REVIEW OF SMALL SCALE WASTE TO ENERGY CONVERSION SYSTEMS

IEA BIOENERGY AGREEMENT - TASK 36

WORK TOPIC 4

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EXECUTIVE SUMMARY

This report has been prepared as part of the IEA Bioenergy Task 36 Agreement (Energy from Integrated Solid Waste Management Systems) – Topic 4. Task 36 generally covers methods of thermal degradation. The separate IEA Bioenergy Task 37 covers energy from biogas and landfill gas (see www.ieabioenergy.com).

The conventional grate fired mass burn systems for Municipal Solid Waste (MSW) have tended to be built as large as possible in order to benefit from the inherent economies of scale. In urban locations, which is where most of the waste is, this has been seen as an appropriate strategy for conversion of MSW. In rural or semi-rural locations the generally lower waste tonnage combined with high transportation costs have ruled out the deployment of large-scale systems. In these cases the interest has been in the application of small-scale (typically less than 50,000 t/y throughput) systems capable of competing with low-cost landfill disposal. The challenge for these small-scale systems has been to compete with the economics of large-scale MSW incineration plants while meeting, indeed exceeding, appropriate emissions regulations.

The aim of this Topic has been to review the technology and economics of small-scale energy conversion systems and report on the level of commercial availability in IEA Bioenergy Task 36 member countries.

The objectives were to:

- collate information on selected small-scale waste treatment systems.
- produce a status report of the technical and economic potential of such systems for waste treatment.

In this study, waste to energy technology developers (with technology at an advanced stage) and suppliers in the IEA Bioenergy Task 36 member countries (Australia, Canada, Japan, Sweden, Norway, Netherlands, and the UK (Germany is an Observer country)) have been contacted where possible, and their technologies reviewed using public domain financial and technical data, usually supplied by the technology provider. Though not actually demonstrated in each case, the requirement was that the end product be electricity, or at least a stream from which electricity could be generated.

An overview of all the technologies reviewed is presented, and of these eight are examined as specific case studies (Appendix 1). These were selected on the basis of an advanced state of pre-commercial demonstration or commercial availability. The case studies selected are:

- EDDITH Thermolysis Process, France
- Energos ASA, Norway
- Foster Wheeler, Finland
- Compact Power, UK
- Naanovo Energy, Canada
- Entech Renewable Energy Systems, Australia
- Wastegen, UK
- TPS, Sweden

Generally, each case study follows the outline of:

1. Technology supplier information
2. Process description, including flow diagram of plant, typical plant size and intended fuels, feedstock preparation details and characteristics, method of thermal conversion and power production, clean-up systems employed, commercial status, reference plants, and mass and energy balances.
3. Environmental parameters

4. References

There are a number of waste to energy processes available, including combustion (incineration), pyrolysis, gasification, hydrolysis, anaerobic digestion, fermentation, cryogenics, plasma gasification and various combinations of the above. For example solid RDF, or gasified waste, might be co-fired with coal in an existing coal-fired power station.

The general trend observed for the technologies closest to commercialisation was to use the processes of pyrolysis, gasification, and high temperature oxidation, sometimes in separate vessels and sometimes in staged single vessels. Pyrolysis and gasification are carried out under sub-stoichiometric conditions, thus the volume of gas for treatment is much reduced, enabling more compact (and cheaper) clean-up systems. Each of the case studies used thermal processes carried out at atmospheric pressure.

There are no technical reasons why small-scale waste to energy systems could not become more widespread. There is a need for technical refinement through longer operational experience, but every successful technology must pass through such a phase. There is every reason to believe that with appropriate financial signals and due regard to the hierarchy of “waste”, one or more of these technologies could become widely accepted as part of a portfolio of measures to manage the waste issue.

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ACKNOWLEDGEMENTS

This study has been carried out for IEA Bioenergy Task 36. The intention has been to review public domain material but not to carry out detailed technology assessment. The content of the case studies contained in this report is based on material provided in large part by the technology providers, including personal communications, website information, and associated studies. The authors would like to acknowledge the considerable input provided from these sources and thank them for their input and comments.

Introduction

This report is the outcome of the IEA Bioenergy Task 36 (Energy from Integrated Solid Waste Management Systems) project entitled "**Small-scale Waste Conversion Systems**", under work programme topic 4.

The project aims to identify small-scale (integrated) waste to energy (WtE) technologies that have potential to replace conventional landfill practice. Small-scale technologies open up community based opportunities in rural or semi-urban areas or regional centres, where the volume of waste, transportation costs or public disapproval rule out large-scale mass-burn incinerator solutions. The challenge for small-scale systems is to effectively meet emission limits and regulations while dealing with the higher specific capital costs that small scale systems often face.

In this study, WtE technology developers (with technology at an advanced stage) and suppliers in the IEA Bioenergy Task 36 member countries (Australia, Canada, Japan, Sweden, Norway, Netherlands, Germany (observer country) and the UK) have been contacted, and their technologies reviewed on a financial and technical basis on the basis of data supplied.

An overview of all the technologies reviewed is presented, and of these eight are examined as specific case studies (Appendix 1).

Scope and criteria for inclusion in the review

- Waste streams

The main waste stream considered in this review is solid commercial and municipal solid waste (MSW), the latter typically primarily comprising household waste. The various forms of processed waste, such as Refuse-derived fuel (RDF), Recovered Fuel (REF), Automotive Shredder Residues (ASR), etc. are not considered specifically but can in most cases be used in the technologies considered [1]. Wet wastes such as sewage and other sludges have not been given specific consideration. Biomass and agricultural resides are not within the scope of Task 36.

- Technologies

Task 36 considers thermal conversion technologies (pyrolysis, gasification & combustion). Other energy technologies are considered under other IEA Bioenergy Tasks – Energy from biogas and landfill gas in Task 37.

- Size

In this review small-scale has been quantified as technologies processing up to approximately 100,000 tonnes per year of waste (~ 280 tonnes per day, ~ 12 tonnes per hour). Assuming a calorific value in the range of 10-20MJ/kg, this equates to 33-67 MW thermal capacity, or approximately 7-14 MW of electricity generation[1].

Background information

Waste management trends

Figure 1 depicts MSW waste management methods in various countries [2]. In Europe (EU-15) there are 362 MSW incineration units with an installed capacity of 44.5 Mt/a of MSW. The average plant capacity is 177,000t/a, with the modern trend towards >200,000t/a [3]. The current total waste generation in the EU is 1400 Mt/a (3.5 t/a per capita) excluding agricultural residues. MSW constitutes roughly 1/6th of the waste: typically 400-600kg/a/capita. The forecasted new energy from waste capacity demand in Europe in 2010 is up to 100 Mt/a. [2].

[1] Assuming 20% overall electrical efficiency.

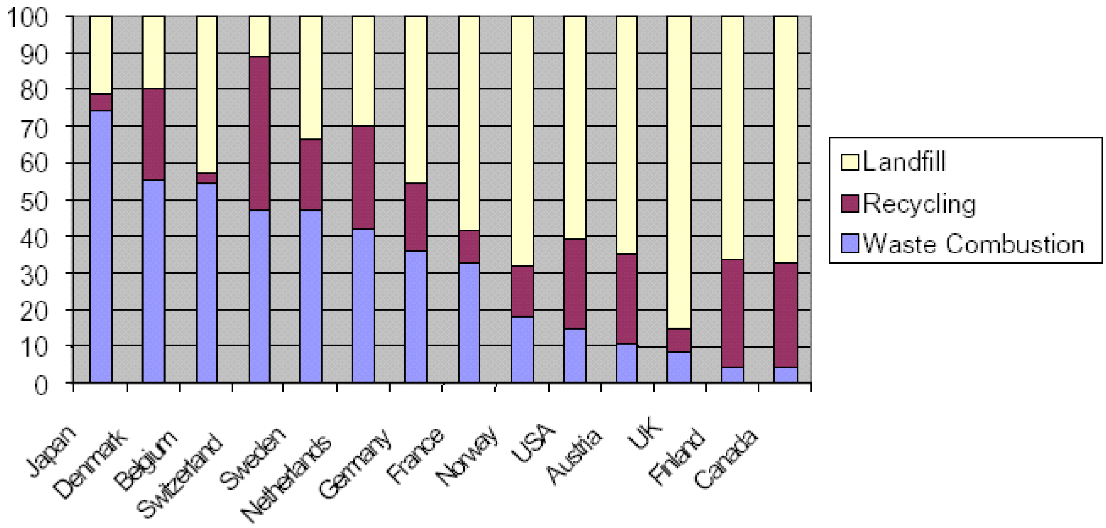

Figure 1: Current MSW management methods as a percentage of each country's total MSW arisings [2]

The landfill avoidance issue has been exercising minds for some time, and strong policies and incentives aimed at reducing the volume of waste to landfill have and are emerging. In many cases, particularly in Europe and Japan, these policies are intended to encourage the development of new and more efficient waste to energy technologies. For example, EU policies and directives include the EC Renewable Energy White Paper[2] and EU Directives on landfill, waste incineration, packaging, renewable energy sources, as well as individual country targets and economic instruments. Policies today increasingly provide economical incentives for waste management and landfill diversion.

Typical waste (MSW) characteristics

The composition of MSW/RDF is an important factor for design and operation of integrated waste to energy plants.

The following table illustrates the composition in MSW in selected countries, and gives an overview of typical composition variations.

Category	Canada '92 figures [wt%]	Finland '98/'99 figures [wt%]	Japan '93 figures* [wt%]	Netherlands '96 figures** [wt%]	Norway '96 figures** [wt%]	Sweden '97 figures** [wt%]	UK '95/'96 figures [wt%]	Australia '93 figures* [wt%]
Paper	21.9	16 ***	46	33	33	32	37	22
Packaging composites	-	1.9	-	-	-	-	-	-
Glass	5.8	9.2	7	7.5	3.6	6	9	9
Metals	3.4	3.2	8	3.5	4.6	3	6	5
Plastics	9	5.4	9	6	8.2	6	10	7
Textiles	-	2	-	-	-	2	1	-
Minerals	-	2	-	-	-	-	-	-
Composites	-	1.1	-	-	-	-	-	-
Nappies	-	2.8	-	-	4.2	6	-	-
Fines / medium grade	-	26.1	-	-	-	-	7	-
Organics (food)	49.5	29.9	26	41	27.9	-	21	50
Misc. Combustibles	-	-	-	-	-	38	7	-
Inorganics	2	-	-	-	-	-	2	-
Hazardous	-	0,4	-	-	-	1	-	-

[2] The White Paper aims at doubling the market penetration of renewable sources by 2010 to 12% - compared to 6% in 1996. See http://www.managenergy.net/products/R26.htm and http://europa.eu.int/comm/energy/res/index_en.htm

Wood	-	-	-	1,5	-	-	-	-
Laminates	-	-	-	-	-	3	-	-
Other	8,4	-	12	7,5	11	3	-	8
Sum	100	100	108	100	92,5	100	100	101

* Figures from worldbank.com
** household waste only
*** paper and cardboard

Table 1: MSW (or household waste when) composition in selected countries
Source [5] unless otherwise stated.

The chemical analysis of MSW obviously varies according to the composition of the waste. Nevertheless, Table 2, below, shows an MSW chemical elemental analysis, including ash & moisture content as well as higher and lower heating value.

	Composition [wt%]	C [wt%]	O [wt%]	H [wt%]	N [wt%]	S [wt%]	Cl [wt%]	Ash [wt%]	Moisture [wt%]	HHV [MJ/kg]	LHV [MJ/kg]
MSW	100	37.53	26.85	4.98	0.96	0.24	0.79	28.6	24.8	15.6	10.2
Paper / Cardboard	33.1	43.11	40.26	5.89	0.2	0.24	0.3	10	10	17.6	14.3
Plastics	6.5	72.89	10.63	10.11	1.1	0.39	3.88	1	10	36.3	28.2
Metal	3.7	-	-	-	-	-	-	100	0	0	0
Glass	6.4	-	-	-	-	-	-	100	0	0	0
Organic Waste	24.4	49	36.41	6.33	2.4	0.23	0.63	5	70	20.7	3.9
Other combustibles	12.6	52.14	31.34	6.57	2	0.66	2.29	5	30	22.6	13.3
Remaining fraction	13.3	-	-	-	-	-	-	100	0	0	0

Table 2: Chemical analysis of MSW and major components.
Source : [5] MSW characteristics

Introduction to thermal processing technologies

This section introduces the most common thermal processing technologies used by industry. This includes combustion / incineration, gasification and pyrolysis.

Combustion / Incineration

There are 3 common kinds of incineration technologies: moving grate, rotary kiln and fluidised bed systems. There are also new developments emerging in close-coupled gasifier-combustor configurations.

The various kinds of moving grate systems all have a grate which supports the waste (illustrated in Figure 2, below). The grate is cooled by air from below, which also acts as primary combustion air. Secondary air is added to ensure complete combustion.

A rotary kiln incinerator consists of an inclined rotating drum, where the waste tumbles down along the longitudinal axis. This process is popular for smaller incineration systems.

Fluidised bed combustors (FBC) consist of a bed of sand (or other mineral), where the fluidising air is also used for combustion of the waste. Due to efficient heat transfer, boiler pipes are placed in the bed. Usually, FBC's cannot support large heavy particles of fuel, and waste must be shredded or large particles removed before being fed to the bed.

