.

This page is left intentionally blank.