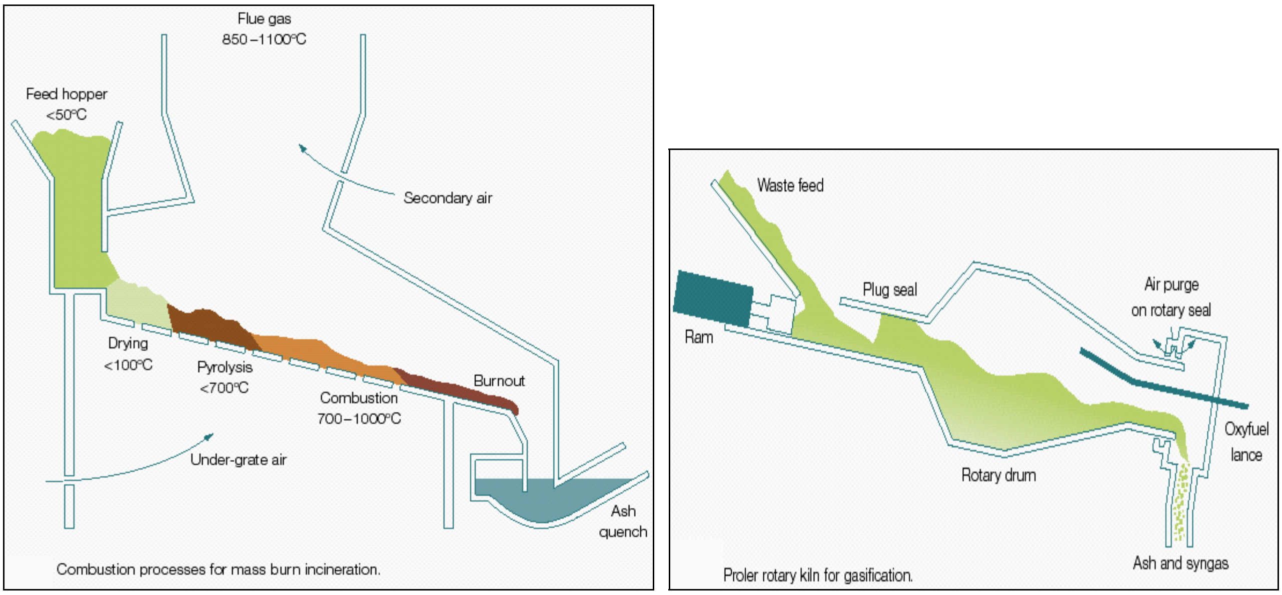

Figure 2: Schematic of moving grate incineration process (left) and rotary kiln reactor (right) [4]

Gasification and pyrolysis processes

Gasification and pyrolysis are not new concepts, and offer significant attraction in small-scale biomass systems where combustion coupled with a Rankine cycle does not gain the benefit of economies of scale. However some development is still required, particularly on specific parts of the process, to produce a mainstream commercially viable technology. Gasification processes utilise partial oxidation with air/oxygen, or react the fuel with steam to produce a fuel gas. The most common gasifier processes are updraught, downdraft, bubbling fluidised bed, circulating fluidised bed and rotary kiln reactors. Pyrolysis is an endothermic reaction and utilises no additional oxygen over that in the feedstock. Furthermore, pyrolysis processes usually produce a liquid fuel product, along with a smaller fraction of non-condensable gases and a solid fuel product (char).

Gasifiers processes are typically smaller scale than combustion technologies, and throughout the 1980's and 1990's were considered by many developers to offer lower emissions than combustion technologies. However, when appropriate flue gas and waste water cleaning technologies are applied, both gasification and combustion systems meet the most stringent environmental limits.

Prime movers for gasifiers are gas engines (small scale) and boiler steam-turbine (Rankine cycle) systems. Pressurised reactors or externally fired systems are under development for gas turbines. Gas quality is critical for the use of gas engines and turbines, and many methods are employed to ensure the necessary contents of tars and dust. Where the gas does not meet requirements for direct combustion in engines or turbines, the gas is often fully oxidised at high temperature to thermally decompose the gas meet emission limits. The released energy may be used for steam raising.

Technology Overview

The table below[3] provides an overview of waste to energy technology developers and suppliers within the constraints of this study. This list is not an exhaustive compilation of all international developments.

Eight specific technologies at an advanced stage of technical or commercial development have been selected from the IEA Bioenergy Task 36 member countries. A case study is presented for each of these. Case studies are found in Appendix 1.

[3] Sources of information for Overview Table: technology supplier web-pages, literature reviews, personal correspondence with company representatives in some cases.

Company name	Country	Webpage	Briefly about technology: size, fuels, commercial status, etc.	Assessment in relation to WtE study objectives
Lurgi Energie und Entsorgung GmbH	Germany	http://www.mg-lee.de/english/index.html	Have various technologies such as rotary kiln, fluid bed and grate fired incinerators, fluid and fixed bed gasifiers as well as an entrained flow gasifier. Mostly medium to large scale. Various fuels including fossil, biomass and waste.	Lurgi mostly deal with medium-large scale technology. It has not been ascertained if Lurgi is able to supply small-scale systems.
PKA Umwelttechnik GmbH	Germany	http://home.t-online.de/home/PKA.DE/engl~1.htm	Pretreatment of MSW and subsequent pyrolysis process, and tar cracking reactor. Electricity generation with gas engine. Approx. target size is 20,000 to 25,000 tpa.	It has not been possible get in contact with representatives from PKA.
Krupp Uhde	Germany	http://www.uhde.biz/home.en.html	Gasification (partial oxidation) of MSW. Krupp Uhde has been involved in the development of diverse routes for the treatment of MSW in the mid 1990's (gasification). Krupp focussed on a technical solution that combined the fluidised bed gasification technology High-Temperature Winkler (HTW), and a down-stream slagging process to solidify the bottom ash withdrawn from the gasification reactor. Krupp teamed up with Sumitomo Heavy Industries (SHI) in Japan, who were licensed a HTW gasifier for MSW in a pilot scale, which went into operation in 2000/2001 in Japan	Japanese SHI is now working on larger scale applications for further commercialisation of HTW for MSW in Japan. Krupp is no longer active in this field.
Thermoselect	Swiss company, but have both German and Japanese licensees	http://www.thermoselect.com/ http://www.thermoselect-karlsruhe.de/	Thermoselect High Temperature Recycling (HTR) process. Fuels: MSW, commercial waste, industrial waste and hazardous waste. Fixed bed oxygen blown gasification process. High emphasis on recovery of raw materials. The syngas is used to produce energy (eg gas engine) or for the synthesis of chemical products There are several operating Thermoselect facilities: - Karlsruhe / Germany 225,000 tpa (3MWe), - Chiba / Japan 100,000 tpa, - Mutsu / Japan 50,000 tpa (2,4MWe) - Fondotoce / Italy (original pilot plant from 1991/1992 : 30,000 tpa.)	It has not been ascertained if Thermoselect are focussing on small-scale markets.
Siemens AG	Germany	http://www.siemens.com/index.jsp	Process called thermal Waste Recycling Process (TWR). TWR WtE plant was closed down in 1999, and process taken over by Japanese company[4]	Siemens no longer operate their TWR process.
SVZ Schwarze Pumpe	Germany	http://www.svz-gmbh.de/GB/Seiten/rahmen.html	Have various well developed technologies for converting solid and liquid waste to syngas and useful energy, including 7 fixed bed gasifiers with a capacity of 15t/hr each.	Technology more suitable for medium-large installations.
Rieckermann (JR)	Germany	http://www.rieckermann.com	Rickermann offer a variety of incinerator solutions,[5] for instance a rotary kiln incineration process, and 'fixed bed incineration'.	Details on size range of technology and target fuels has not been ascertained

[4] http://solstice.crest.org/discussion/gasification/200102/msg00067.html

[5] http://www.rieckermann.com/control/view?id=19216800202610315645482780 1042&defn=country.de.jrhh.categorylist&ccode=JRHH

Foster Wheeler Inc.	Finland	http://www.fwc.com/	Foster Wheeler offer fluid bed (FB) gasifiers in the range 15-120 MWt [3]. The smallest FB gasifiers could be in the range 25-50,000 tpa depending of fuel characteristics. Foster Wheeler built a 40 MWth BFB gasifier in Varkaus, which recovers 2100 metric tonnes of aluminium a year. The ~ 40-70 MWt Lahti gasifier is operated on a mixture of fuels, including a waste derived fuel (up to 20% of fuel mixture). Gasifiers commercially developed.	Unsure of Foster Wheeler's focus on small-scale solutions.
SFT company (subsidiary of the **Nexus** Technologies)	France	http://www.irisa.fr/ProHPC/SFT_E.HTM	"Thermolysis" process (gasification) for industrial waste treatment. Optimal operating capacity of 30 000 tons a year.	It has not been possible get in contact with representatives from Nexus Technologies.
EDDITh thermolysis process, IFP. (Markedet by THIDE)	France	http://www.thide.com/ and www.ifp.fr	Indirectly heated rotary kiln pyrolysis unit for MSW. The process produces a clean solid fuel product (which can be sold and used in combustion systems) and non condensable gases, typically used for drying the waste. Solid fuel product represents about 45% of waste energy content. Target Fuels: MSW, RDF, auto shredder residue, industrial waste, electronic waste, sewage sludge, etc. Technology licensed to Hitachi Ltd in Japan, who have 3 commercial operating plants. A fourth plant is currently under construction in Arthelyse in France, for the treatment of 50,000 tpa of MSW.	Specially developed for small-scale MSW, suitable size range is between 10,000 and 70,000 tonnes/yr
Brightstar (SWERF**)**	Australia	http://www.brightstarenvironmental.com/html/Swerf.htm	Solid Waste to Energy Recycling Facility (**SWERF**) Waste pre-treatment system followed by gasifier / pyrolysis unit. Electricity generation in internal combustion engines.	Technology suitable for small-scale WtE projects. Development of this technology has ceased.
ESI (Enersludge**)**	Australia	http://www.environ.com.au/enersludge.shtml	Pyrolysis process for conversion of sewage sludge "Enersludge". Produces a solid fuel product (char) and liquid fuel "bio-oil". Char utilised for sludge drying. The Subiaco plant in Western Australia was constructed in the late 90s and treats approx. 25 dry tonnes per day of sewage sludge. The "bio-oil" yield is approx. 30% of the fuel on a weight basis, and almost 50% on an energy basis. Process commercially developed.	Technology mainly suitable for sewage sludge and other sludges
TPS Termiska Processer AB	Sweden	http://www.tps.se/index_en.htm	TPS offer CFB systems for biomass and waste. In the late 90s TPS installed 2 x 15MWth RDF gasifiers (~40,000 tpa each) in Italy that produce gas for a boiler (coupled to a steam turbine) and a cement furnace. Commercially developed.	Well suited for RDF.
Energos	Norway	http://www.energos.com	Standard combustion system w. boiler & necessary flue gas clean-up systems. Small-scale focus: ~35,000 tonnes per annum of waste (MSW, RDF). Energos have at least 6 operational plants in Norway.	Technology suitable for small-scale WtE projects
EnviroArc (PyroArc process)	Norway	http://www.enviroarc.com/default.asp	Plasma torch gasification of tannery waste and other solid wastes. Have experience with tannery waste (15,000 tpa plant) and a solid waste pilot plant. Uses internal combustion engine for electricity generation.	Technology suitable for small-scale WtE projects
The **Institute of Applied Energy** & New Energy and Industrial	Japan	http://www.iae.or.jp/ABOUT.html http://www.nedo.go.j	NEDO and IAE have been engaged in a project to develop new small-scale WtE pyrolysis/gasification technology. Size range considered: 50-200 t/d.	Still at R&D stage.

Technology Development Organization **(NEDO)**		p/english/index.html	NEDO and IAE's activities are mainly centred on feasibility studies and specific R&D aimed at optimising performance and efficiency of the gasifier process (eg. Gas quality, engine performance, etc.) No pilot plants have yet been installed (to the knowledge of the authors)	
Nippon Steel, Japan	Japan	http://www0.nsc.co.jp/shinnihon_english/	Operate a plasma gasifier. Further details have not been made available.	Further details have not been made available.
Ebara Corporation	Japan	http://www.ebara.co.jp/en/index.html	Various types of WtE solutions: FB gasifier-combustor, FB combustor, grate fired incinerator. Technologies well developed. Information on target fuels and size range has not been obtained.	Unsure of scale. Further details have not been made available.
Hitachi Zosen Corp.	Japan	http://www.hitachizosen.co.jp/english/index-e.html http://www.hitachizosen.co.jp/english/solution/set_ind1-e.html	Have built about 50 waste treatment facilities with power generation capacity totalling nearly 300 MW. They also have smaller installations such as 2,6MWe and 15MWe. Technology is based on incineration.	Unsure if Hitachi focus on small-scale markets.
Mitsui Engineering and shipbuilding (**MES**) - Mitsui Babcok Energy (MBEL)	Japan	http://www.mes.co.jp/english/ http://www.mitsuibabcock.com/home.asp	MES have delivered 3 WtE plants in Japan, "R21" pyrolysis process. Further details have not been made available.	Need more information to assess technology
JF Bioenergy Inc / JF Ventures Ltd (JFB & JFV)	Canada	http://www.jfbioenergy.com/	Pyrolysis to generate syngas, bio-oil and charcoal. Size: About 120 wet tonnes of feed a day ~40,000 tonnes a year. Technology is currently undergoing further testing, in particular relating to stack emissions.	Need further R&D before technology is commercially available.
Enerkem Technologies (associated with Sherbrooke University)	Canada	http://www.enerkem.com/	Enerkem - BioSyn process, uses fluid bed technology to produce a clean syngas. Enerkem have a pilot-scale gasifier operating in Sherbrooke, Quebec (since fall 2001) that can convert 2.5 tonnes per day of sorted MSW into syngas. There are plans to build a larger gasifier, also in Sherbrooke, to treat 25,000 tonnes per annum. Enerkem have licensed their technology to EIE SL in Spain, who have constructed a gasifier for non-recyclable plastics. Gas is fed to a power plant that generates 6.8 MWe. A second Enerkem gasifier was to have opened in fall 2002.	Technology suitable for small-scale WtE projects
Naanovo Energy Inc. (NEI)	Canada / Sweden	http://www.naanovo.com	Turnkey incinerator solutions processing about 64,000 tonnes of MSW a year, or about 5-8MWe.	Technology suitable for small-medium scale WtE projects
Plasma Environmental Technologies Inc.	Canada	http://www.plasmaenvironmental.com	The Plasma Assisted Gasifier (PAG) unit is set-up with gas cleaning equipment and a gas-engine that generates electricity. Process up to about 10,000 tonnes per year. PET are planning to build a 5 tonne per day unit in late 2003.	Technology is currently undergoing further development.
Resorption Canada Limited (RCL**)**	Canada	http://www.rcl-plasma.com	Plasma gasification of waste fractions (MSW, biomedical waste, incinerator ash, chemical sludges and contaminated oils). No specific size range; technology technically feasible over a wide range of annual throughputs.	Technology suitable for small-scale WtE projects
Trecan Combustion Limited	Canada	http://www.trecan.com	Very small-scale solid waste incineration systems (max 10,000 tpa). Have 12 standard sized systems that produce steam, hot water or hot air.	Technology aims at a very small throughput.

CompactPower	UK	http://www.compactpower.co.uk/	Close coupled gasifier-combustor process for treating MSW. Includes waste pre-treatment for materials recovery.	Technology suitable for small-scale WtE projects
Asgardsystems	UK	http://www.asgardsystems.co.uk/	Cardboard and paper waste, as well as wood waste materials. Combustor + boiler systems for hot air or hot water. Size up to perhaps 1,000 tpa.	Not aimed at MSW, and also focussed on very small scale.
Bioflame	UK	http://www.bioflame.com/	up to 250kW,e + 1MW heat (2-4,000 tpa) Gasifier + gas engine process.	Need further R&D funding if MSW as a fuel is to be pursued.[6]
IET Energy and **Entech Renewable Energy Systems**	UK / Australia	http://www.ietenergy.com	Various kinds of waste: MSW, food waste, hazardous waste, clinical waste Gasifier - combustor system used to generate process steam. (no steam turbine solutions). Technology seems relatively well developed with 6 installed plants on different wastes. Case studies indicate size range up to 30,000 tpa	Technology suitable for small-scale WtE projects
WasteGen UK	UK	http://www.wastegen.com/wastegenuk.htm	Rotary kiln pyrolysis process for MSW & RDF with boiler and steam turbine for electricity generation. Based on a 1983 German reference installation (generates 2,2MWe, ie size ~30,000 tpa).	Technology suitable for small-scale WtE projects
Waste Gas Technology (**WTG**)	UK	http://www.wgtuk.com/ukindex.html	Various biomass and solid waste. Their 60kg/hr pilot rig has successfully handled MSW and household waste. The rig is set-up to generate electricity with an IC gas engine. "semi-commercial" ½ tonne/hr plant (~4,000 tpa) in Nash in 1998, running on sewage sludge. A gas engine for electricity generation tests was equipped in 2000.	Technology may be suitable for small-scale WtE projects

[6] Source: personal communication with Bioflame (Victor Buchanan)

References

[1] EC report, Refuse derived fuel, current practice and perspectives, B4-3040/2000/306517/MAR/E3, July 2003

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[3] EC Joint Research Centre, Draft Reference document on Best Available Techniques for Waste Incineration, Draft May 2003

[4] C-Tech Innovation Ltd: *"Thermal methods of municipal waste treatment"*, 2003. http://www.capenhurst.com

[5] IEA Bioenergy: *"Accomplishments from IEA Bioenergy Task 23 : Energy from Thermal Conversion of MSW and RDF"*, 2000

[6] Warnken Industrial and Social Ecology Pty Ltd for the Energy From Waste Division of the Waste Management Association of Australia.: "*Energy From Waste Sustainability Project",* September 2002. http://www.warnkenise.com.au

Note: Case study specific references are listed at the end of each case studies

Appendix 1 - Case studies

This appendix includes more detailed information on the eight technologies listed in the table below.

Case study no. - Technology	Country	Webpage(s)
1: EDDITh thermolysis process Pyrolysis process by IFP (French Institute for Petroleum) specially designed for MSW at small scale. Indirectly heated rotary kiln pyrolysis unit. Technology sold to Hitachi Ltd & 3 commercial plants built in Japan.	France	http://www.thide.com/ and http://www.ifp.fr/ (Not much info on IFP homepage about EDDITh process)
2: Energos. Combustion system with boiler and flue gas cleanup systems. Have 6 operational plants in Norway. Fuels: MSW, RDF	Norway	http://www.energos.com/
3: Foster Wheeler, Finland Large gasifier supplier. Case study based on Lahti-plant in Finland.	Finland	http://www.fwc.com/
4: Compact-Power MSW Gasifier-combustor system	UK	http://www.compactpower.co.uk/
5: Naanovo Energy Inc. (NEI) Turn-key WtE solutions at about 64,000 tpa.	Canada	http://www.naanovo.com
6: Entech Renewable Energy Systems. Well developed MSW gasifier - combustor system. Many references plants. Size range approx. 40,000 - 180,000 tpa	Australia (UK licensee: IET Energy)	http://www.entech.net.au http://www.ietenergy.com/
7: WasteGen UK MSW separation and recycling system, gasifier thermal process for energy recovery. Technology based on 35,000 tpa reference plant operational since 1983.	UK	http:www.wastegen.com/template.htm
8: TPS Termiska Processer AB CFB gasifier system with specially deigned combustor & boiler, that generates steam for a steam turbine. Information based on two operational RDF-fired gasifiers (2 x 15MW) installed in the late 90s in Italy.	Sweden	http://www.tps.se/index_en.htm

Case study 1 : EDDITh thermolysis process, France

Technology supplier information

The EDDITh process was developed by IFP (the French Institute for Petroleum). The French company Thide Environment (www.thide.com) is now in charge of the commercialisation/operation of the process.

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THIDE ENVIRONNEMENT
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E-MAIL : thide@thide.com

Ownership details, licensees, partnerships & other relevant information:

As mentioned the process was developed by IFP, and is now being commercialised by THIDE. In 1999 a license for the EDDITh process was sold to Japanese Hitachi, who have built several plants based on the technology. See "reference plants" below.

Process description

Description of process

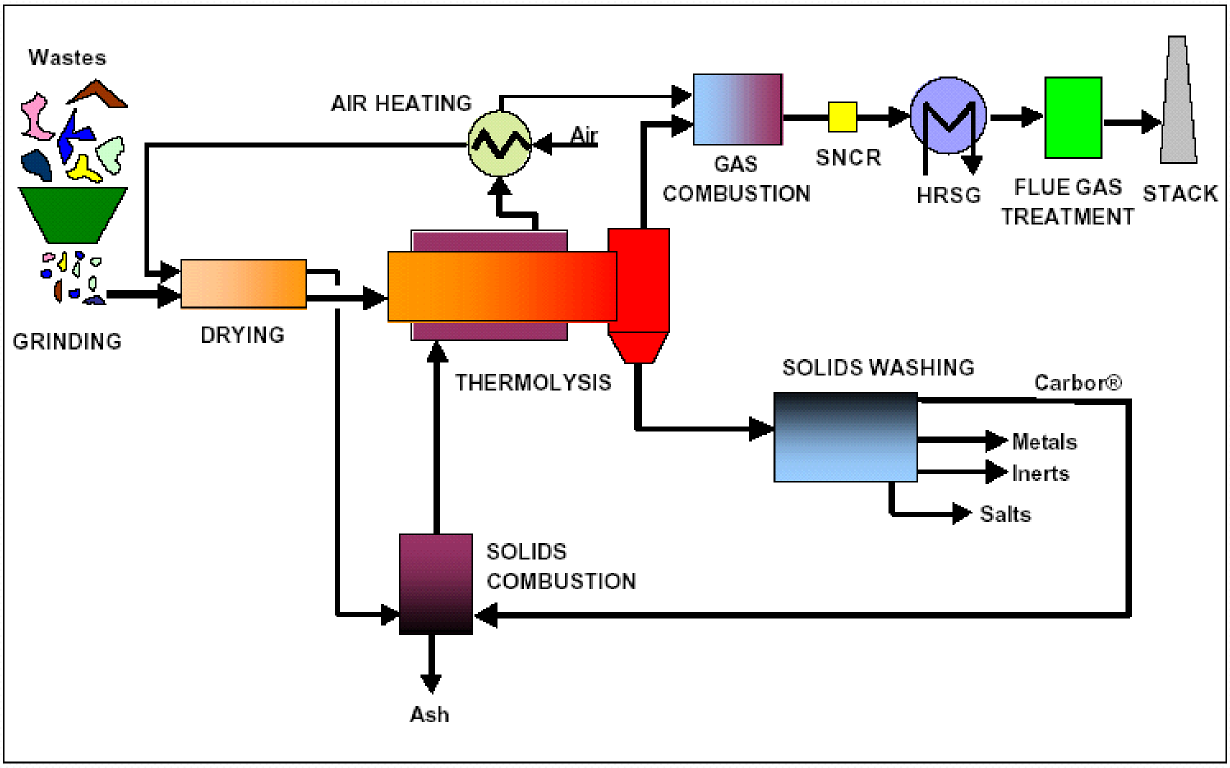
Indirectly heated atmospheric pressure rotary kiln pyrolysis unit ("thermolysis process"). A 500kg/hr pilot plant is built in Vernouillet (France) and 3 plants are operating in Japan and 1 plant is starting in France. The heating rate is 10-50K/min up to a final temperature of 400-700°C, which yields a residence time of 45-60 minutes. Metals and inerts are separated out of the thermolysis reactor.

The main product from the process is a solid fuel for combustion, called Carbor®, and non-condensable gases. The solid fuel yield is approx. 45% of the waste energy content.

The processes isn't directly coupled to a electricity generating unit, although the solid fuel product could be used for this purpose, if deemed viable. Gases are used for thermal energy such as drying, hot water or steam or power production after conditioning.

Process flow diagram & plant pictures

There can be various flow-diagram configurations depending on where the gas and solid fuels are used. The figure below should be taken as an example only.



Simplified scheme of integrated version of the Eddith process

Typical plant size and intended fuels

Process specially developed for small-scale MSW, suitable size range between 10,000 and 80,000 tonnes/yr.

Fuels: MSW, RDF, auto shredder residue, industrial waste, electronic waste, sewage sludge, etc.

Feedstock preparation details, feed requirements, and typical feed characteristics

Process has limited special feedstock requirements.

Feed is ground and dried prior to the thermolysis reactor.

As an example of typical feed characteristics, the French Arthelyse plant (see "reference plants" below) consumes 40,000 tonnes per annum of domestic waste, 8000 tonnes per annum of general industrial waste and 2000 tonnes per annum of waste treatment sludge. The fuel moisture content is 31-44%, and has a LHV of 7,5 - 9,4 MJ/kg.

Method of thermal conversion

Indirectly heated rotary kiln gasifier, as described above.

Dry gas composition (based on Arthelyse Plant):

H_2	12,7 vol%
CH_4	16,0 vol%
CO	19,1 vol%
CO_2	28,8 vol%
C_2H_4	5,5 vol%
C_2H_6	4,9 vol%
C3+	13,0 vol%
LHV	23,1 MJ/kg

Method of power production

The technology produces a solid fuel product that can be used for combustion, and hence electricity production. However, power generation is not always a financially viable solution in small-scale, according to E Marty from IFP. See "reference plants" section for details on current usage of solid fuel product.

Downstream clean-up systems

Solid fuel product (Carbor®) : ash and metals are removed (washing)

Filtration with fabric filter prior to stack.

Commercial status

The process has been fully demonstrated at an industrial scale. Hitachi Ltd has 3 commercial operating plants built in Japan.

Remaining developments include:

* gas upgrading and conditioning
* develop use of solid fuel

Reference plants

Technology based on 500kg/hr pilot plant in Vernouillet, France

Since 1999, three plants based on the EDDITh process have been erected in Japan, and one is currently at the end of the start-up operations stage in France (the Arthelyse Plant) for the treatment of 50,000 tonnes of waste per year.

Details on Japanese plants:

Plant	Date operational	Fuel	Fuel Consumption	Comments
Nakaminto Plant, Japan	1997	MSW	1000 kg-hr, or approx. 8000 tonnes per annum.	pilot plant
Itoigawa Plant, Japan	April 2002	MSW	18,000 tonnes per annum	Produces hot water for a fitness centre close to the plant. Solid fuel product sold to a cement plant.
Itzumo plant	?	MSW	70,000 tonnes per annum	

Mass and energy balances:

Mass balance based on Arthelyse Plant

Mass in:

1000 kg fuel: 80% MSW, 16% industrial waste, 4% sludge

220 kg of water out of dryer
780 kg of dried waste to thermolysis process

Mass out:

240 kg of solid fuel product (Carbor®)
380 kg of thermolysis gas (use in eg. drying process)
60 kg metals
90 kg inerts
10 kg salt

The Carbor® solid fuel product represents approx. 45% of the waste energy content.

Environmental parameters

Complies with stack emission requirements

References

Personal communication with Eric Marty from IFP (French Petroleum Institute), September 2003

Giroudiére, F and Marty, E: *"Waste to Power and Energy by the EDDITh Thermolysis Process, Recent Industrial Developments"*. IT3'03 Conference, Orlando, Florida, 2003

Marty, E: *"Case study: Production of Fuels from Waste & Biomass by the EDDITh Thermolysis Process. Recent Industrial Developments"*. Presentation held at the Pyrolysis and Gasification of Biomass and Waste Expert Meeting in Strasbourg, October 2002.

Case study 2 : Energos ASA, Norway

Technology supplier information

Energos ASA

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http://www.energos.com

Ownership details, licensees, partnerships & other relevant information:

The Company designs, owns and operates small-scale energy plants based on its own proprietary and patented technology.

Energos ASA was incorporated in Norway on 26 March 1995 under the Limited Companies Act 1976 as a private limited company, under the former name Aitos AS. Aitos changed its name to Energos AS in December 1997.

Process description

Description of process

Energos' technological solutions have certain proprietary elements and are otherwise based on standard combustion and other components purchased from third parties. Energos has patented the design of the furnace in which the combustion is controlled by Energos' proprietary software. Energos' software enables the company to offer a cost- competitive, efficient, small-scale and environmentally compliant energy solution. The software allows plant operators full control over the combustion process, which together with the company's proprietary furnace design, creates a differentiated and more complete combustion. This combustion process reduces the need to invest in high-cost pollution cleaning systems, enabling the system to be more cost-effective.

Drying, pyrolysis and gasification of the pre-treated waste is carried out in the primary chamber under sub-stoichiometric conditions. The syn-gas generated in the primary chamber is transferred to a separate secondary chamber where a final high-temperature oxidation takes place.

The Energos furnace unit is horizontally divided into a primary chamber on the bottom, where the gasification of the solid waste takes place, and a secondary chamber on top of the primary chamber, where the combustion of primary gases is completed.

The waste is pre-treated to ensure a sufficiently high surface-to-volume ratio and a low content of metals.

In the primary chamber the waste is fed into the furnace in a controlled fashion, where it first falls onto a specially designed grate. At the cold input side of the primary chamber, the dominant process occurring is drying of the waste. Then follows a section of pyrolysis, and finally there is a carbon burnout section at the hot end, before the burnt out waste falls into a water bath / air lock and is removed and transported as bottom ash. The grate is stationary, i.e. it has no moving parts, and its surface temperature is controlled. It is divided into twelve sections, and individually controlled air supplies provide primary air for each of the twelve grate sections. Overfire air in the primary chamber provides an additional degree of freedom with respect to control of both combustion atmosphere and temperatures.

The transport mechanism is designed in such a manner that in addition to the longitudinal transport there is good local mixing of the moving waste bed, again in order to promote the local homogeneity of the combustion process.

After the combustible gases have left the primary chamber, secondary air and recycled flue gas is added at several addition points, in order to achieve both a suitable combustion atmosphere and the right temperature trajectory.

The furnace design outlined above makes it possible to simultaneously achieve :

-Good burnout of bottom ashes (and a low content of some heavy metals).
-Good CO stability on a very low level and a high degree of cracking of organic substances.
-Low and stable NOX.

The Energos boiler system is designed to allow for rapid cooling of the flue gas. There are no cooled surfaces in the Energos furnace. When the flue gas enters the boiler system it has a temperature of about 900 degrees Centigrade. It is well known that dioxins and furans may be re-synthesized in the boiler system. Therefore a compact boiler system has been selected, based on a standard flue gas tube boiler design, followed by a standard water-tube economizer. In order to achieve rapid cooling and a compact design, the flue gas velocity needs to be substantially higher than what is common in traditional waste boiler systems.

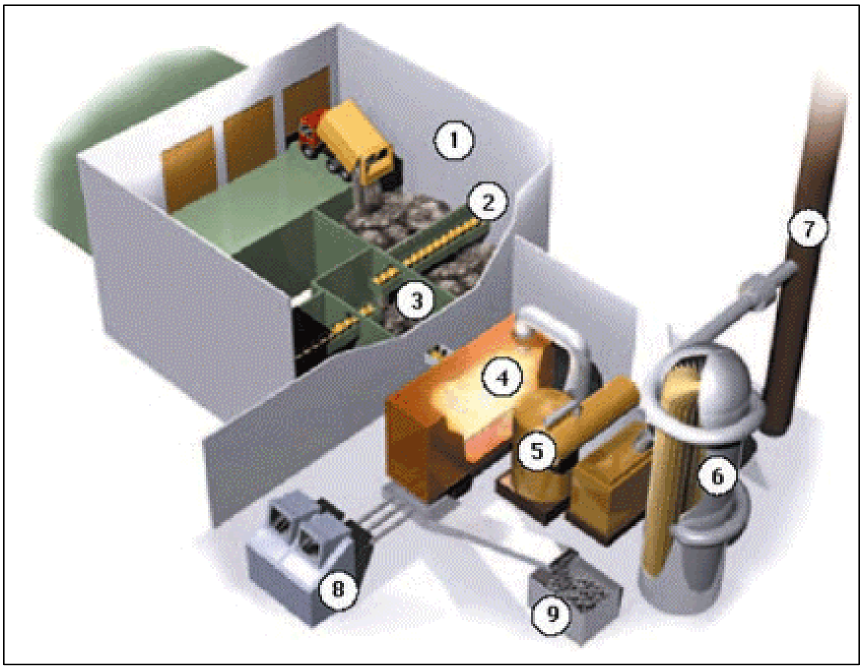
The Energos flue gas cleaning system is designed to remove fly ash, metals (incl. heavy metals) in the flue gas stream, remaining organic trace compounds and acidic components. It is based on a standard baghouse filter with a high-performance membrane coating, with injection of lime and active carbon.

The Energos Process Control system has been designed to counteract disturbances in the waste feed, and thereby keep emissions below limits.

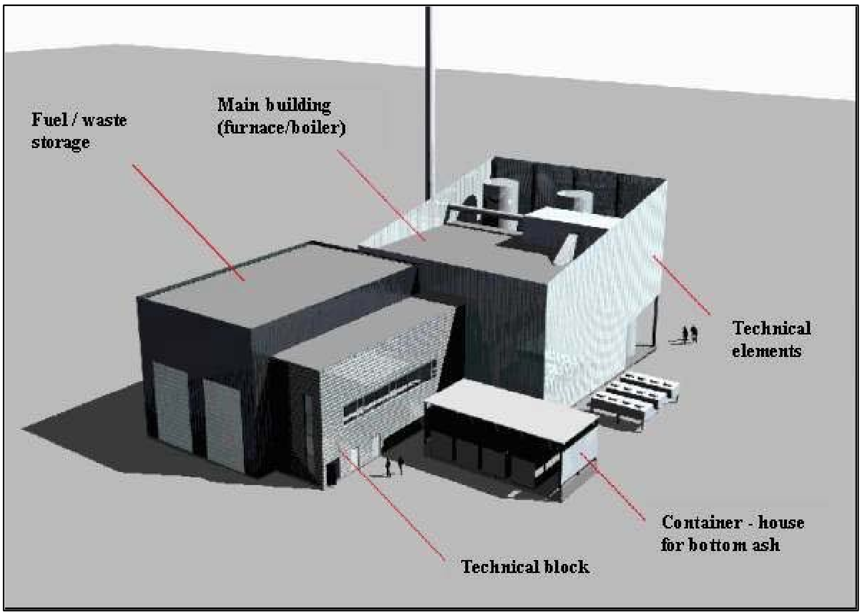
The outer loop in the furnace control system controls the feed rate to the furnace by feedback control from the desired duty set point for the steam production in the boiler system. Inner loops control the addition of combustion air and recycled flue gas air at the various inlets.

The control of the filter system (carbon and lime addition and filter pulsing pattern) is based on on-line measurement of the emission parameters to be controlled, with additional information relating the pressure drop across the filter system to basic filter characteristics.

Process flow diagram & plant pictures



1. Solid fuel bunker
2. Screw conveyer
3. Fuel supply chamber
4. Furnace
5. Boiler
6. Filter system
7. Stack
8. Control and monitoring system
9. Ash container



A single processing line consists of the following main systems:

* Fuel storage and transport system
* Combustion furnace system
* Boiler system
* Flue gas cleaning system
* Control and monitoring system

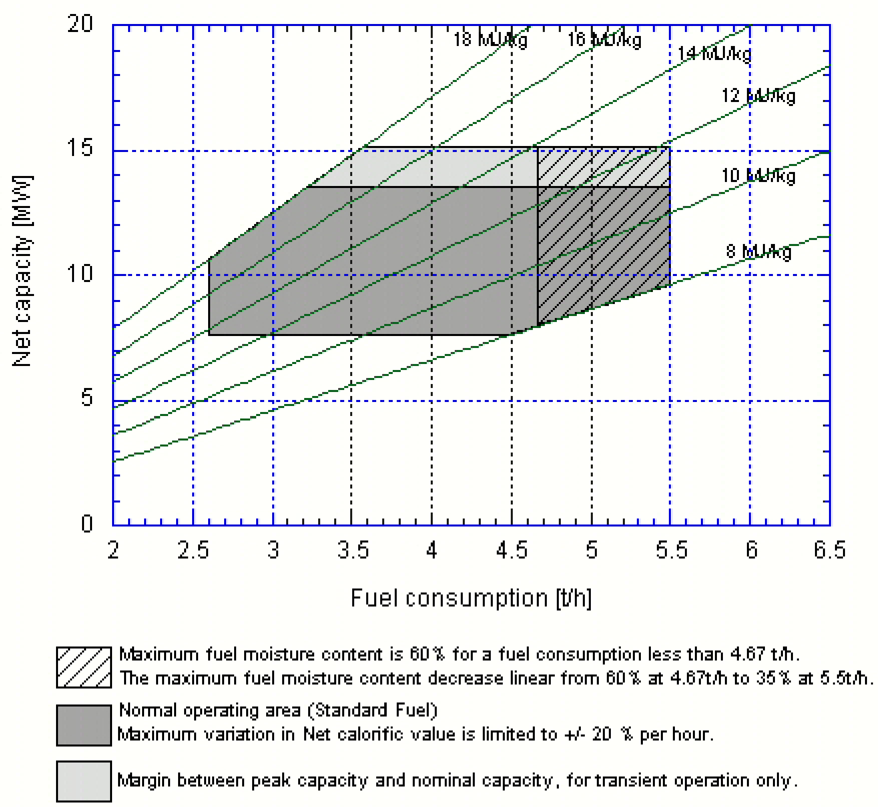
Typical plant size and intended fuels

Intended fuels for the Energos plants are MSW or RDF.

Typical plant size is 35,000 – 40,000 tpa per line (modular) - or roughly 15 MWth. A typical Energos plant consists of one or two lines in parallel. Type 41 and 51 in the table below represent a single line, and type 42 and 52 the double line version.

	Type 41	Type 42	Type 51	Type 52
Maximum fuel consumption (t/h)	5.5	11	5.5	11
Minimum fuel consumption (t/h)	2.6	5.2	2.6	5.2
Maximum NCV (MJ/kg)	18	18	18	18
Minimum NCV (MJ/kg)	8	8	8	8
Nominal capacity (MW)	13.5	27	16.4	32.8
Building area (sq. meters)	1,500	2,200	1,600	2,300
Site area (sq. meters)	6,000	9,800	6,200	10,200

A capacity diagram showing the type 41 plant's net boiler capacity as a function of NCV and fuel consumption is shown below.



Feedstock preparation details, feed requirements, and typical feed characteristics

Pre-treatment of received waste in required for Energos plants. The received waste has to be shredded and ferrous metals removed by magnetic separation A system for pre-treatment of waste is an integrated part of an Energos plant

Fuel bulk density requirements after shredding and mixing are as follows:
* greater than 150 kg/m3
* less than 500 kg/m3

Size: The different waste fractions have to be shredded to ensure particle size according to the following:
* 90% less than 150 mm
* 100% less than 200 mm

Content of metals:

The content of other metals such as steel, stainless steel, iron and brass are < 0.5 % in weight, and max. particle size < 40 mm after shredding.

Method of thermal conversion

Grate fired combustion system.

Method of power production

Energos offer energy recovery plants for power production and CHP. Power production is done by steam turbines. Two such plants are in operation at present and two double line plants for CHP are presently in the engineering phase.

Downstream clean-up systems

A standard Energos plant is equipped with a dry flue-gas cleaning system, where lime and activated carbon is injected in the flue-gas upstream of a bag-house filter.

Lime will absorb acid components (SO2, HCL and F) in the flue gas while activated carbon will absorb TOC, heavy metals and dioxins. Dust/particles, lime and activated carbon will be separated from the flue-gas by the bag house filters.

Commercial status

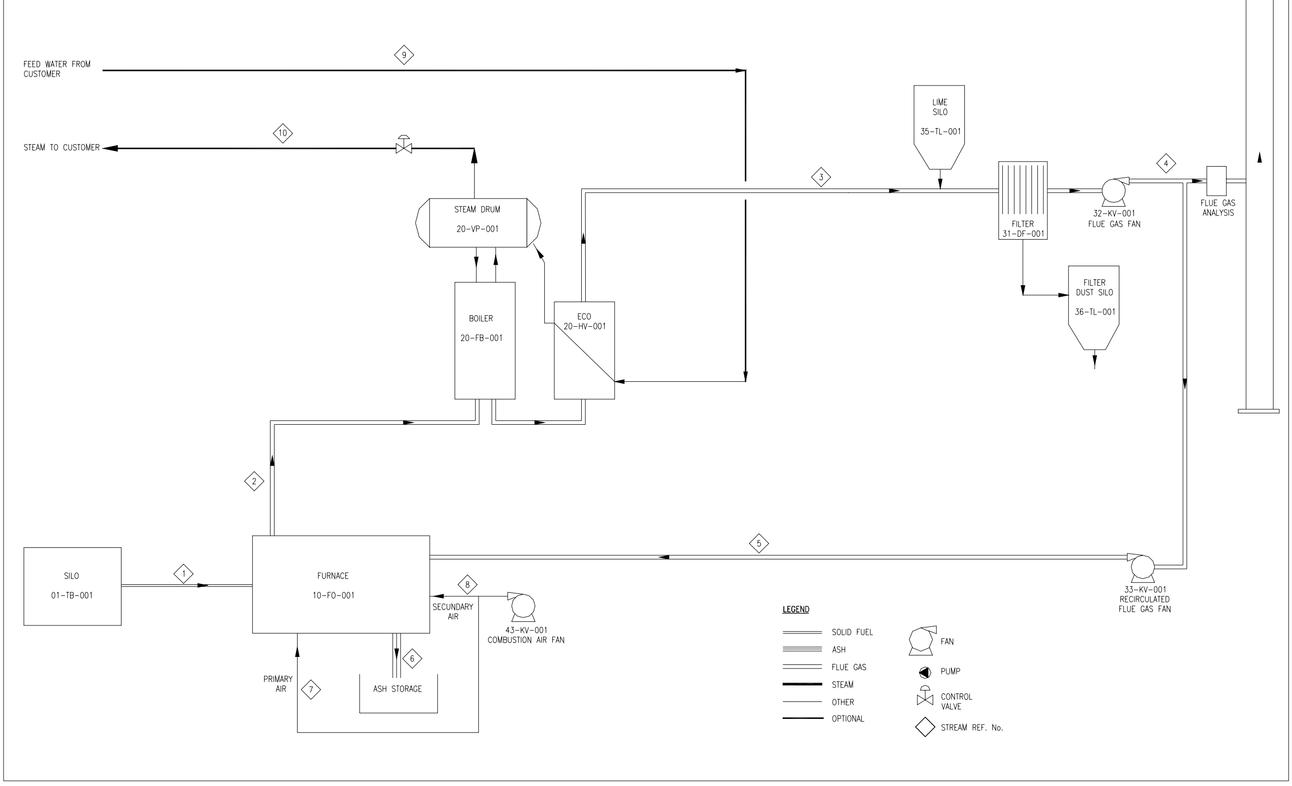
Well developed with 6 operating plants.

Reference plants

Plant	Date operational	Fuel	Fuel Consumption [tonnes per year]	Boiler Capacity [MW]	Steam Production [GWh]
Ranheim	1998	RDF, Reject	10000	4	25
Averøy	2000	MSW, RDF	30000	9.2	65
Hurum	2001	MSW, RDF, Reject	35000	13.5	90
Sarpsborg	2002	MSW, RDF	70000	2 x 15	190-240
Forus	2002	MSW, RDF	37000	15	90
Minden	2002	MSW, RDF	37000	15	110

Mass and energy balances:

STREAM REF. No.		1	2	3	4	5	6	7	8	9	10	11
MEDIA		FUEL	FLUE GAS	FLUE GAS	FLUE GAS	FLUE GAS	ASH(WET)	AIR	AIR	FEED WATER	STEAM	FLUE GAS
OPERATIONS PRESSURE	bara		ATM	ATM	1,02	1,05		1,05	1,05		16	ATM
OPERATIONS TEMPERATURE	°C	20	900	150	150	150		25	25	105	201,5	130
TOTAL FLOW	t/h	4,7					0,82			19,8	19,8	
TOTAL FLOW	Nm3/h		46683	46683	46683	20823		7954	14445			25860
HEAT VALUE	MJ/Kg	12,1										



Environmental parameters

Process residues:

Water from boiler blowdown is used in the slag discharge basin.
Shredder reject (from waste pre-treatment) is sent to further re-cycling.
Slag is typically used as topsoil at existing landfills.
Filter dust is sent to special landfill sites (hazardous waste).

Stack emissions:

Emissions to air through the stack consist of 10% carbon dioxide, 15% water; 5% oxygen; 70% nitrogen. Less than 0.1% of the emissions consist of harmful, polluting components. These emissions are well below the new EU emission requirements approved by the EU Parliament December 2000, ranging from 1% - 50% of the limits. Emissions in the vicinity of the plant have insignificant impact on soil quality, flora and fauna. Scientific reports on these topics can be obtained from Energos ASA.

Component	Symbol	Energos Emissions [mg/Nm3]	EU Standard Emissions [mg/Nm3]	% of EU Standard
Dust	-	0.3 -0.7	10.0	3.0%
Mercury	Hg	0.001-0.007	0.03	3.0%
Cadmium & Thallium	Cd & TI	0.00004	0.05	0.1%
Heavy Metals	-	0.0008	0.5	0.2%
Carbon Monoxide	CO	1.0-10.0	50.0	2.0%
Hydrogen Fluoride	HF	0.04-0.2	1.0	4.0%
Hydrogen Chloride	HCL	0.3-2.0 10.0	10.0	3.0%
Total Organic Compounds	-	0.0.-0.6	10.0	0.0%
Sulphur Dioxide	SO2	9.0-40.0	50.0	18.0%
Nitrogen Oxides	NOx	30.0-120.0	200.0	15.0%
Ammonia	NH3	0.04	10.0	0.4%
Dioxins(1)	-	0.008-0.037	0.1	8.0%

(1) unit: ng TEQ/Nm3

Metals, including heavy metals:

The metals entering an Energos plant will to a large extent pass through the primary combustion chamber and end up in the bottom ash, partly oxidised. At the temperatures prevalent in the primary chamber, most of the metals will have a negligible vapour pressure, so only a small fraction of them will evaporate and follow the flue gas. Some of them, such as lead and zinc, may chemically react with substances with increased vapour pressure, and may be carried along with the flue gas. Minor entrainment of all metals as small metal particles may be expected. These metals will generally be retained by the flue gas cleaning system. Mercury, and to some extent cadmium, are more volatile. The mercury content of the fuel will tend to vaporise and follow the flue gas. When the flue gas is cooled, more than 95% of the mercury, and more than 99% of the cadmium, will condense or adsorb on dust and lime, and will thus be retained in the flue gas cleaning system.

In a commissioned report to Energos, it has been estimated that for Energos plants operating within current operating limits, the fractions of these components present in the feed that eventually end up as emissions to the air are:

Mercury: 2 – 5 %
Cadmium: < 0.01 %
Arsenic: < 0.03 %
Cobalt: < 0.05 %
Nickel: < 0.03 %
All other metals: < 0.01 %

The distribution of these components between bottom ash and filter ash may be manipulated to some extent by changing the temperature of the primary combustion chamber. (Higher temperatures lead to less of the components in the bottom and more in the filter).

Economic details

Energos stipulate that the turnkey prices listed below for their boiler plant are for illustrative purposes only and should not be used for any other purpose. Energos reserves the right to change these prices.

	Type 41	Type 42	Type 51	Type 52
Description	Single-line	Double-line	Single-line	Double-line
Turnkey price (estimate)	€16 Million	€27 Million	€18 Million	€31 Million
Designed Fuel NCV	8-18 MJ/kg	8-18 MJ/kg	8-18 MJ/kg	8-18 MJ/kg
Max. Fuel Throughput (t/hr)	5.5	11	5.5	11
MW (thermal)	13.5	27	16.4	32.8
Building area (sq. meters)	1,500	2,200	1,600	2,300

O&M costs (excluding slag disposal) add approximately 1.7 mill €/yr for the type 41 plant and 1.8 mill €/yr for the type 51 plant.

For a condensing steam turbine the additional investment cost will typically be as follows:

Single line plant, approx. 3 mill €
Double line plant, approx 4.5 mill €

The illustrative prices for **a standard turnkey contract** listed above have included such items as:

- Waste pre-treatment (Shredder and metal separation)
- Project engineering, management and administration
- Basic ground works for the plant (see below)
- Building
- Electrical and Instruments
- Piping and Mechanical
- Thermal conversion system
- Boiler system (16 bara of saturated steam)
- Feed-water system
- Dry-flue gas cleaning system
- Flue gas analysis system
- Waste, fuel and ash handling systems
- Insurance
- Fuel oil tank
- Tools
- Furniture
- ICT
- Commissioning and test run

However, some elements are excluded from the illustrative prices listed above, such as:

- Responsibility for unforeseen ground condition (contamination, piling and skeet piling, replacing soil/aggregate, anchoring of construction elements, reinforcement of civil construction due to ground conditions etc.)

- Exterior ground works (green area, asphalting etc.)
- Required ICT licenses and transmission lines
- Infrastructure to the plant (has to be established prior to commence construction works)
- Temporary power supply and consumption during the project period
- Public taxes and fees related to establishing and operating the plant

This example is for illustrative purposes only. There are no subsidies or grants assumed.
All thermal energy is assumed converted into electricity. A higher IRR might be achieved by selling the thermal energy directly as process steam for industrial companies or district heating. Selling thermal energy directly avoids the conversion loss (70%-75%) of converting steam into electricity.

(Figures in € Million except where noted with *)

Project Summary				
Description	Type 42 plant (double-line)			
Project Cost	35 (price estimate includes turbine, site ground works, etc.)			
Project Equity	33%			
Project Debt	67%			
Depreciation	20 years			
Payback Period	6-7 years			
Project IRR (15 years)	14%			
Equity IRR (15 years)	25%			
Plant Economics	**Year 1**		**Year 5**	
Waste Price*	€75 /tonne		€83 /tonne	
Waste Revenue	6.9	(84%)	7.5	(84%)
Electricity Price*	€23 /MWh		€25 /MWh	
Energy Revenue	1.3	(16%)	1.4	(16%)
Total Revenue	**8.2**	**(100%)**	**8.9**	**(100%)**
Operating Costs	3.1		3.4	
EBITDA	5.1		5.5	
EBITDA Margin	62%		62%	
Depreciation	1.8		1.8	
Net Finance Expense	1.4		0.8	
Profit Before Tax	**1.9**		**2.9**	

References

Personal communication (email and phone call) with Energos staff, Sep. 2003 – March 2004

Information on the Energos web-site: http://www.energos.com

Case study 3 : Foster Wheeler, Finland

Technology supplier information

Foster Wheeler

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Background information:

Foster Wheeler offer fluid bed (FB) gasifiers in the range 15-120 MWth. This translates to approximately 25-50,000 tpa at the smaller end of the range, depending on fuel characteristics.

Foster Wheeler have constructed a 40 MWt BFB gasifier in Varkaus, which recovers 2100 metric tonnes of aluminium/year.

This case study will focus on the CFB Lahti gasifier in Finland. The 45-70 MWth Lahti gasifier is operated on 80,000-100,000t/yr of a mixture of biomass fuels, mainly wood and a waste derived fuel (the latter up to 30% of fuel mixture).The gas from this gasifier is co-fired with coal to provide a total plant output of 167MWe, and 240MWth for district heating. The Lahti gasifier is described well in a previous IEA Bioenergy task 36 case study [Granatstein, 2002]. Much of the information in this case study is taken from this report, and further detail may be found here.

Ownership details, licensees, partnerships & other relevant information:

Lahden Lämpövoima Oy (LLV) is a Finnish power company (established 1971) producing power and district heat for the city of Lahti.

With assistance (25%) from the EU-THERMIE programme (BM 15/96), the CFB gasifier was constructed in 1997, and provided low-Btu gas to the coal boiler in January 1998. Commercial demonstration of the gasifier started in March 1998. The goal of the project was to demonstrate on a commercial scale the direct gasification of wet biofuel/waste, and combustion of hot raw product gas (low calorific value) in the existing conventional pulverized coal-fired power plant. Project partners included:

- Lahden Lämpövoima Oy, Finland, as the project coordinator and plant operator;
- Foster Wheeler Energy Oy, Finland, for design and construction of the CFB gasifier;
- Plibrico Ab, Sweden, for supply/installation of refractories;
- Elkraft, Denmark, for project monitoring and dissemination; and
- VTT Energy, Finland, for project monitoring and dissemination.

In addition, Roxon Oy (Sandvik) supplied/erected the feed preparation and handling system.

Process description

Description of process

The circulating fluidized bed gasification system consists of a steel reactor, a uniflow cyclone and a return pipe, all refractory lined. Preheated gasification air, blown with a high-pressure air fan, enters the gasifier vessel at the bottom via an air distribution grid. The velocity of this air is sufficient to fluidize solid particles making up the bed. The bed expands and individual particles move rapidly, some conveyed out of the reactor into the uniflow cyclone. In the uniflow cyclone, gas and circulating solids flow downwards, with solids flowing down the return pipe, and gases transferred to the air preheater.

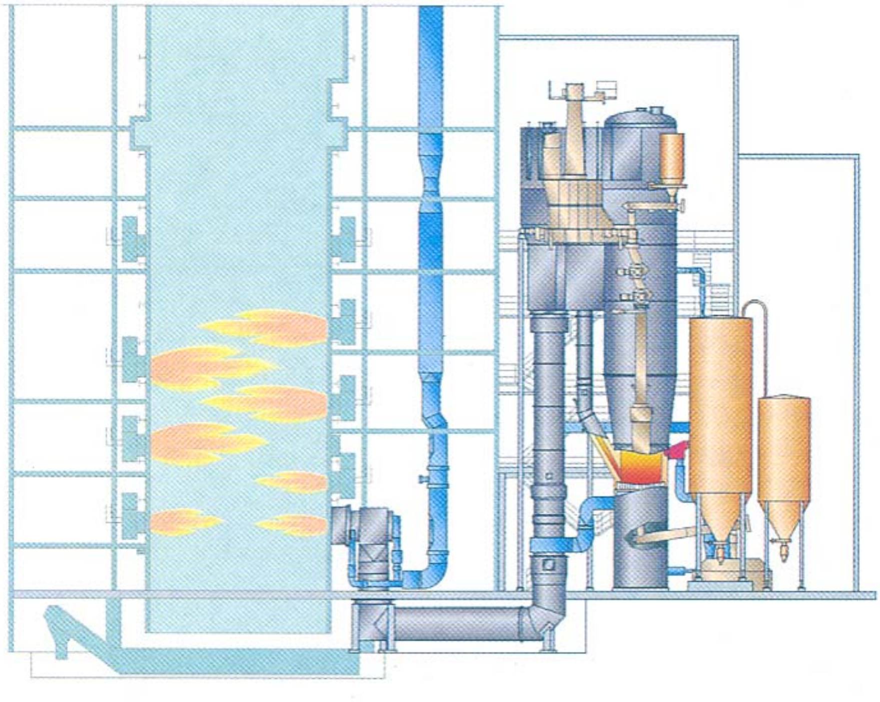
In normal operation, the fuel feed rate defines the capacity of the gasifier, while the air feed rate controls the gasifier temperature. Fuel is fed to the gasifier above the air distribution grid. This fuel is less than 5 cm in major dimension, and typically contains 20-60% moisture, 40-80% combustibles, and 1-2% ash.

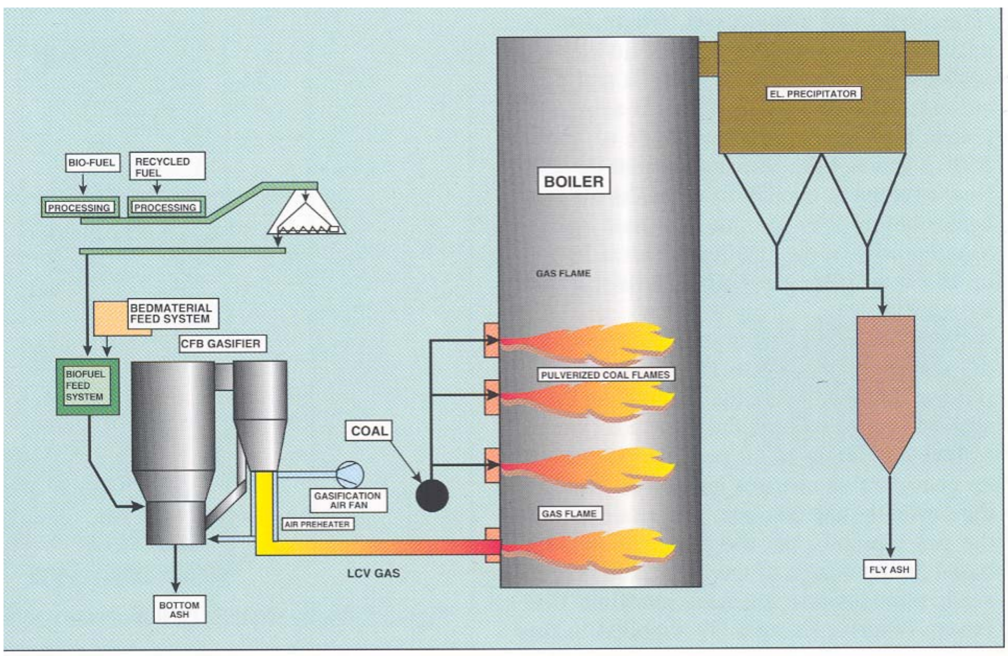
The gasifier operating temperature is in the range of 800ºC-1000ºC, depending on fuel properties. As fuel particles enter the gasifier, rapid drying takes place, and the primary phase of reaction, pyrolysis, occurs. This involves driving off of volatiles and conversion of fuel particles into gas, char and tars. Some of the char falls to the bottom of the bed, where it is combusted, generating CO, CO_2 and heat. These products flow up the reactor, where secondary reactions occur - heterogeneous (char and gas); and homogeneous (gas only) reactions. These reactions result in production of a combustible, low cv product gas which enters the uniflow cyclone, and leaves with a small percentage of fine dust.

Solids (mainly char) are separated in the cyclone and return to the gasifier bed near the bottom. Combustion of this char in the oxygen-rich fluidizing air stream produces the heat required for the previously mentioned pyrolysis, heterogeneous and homogeneous reactions to occur. Coarse ash accumulates at the bottom of the gasifier, and is removed with a water-cooled bottom ash screw.

The produced combustible gas enters a heat exchanger, lowering its temperature somewhat while preheating the fluidization air. The gas is then transported through a duct to two burners located below the coal burners in the main boiler. These burners are of a unique design developed through pilot-scale combustion tests and CFD modelling. Originally, it was envisioned that the burners would be placed above the coal burners, in the reburning mode, to control NOx; however, pilot testing showed that maximum heat and residence time for impurity destruction were produced with the gas burners below the coal burners. Figures 1-3 illustrate the gasifier and its connection to the boiler.

Process flow diagram & plant pictures





Typical plant size and intended fuels

Foster Wheeler offer fluid bed gasifiers in the range 15-120 MWth, corresponding to a biomass fuel flow rate of approximately 25-50,000 tpa for the smaller end of the capacity range.

Fluid bed gasifiers are very fuel flexible. The Lahti gasifier has been fed with a mixture of RDF, railway ties, shredded tires, paper plastics and conventional biomass (sawdust, bark, wood chips and woodworking wastes). The RDF fraction has been up to almost 30% of the total fuel on a weight basis.

Feedstock preparation details, feed requirements, and typical feed characteristics

The entire fuel preparation and handling system at the Lahti plant was supplied in 1997-early 1998 by Roxon Oy (a Sandvik company). The system handles two types of fuel—recycled energy fuel (REF) and biofuel—and blends the two prior to the gasifier. REF processing from source-separated waste was begun in 1997 by the municipally-owned waste management company Päijät-Hämeen Jätehuolto Oy. Components and operation of the fuel preparation/handling system are as follows:

- REF and biofuel are received in two separate receiving stations, specifically designed for rear unloading transport vehicles.
- REF is tipped onto the floor of the receiving station from where it is pushed via a bucket loader onto an apron conveyor feeding the primary shredder. The primary shredder (Roxon MNR) is hydraulically driven, and has a capacity of 150 m^3/h of REF and 50 m^3/h of wood waste.
- Biofuel is discharged from its own receiving station through a disc screen onto a conveyor starting below the primary shredder in the REF receiving station. The conveyor takes this material and the precrushed REF through magnetic separation, screening and secondary shredding. The secondary shredder (Roxon MNL) is electric motor-driven, with a capacity of 50 m^3/h.
- From secondary shredding, material at the final product size is conveyed to the intermediate storage building.
- A travelling screw reclaimer at the floor of the intermediate storage building discharges material, along the full length of the building, onto a belt conveyor, and further onto chain conveyors to the gasifier feed bins. Material flow from intermediate storage to the gasifier bins is completely automated. Bin level indicators control operation of the discharging screw reclaimer and subsequent conveyors, while speed is adjusted with a frequency converter. The reclaimer operates in such a way that the fuel is optimally homogenized for downstream gasification.

Method of thermal conversion

Gasification. See Process Description details above.

Method of power production

Co-firing of product gas into existing coal-fired power station.

Downstream clean-up systems

The gasifier syngas is cleaned with a simple hot gas cyclone.

Commercial status

Gasifier commercially available.

Reference plants

Plant	Date operational	Fuel	Fuel Consumption	Comments
Lahti CFB gasifier	1998	Biomass & waste	80-100,000 tonnes / year, approximately 20-30% of this is REF, the balance wood	
Varkaus BFB gasifier		Cartons		40MWt. Recovers 2100 tonnes of aluminium a year

Mass and energy balances:

Energy balance for gasifier [Granatstein, 2002, site visit]:

Input:

5.09 kg/s feed at 10.3 MJ/kg and 32.8% moisture (52.4 MWth)
3.45 Nm^3/s air at 365ºC (heat-exchanged with product gas)

Output:

19.2 Nm^3/s product gas at 2.48 MJ/Nm^3, 6 mbar and 810ºC (47.6 MWth)

Product gas enters the boiler, in equal streams, through two bottom burners at 712ºC, after heat-exchange with the input air stream. This gas has the following composition:

CO – 9.6%
CO_2 – 12.3%
CH_4 – 3.3%
H_2 – 6.7%
H_2O – 35.0%
Balance N_2

The overall energy balance (52.4/47.6) is 90.8%. The usual gasification efficiency is approximately 92%.

Environmental parameters

Effect of the gasifier on main boiler emissions:

Emission	Change Caused by Gasifier
NOx	Decrease by 10 mg/MJ (5-10%) [current limit - 240 mg/MJ]
SOx	Decrease by 20-25 mg/MJ [current limit - 240 mg/MJ]
HCl	Increase by 5 mg/MJ (base level low)
CO	No change
Particulates	Decrease by 15 mg/Nm^3
Heavy metals	Slight increase in some elements (base level low)
Dioxins/furans	No change
PAHs	No change
Benzenes	No change
Phenols	No change

Typical trace pollutant concentration of product gas:

Gas Component	Concentration Range (mg/m^3, dry)
NH_3	800-1 000
HCN	25-45
HCl	30-90
H_2S	50-80
Benzene	7-12
Tars	7-12
Alkalis	<0.1
particulates	6-10

Bottom ash from the gasifier consisted mainly of bed sand and limestone plus small amounts of metal chunks and concrete, etc. Carbon content was typically less than 0.5%, and chlorine levels were negligible. The ash also contained trace amounts of certain heavy metals; however, leachability was low.

Gasifier ash makes up only a small proportion (3-5%) of total main boiler ash. Unburned carbon and alkali levels were unchanged, but some heavy metal levels increased slightly, depending on the type of feedstock. For example, zinc content increased when shredded tires were gasified. No changes in trace organics, such as dioxins, were detected. Leachability test results were satisfactory, and the plant is permitted to use boiler ash as before.

Economic details

Total capital cost of the Lahti gasification project was about 12 MEUR. This figure included fuel preparation, civil works, the gasifier, instrumentation and control, electrification, and modifications to the main boiler. Of this amount, 3 MEUR (25%) was received under the EU THERMIE Programme.

The following table shows a comparison of capital and operating cost projections for a 20 MWe biomass plant [Granatstein, 2002]:

Capital and Operating Costs for 20 MWe Biomass Plant

Concept	Specific Investment (EUR/kWe)	Total Cost (MEUR)	Annual Cost (MEUR/a)	Electricity Cost (EUR/kWh)
Direct cofiring	680	14	0.45	0.021
Upstream gasification	1270	25	1.7	0.029
Upstream combustion (steam-side integration)	1360	27	1.8	0.030

The table is based on the following assumptions:

Cost of capital – 10.3%
Cost of biomass – zero
Operating cost – 0.36 MEUR/a
Maintenance cost – 2.5% of investment cost/a
Overhead – 40% of O & M costs
Coal cost – 50 EUR/t
O & M and depreciation of existing coal-fired plant – 0.018 EUR/kWh
Operation – 7 500 h/a

References

Granatstein, D.L: *Case study on Lahden Lampovoma Gasification Project, Kymijarvi Power. Station, Lahti Finland*. Undertaken for IEA Bioenergy agreement – task 36. Natural Resources Canada / CANMET Energy Technology Centre (CETC). November 2002.

Foster Wheeler homepage: http://www.fwc.com

Case study 4 : Compact Power, UK

Technology supplier information

Compact Power

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Ph: +44 (0)117 980 2900
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Email: info@compactpower.co.uk
Web: www.compactpower.co.uk

Ownership details, licensees, partnerships & other relevant information:

Compact Power is a company in the United Kingdom, formed in 1992. It supplies plants for the thermal degradation of MSW and other hazardous wastes. The plants have a nominal throughput of 6,000 to 30,000t/yr of waste, and energy can be recovered to generate heat and/or electricity.

The technology is modular such that larger waste streams can be handled through the combination of two or more systems.

Compact Power have a small demonstration system operating on a commercial basis at Avonmouth, UK, using primarily clinical waste as the waste resource. It is handling around 8,000t/yr, the final residue going to landfill at present. The steam recovered is used to run 300kW_e steam turbine and generator, but it is intended to divert this stream to a sterilisation plant located adjacent to the plant.

Process description

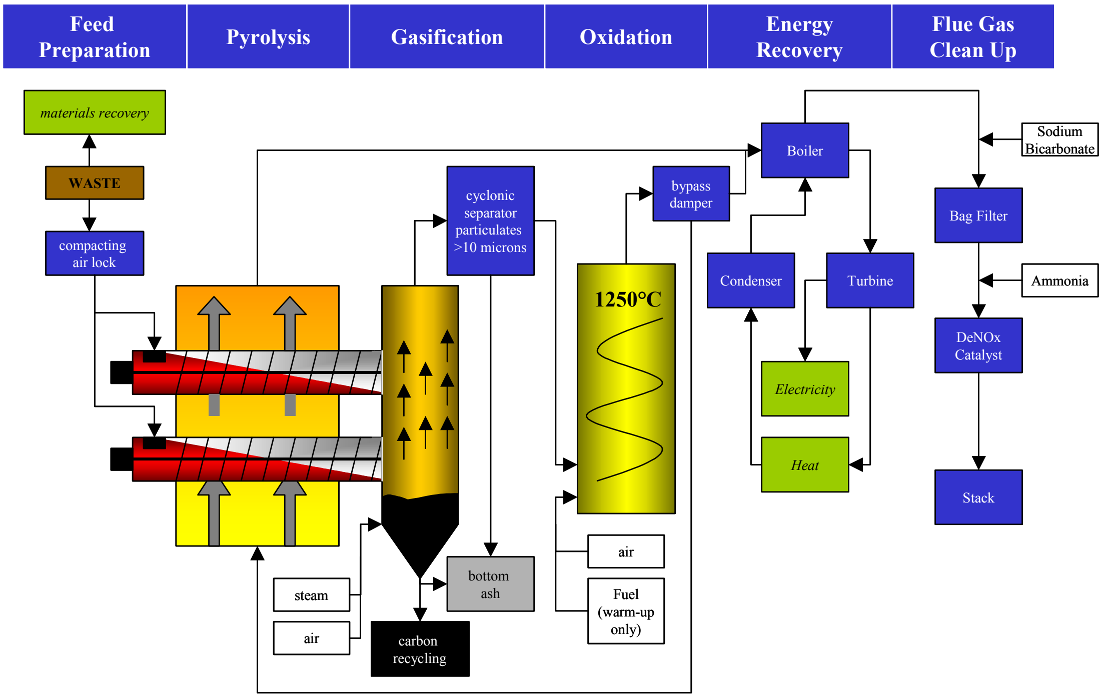
Description of process, including process flow diagram and plant pictures

The process decouples the standard combustion process into its respective stages

1. drying and pyrolysis
2. gasification
3. complete oxidation

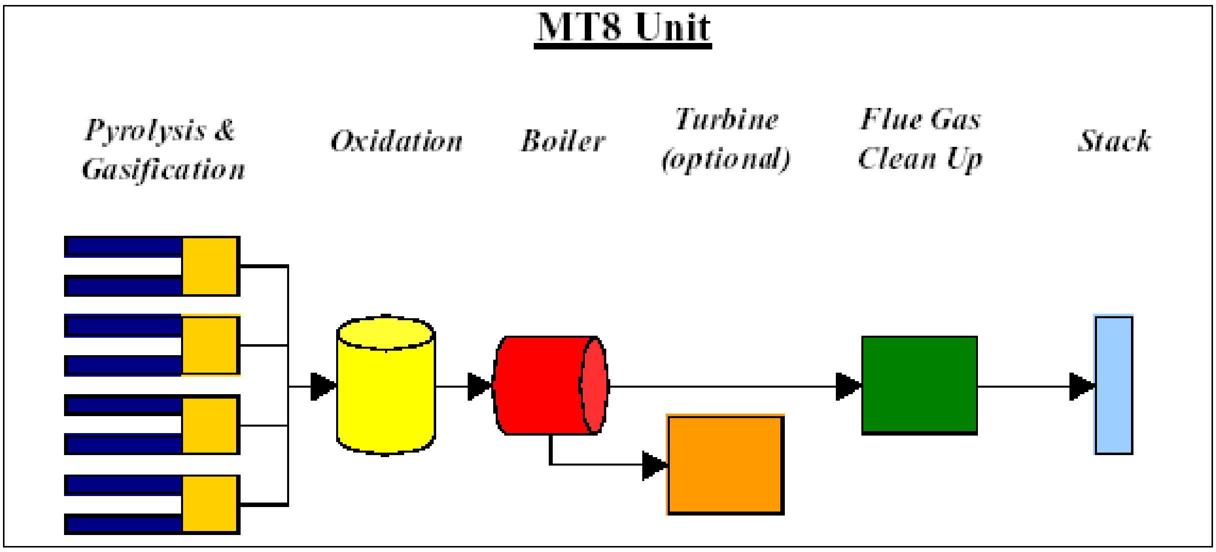
The design temperature of the final flue gas stream is 1250^{o}C and is available to raise steam for CHP purposes.

The process schematic is shown in the following figure.



Process schematic of a single MT2 module designed to process 8,000t/yr.

A feature of the Compact Power design is modularity. A Compact Power facility would comprise multiples of a standard plant module, denoted MT2. Each MT2 module is designed to process 8,000 tonnes/yr of MSW. Thus a 32,000 tonne/yr MSW stream would comprise four MT2 modules – eight pyrolysis tubes, four gasification chambers, but one common oxidation chamber and one common boiler. The advantage of such a system design is not just ease of scalability (many gasifiers exhibit limitations to scaling up), but the front end of each module can be optimised to cater for a particular waste stream when the waste resource is mixed. This would involve adapting the feed handling system and controlling the pyrolysis chamber temperatures and residence times to suit each stream. In addition, multiple waste streams with different gate fees can be accepted with the aim of enhancing overall economic value.



Schematic of an MT8 system, comprising four MT2 front ends and a common oxidation chamber and boiler. Multiple MT8 units handle larger MSW flows.

Pyrolysis

A compactor upstream of the pyrolysis screw is used to create a "plug seal" of waste, ensuring no air leakage into the pyrolysis process.

The pyrolysis chamber comprises two tubes, each with a screw feed. Each tube is approximately 3.54m long with a diameter of 0.5m, and can each handle 500kg/hr. Speed is controlled to give the material a residence time of approximately ½ hr, however screw speed can also be adjusted such that material with variable calorific value can be accommodated (over a small range). The constant rotation of the material helps ensure good heat transfer through the feedstock.

The pyrolysis, gasification and oxidation vessels are at a small negative pressure and the speed of screw rotation controls feed flow.

The pyrolysis chamber is heated (indirectly) by flue gas at 1250°C. The pyrolysed material exits at 600°C – 750°C, and approximately 43 wt.% will have been converted to pyrolysis gas (H_2O, CO, H_2, tars, PAH's, CH_4 and CO_2). The balance is ash and char. The ash comprises inert grits and heavy metals, most of the heavy metals being in a non-leachable form.

Gasifier

Controlled flows of steam and air are introduced to react the char in a water gas shift reaction. The gas mixture leaving the gasifier comprises remaining pyrolysis gas and producer gas (CO, H_2 and CO_2). Solid residues are removed as bottom ash (some metal recovery possible) and particulates. The gas then enters the oxidizing chamber at about 850°C. A minimum calorific value of the waste at 9MJ/kg is required at this point, and back-up fuel can be used to achieve this if required.

Oxidation

The gases are reacted with air in the oxidation chamber at a temperature of 1250°C and a relatively long residence time of greater than 2 seconds. The gases are fully oxidized (11-12% excess O_2) to ensure complete break-down of tars and other hydrocarbons. The resulting flue gas is then used to heat the pyrolysis chamber, and leaves the chamber at 900-1100°C.

Boiler and turbine

The MT2 module uses a 2-pass firetube boiler.

For an initial MSW stream of 4000kg/hr with a calorific value of 12MJ/kg (ie MT8 plant), the flue gas available to the boiler is 29,440kg/hr (mainly N_2) at 900°C. This could be used to raise about 11,500kg/hr of steam at 350°C, 35bar, and would generate about 2.2MW_e. The condenser would generally be air-cooled, partly to avoid the common public misconception that the plume emanating from a wet-cooling towers is smoke. The spent flue gas passes through a bag filter and deNOx reactor, leaving through a stack at around 200°C. This temperature allows acid remediation, is high enough to maintain deNOx operation (performance drops off below 150°C), and is below dioxin reformation temperature. It is also above pluming point for most weather conditions. The gas has a very fast residence time in the boiler (<0.2s) to minimize dioxin formation.

Performance of MT8 and 2xMT8 plant configurations

The following tables show expected plant performance for an MT8 plant.

Plant type MT8 having a nominal throughput of 32,000 tpa MSW

Plant throughput MSW		Calorific value	Steam flow	Electrical output @ 20 % thermal efficiency	Residual ash	Population equivalent (MSW @ 1 kg/head/day) (For gross waste stream assuming 40% recycling)	Population equivalent electricity supply @ 0.34 kW per head	Population equivalent heat supply @ 1.71kW per head
T/Hr	T/Yr*	MJ/Kg	MWth	MWe	%			
4.00	32,000	8.5	6	1.66	25-30	140,000	9,700	3,000
4.00	32,000	10	7.2	1.99	21-25	140,000	12,000	3,500
4.00	32,000	12	8.8	2.42	18-21	140,000	14,700	4,300
3.37	27,000	15	11.1	2.7	15-18	126,000	8,000	5,500

Plant type 2 x MT8 having a nominal throughput of 64,000 tpa MSW

Plant throughput MSW		Calorific value	Steam flow	Electrical output @ 20 % thermal efficiency	Residual ash	Population equivalent (MSW @ 1 kg/head/day) (For gross waste stream assuming 40% recycling)	Population equivalent electricity supply @ 0.34 kW per head	Population equivalent heat supply @ 1.71kW per head
T/Hr	T/Yr*	MJ/Kg	MWth	MWe	%			
8	64,000	8.5	12	3.3	25-30	280,000	48,000	7,000
8	64,000	10	15	4	21-25	280,000	59,000	9,000
8	64,000	12	18	5	18-21	280,000	72,000	10,500
6.75	54,000	15	23	5.6	15-18	250,000	16,500	13,500

Typical plant size and intended fuels

Modular design based on standard plant module MT2, processing 8,000 tonnes/yr. This corresponds to roughly 3.3 MW_{th}

Fuels: MSW, RDF, Clinical, Pharmaceutical, Industrial, Abattoir

Feedstock preparation details, feed requirements, and typical feed characteristics

Feed is specified in order to be borne by the mechanical handling in the plant. This means all particles passing a 75mm sieve, though these may be contained in larger articles, as with clinical waste sharps containers and such.

Method of thermal conversion

Pyrolysis, gasification and oxidation.

Method of power production

Steam turbine & generator

Downstream clean-up systems

Bag filter and deNOx reactor

Commercial status

Demonstration scale reference plant in Avonmouth (UK) operating under commercial conditions

Reference plant(s)

Plant	Date operational	Fuel	Fuel Consumption	Comments
Avonmouth, UK		Mainly clinical waste	8000 tonnes per year	There are plans to use the recovered energy to run a 300kW$_e$ steam turbine and generator. Plant operating on a commercial basis.

Mass and energy balances:

See process description, above.

Environmental parameters

Stack emissions

The thermal degradation process described above in effect separates what would otherwise be a conventional combustion process into the intermediate steps of pyrolysis, gasification and oxidation. This enables control of each stage of the process so that the emissions prior to the bag filter are lower, allowing smaller and less costly pollution control equipment. The table below shows measured stack emissions from a trial with clinical waste.

	Waste Incineration Directive limits (mg/Nm^3)	Compact Power levels (mg/Nm^3)	Percentage of WID limit
Dust/particulates	10	2.1	**21%**
Volatile Organic Compounds	10	0.34	**3%**
Hydrogen Chloride	10	0.91	**9%**
Hydrogen Fluoride	1	<0.1	**<10%**
Sulphur Dioxide	50	0.34	**1%**
Oxides of Nitrogen	200	30.3	**15%**
Cd + Tl	0.05	0.006	**12%**
NH3	10	0.29	**3%**
Pb+Cr+Cu+Mn+Ni+As+Sb+Co+V	0.5	0.006	**1%**
Dioxins + Furans (ng/Nm^3)	0.1	<0.003	**<3%**
Carbon Monoxide	50	1.45	**3%**

Emissions from RDF trial Compact Power Avonmouth June 2002

Economic details

The following techno-economic data has been provided by Compact Power. It is indicative only, depending on the make-up of the waste stream.

Plant Configuration: MT8-1G

COMPACT POWER
Solutions to Waste

Date: February 26th, 2003

WASTE: MSW @ 12MJ/kg	
Processing capacity in tonnes per year	30,000
Plant availability	85.0%

1. COSTS

Variable Costs	Amount (tpa)	Price per te	Cost pa	£/te waste processed
Auxiliary Fuel Oil	238	£170	£40,460	£1.35
Sodium Bicarbonate	542	£170	£92,140	£3.07
Ammonia	42	£500	£21,000	£0.70
Landfill of ash + APC residue	6,074	£36	£218,664	£7.29
Water	3,574	£0.77	£2,752	£0.09
TOTAL =			£375,016	£12.50

Fixed Costs			Cost pa	£/te waste processed
Staffing	?	?	£421,000	£14.03
Environmental	?	?	£36,000	£1.20
Other general costs	?	?	£28,000	£0.93
Insurance	?	?	£17,000	£0.57
Rent & rates	?	?	£10,000	£0.33
Maintenance	?	?	£410,000	£13.67
TOTAL =			£922,000	£30.73

Total Fixed & Variable OPEX	£1,297,016	£43.23

Investment	Cost	£/te waste processed (payback: 15 years - rate: 7%)
Plant process (feed treatment & handling, hook-up & piping, pyrolysis, gasification, thermal oxidation, waste heat recovery & exhaust gas, exhaust gas cleaning, power generation, electrical, instrumentation & control, hook-up & piping, design)	£7,175,000	£26.26
Civil and infrastructure costs	£1,500,000	£5.49
Commissioning costs	£130,000	£0.48
Total investment:	£8,805,000	£32.22

2. ENERGY REVENUES

Gross Electrical Output	2.2	MWe
Parasitic Load	0.40	MWe
Net Electrical Output (MWe)	1.8	MWe
Net Electrical Output (MWhr/yr)	13,403	MWhr/yr
Electricity Price	36.00	£/MWhr

3. PROCESSING COST

Capital investment (annualised)	32 £/tonne
Operational costs	43 £/tonne
Electricity revenue	-16 £/tonne
Processing cost	**59 £/tonne**

References

Site visit and personal communication with Compact Power, mid 2003.

Information obtained from the Compact Power homepage (http://www.compactpower.co.uk)

Case study 5 : Naanovo Energy, Canada

Technology supplier information

Naanovo Energy Inc.

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Ownership details, licensees, partnerships & other relevant information:

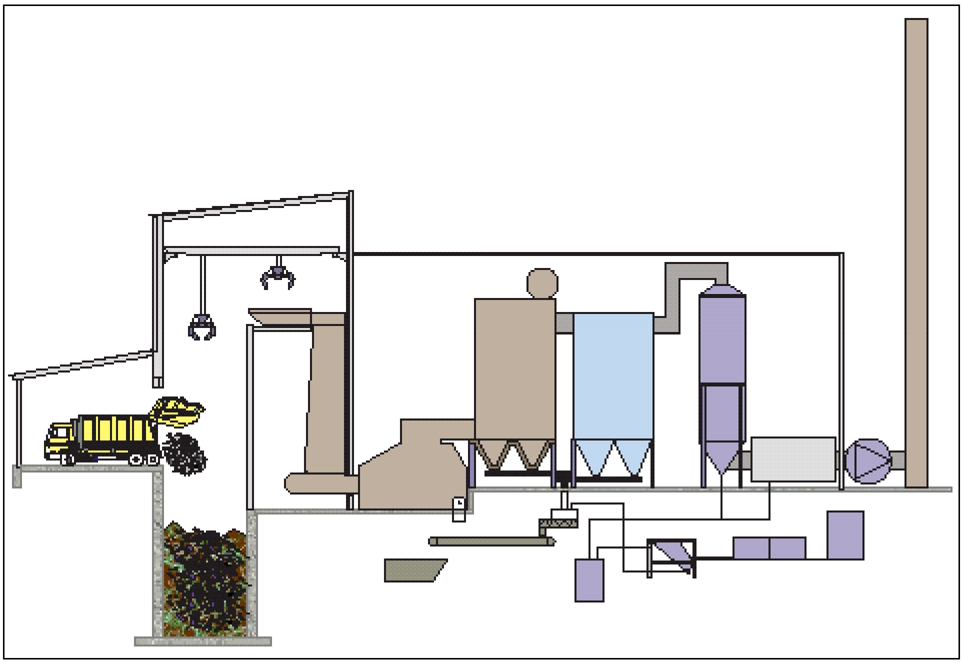
Naanovo Energy Inc. is a global company based in North America with offices in Angelholm, Sweden. Its recent amalgamation with two Swedish companies, Anovo AB and AddPower AB, has made Naanovo a world leader in biomass and municipal solid waste incineration technology, as well as new and innovative waste-heat to energy technologies.

Process description

Description of process

Anovo Technique™ is a turnkey solid waste-to-energy technology developed in Sweden. This state of the art incineration technology is capable of disposing of 64,000 tons of garbage annually while producing 15 Megawatts of continuous total energy in the form of hot water and electricity (approx 5-6MWe).

Process flow diagram & plant pictures



Typical plant size and intended fuels

MSW, biomass, or a combination

Method of thermal conversion

Moving grate combustion

Method of power production

Steam turbine

Environmental parameters

"Virtually emission free". No further details have been made available

Economic details

Quoted capital cost of 18 M$ US, 3100 US$/kWe

References

Information from the Naanovo homepage: http://www.naanovo.com

Case study 6 : Entech Renewable Energy Systems (Australia), and NTech Environmental.

Technology supplier information

The technology described in this case study is based on in-service, pyrolytic gasification systems of Entech Renewable Energy Systems.

NTech Environmental is a marketing and client support company created solely for the purpose of promoting Entech Renewable Energy Systems, who have representative offices in Spain, the United Kingdom, Ireland, Greece, Canada, the United States .

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Ntech Environmental Greece

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Homepage not available at time of publication

NTech Environmental Canada Offices being formed

NTech Environmental USA Offices being formed

For other countries contact NTech Environmental main office.

Ownership details, licensees, partnerships & other relevant information:

Entech Renewable Energy Systems are engineers and manufacturers of systems for the conversion of biomass and waste into energy using third generation combustion technology know as pyrolytic gasification.

Complete ranges of units are offered, which are tailor-made in accordance to the type of waste processed. They are Multiple Stepped Hearth, single stepped hearth, Rotary Kiln and liquid waste injection system (Liquifire ™)

A wide range of capacities is available up to 300 GJ/Hr heat energy output.

NTech Environmental is a marketing and client support company created solely for the purpose of promoting the Entech Renewable Energy Systems.

Process description

Description of process ("Pyrolytic Gasification Systems for Biomass and Waste")

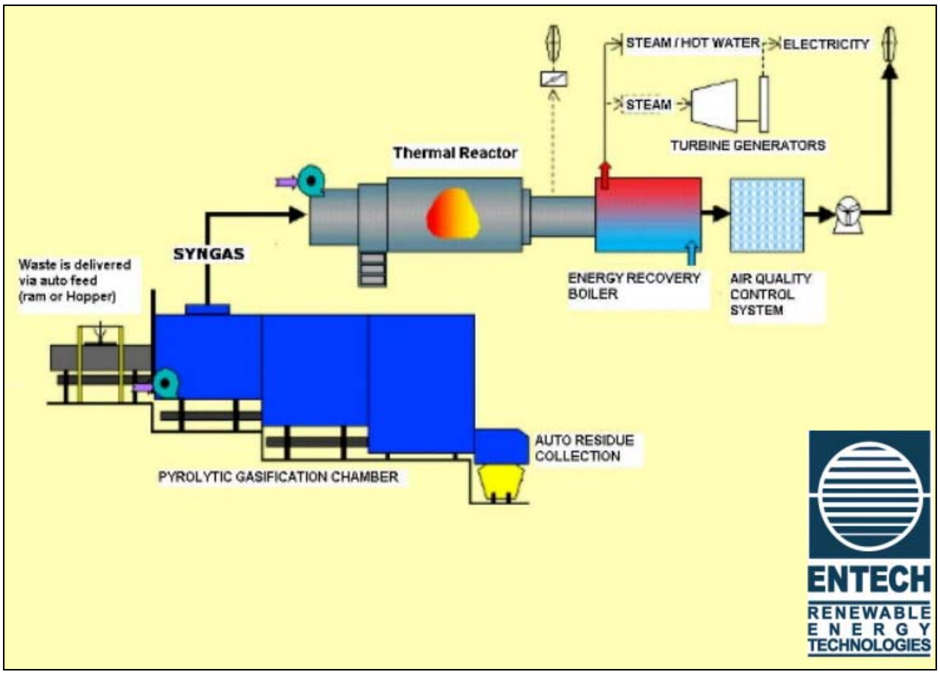
Entech offer various waste-to-energy solutions through standard sized systems. There may be a difference in the mechanical design of conversion reactors depending on the type of waste, however all systems are based on gasification.

A typical process description (provided by Entech Renewable Energy Systems) is as follows:

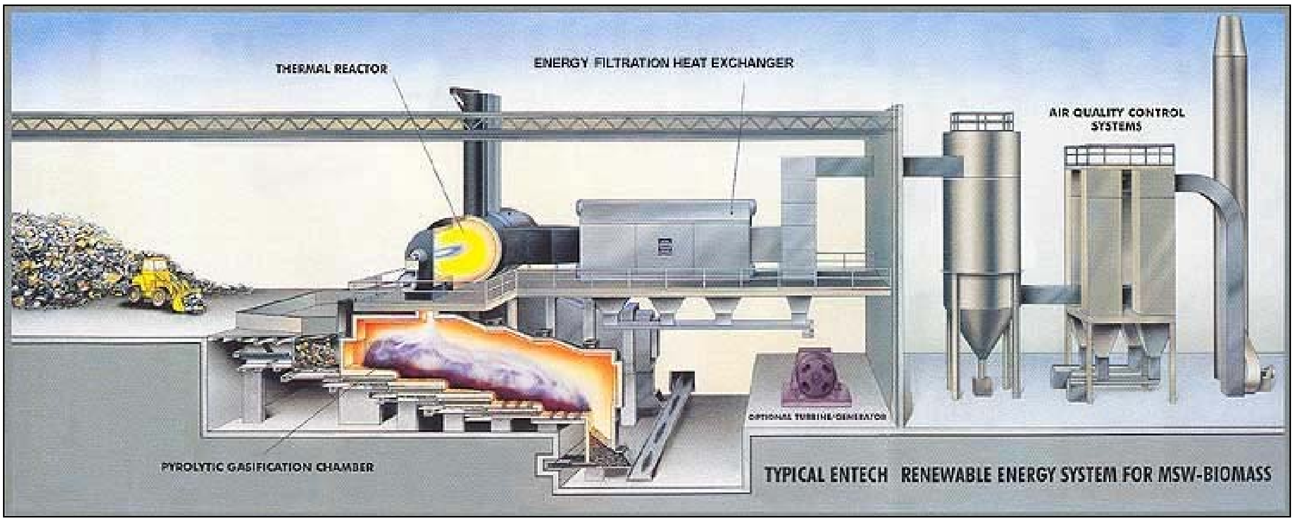
> In many cases biomass or waste requires minimal or nil pre-treatment (e.g. no sorting, no shredding, etc.).
>
> First Stage: Biomass or waste is fed into a Pyrolytic Gasification Chamber and is heated to the required ignition temperature of approximately 550°C in a sub-stoichiometric (reduced oxygen) environment, which maintains the necessary reaction heat required for gasification. The gasification produces a volatile gas (syngas).
>
> Second Stage: The syngas is fired like other conventional gases - in a large gas burner that is referred to as a Thermal Rector. The firing of syngas results in a clean high temperature off-gas very low in emissions, which is environmentally superior to firing of many conventional fossil fuels.
>
> Third Stage: As syngas is fired at temperatures of up to 1,200 C, the off-gas is a significant heat energy source. Utilization of this energy source is accomplished by a heat exchanger (steam or hot water boiler) which can be used to generate electrical power or steam or hot water for process use or heating.
>
> Fourth Stage: To minimize environmental impact (to surpass all standards required under EU Directives and US-EPA requirements) and produce an off-gas equivalent to say gas fired power stations; the off-gas is treated by an air quality control system. Emissions consist primarily of CO_2 and water vapour and hazardous constituents are well below the requirements of EUD/2000/76.

Process flow diagram & plant pictures

Flow diagram of Stepped Hearth configuration



Typical plant arrangement



Typical plant size and intended fuels

Fuels: various solid waste such as MSW, RDF, forestry by-products, hazardous waste, industrial waste, clinical waste, liquid waste, the post treatment of carbonaceous ash and fly ash from incinerators.

Typical size range: 0.25 t/day – 125t/day with multiple unit capacity up to 500t/day

Feedstock preparation details, feed requirements, and typical feed characteristics

Feedstock pre-treatment requirements are minimal (ie often not necessary to sort or shred waste).

Method of thermal conversion

Pyrolytic gasification

Method of power production

Steam turbine generator (energy can be delivered as electricity and/or steam and/or hot water)

Downstream clean-up systems

Dry or Semi- Dry Air Quality Control system

Commercial status

Commercially available

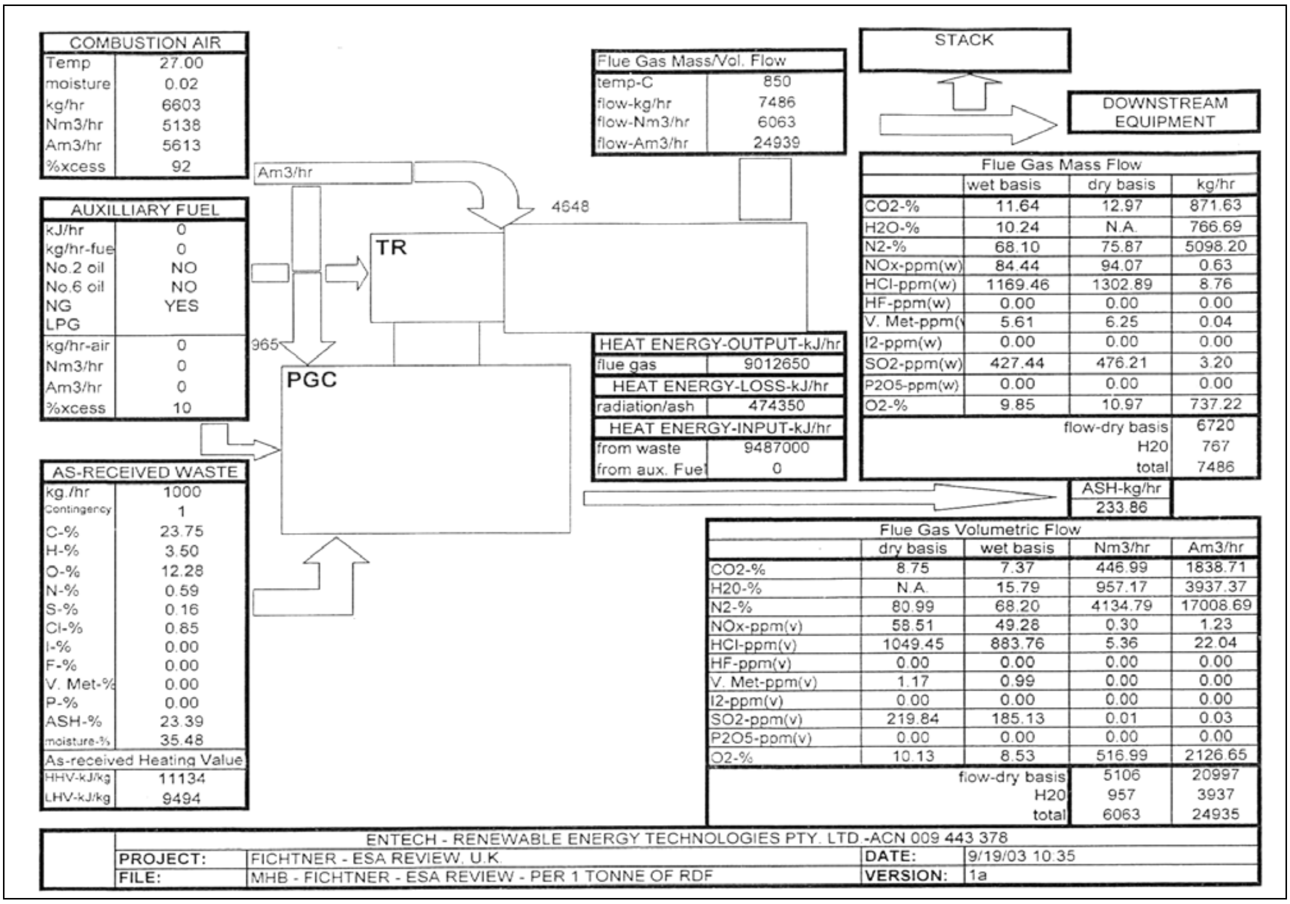
Reference plants

Six reference plants have been selected from a longer list supplied by Entech. The complete list is available from Entech.

Plant	Date operational	Fuel	Fuel Consumption	Comments
Case study 1 "MSW - Biomass"	?	MSW-biomass	~ 50 T/dy (~20,000 tpa)	majority of energy being used to generate hot water for use in domestic heating
Entech Project no. 1016 Location: Hong Kong	1988	MSW-biomass	~ 60 T/day	4,2 MWt output
Entech Project no. 1032 Location: Australia	1989/90	Biohazardous & Quarantine Wastes	~ 36 T/day	4,8 MWt output
Entech Project no. 1106 Location: Korea	1997	Waste derived fuel	~20 T/day	4,1 MWt as steam
Entech Project no. 1123 Location: Singapore	1997	Waste derived fuel	~72 T/day	2,5 MWt as steam
Entech Project no. 1142 Location: Singapore	2001	Pharmaceutical production, hazardous waste	~14 T/day	2,5 MWt as steam

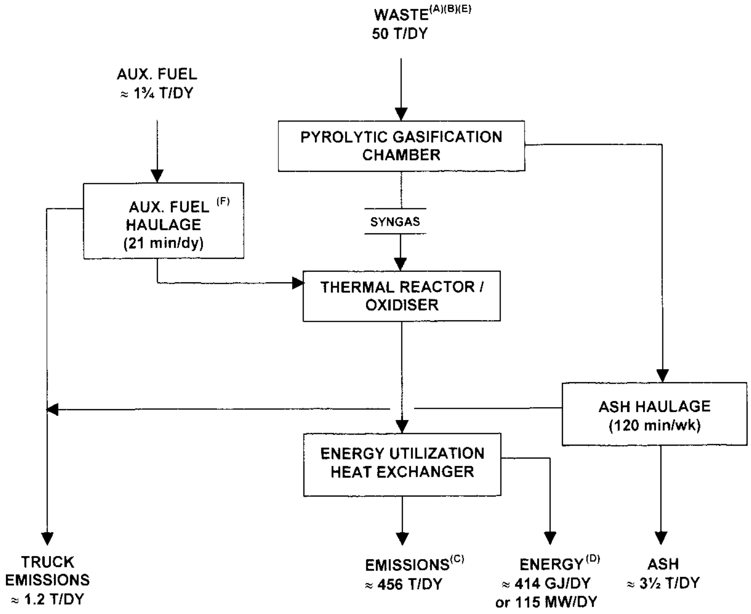
Mass and energy balances:

Mass and energy balance for 1 tonne/hr of RDF.
PGC = Pyrolytic Gasification Chamber. TR = Thermal reactor



Mass balance based on case study 1 in Reference Plant Table

RENEWABLE ENERGY SYSTEM (“RES”)



NOTES:

A. INDICATIVE WASTE QUANTITY. FOR ALTERNATIVE WASTE QUANTITY THE FLOW RATES SHALL BE PROPORTIONAL TO THOSE NOTED.

B. BASED UPON WASTE COMPOSITION OF:
- FREE MOIST. = 7% - PLASTICS = 7% - OTHER = 8%
- BOUND MOIST. = 35% - FOOD = 25%
- PAPER/CARD = 21% - GLASS/AL/FE = 7%

C. RESULT OF MASS & HEAT BALANCE CALCULATION FROM WASTE COMPOSITION IN NOTE “B” ABOVE, HAVING ULTIMATE ANALYSIS OF:
- C = 25.76% - O = 21.72% - INCOMB. = 7.00%
- H = 3.54% - H_2O = 41.99% - HHV = 10.8 MJ/KG

D. ENERGY CAN BE UTILIZED FOR STEAM OR HOT WATER PRODUCTION, THUS APPLIED TO:
- COGENERATION (ELECTRIC POWER GENERATION)
- DISTILLATION (CLEAN WATER PRODUCTION)
- AIR CONDITIONING (STEAM SUPPLY TO AN ABSORPTION CHILLER)
- STEAM MOTOR (E.G. FOR LARGE PUMPS, COMPRESSORS, ETC.)
- HEATING
- DRYING (E.G. SEWAGE SLUDGE DRYING)

E. SYSTEM FEED CAN INCLUDE DRIED SEWAGE SLUDGE BIOMASS. (SUBSEQUENT ENVIRONMENTAL IMPACT BENEFITS ARE NOT DETAILED IN THIS DOCUMENT).

F. BASED UPON 30T TRUCK LOAD EVERY 17 DAYS, WITH ROUND TRIP OF 360 MINUTES.

G. VALUE OF “FREE” RENEWABLE ENERGY IS ≈US$ 1,500,000 PER YEAR (AU$ 2,500,000).

For MSW it is not necessary to pre-treat the fuel, and hence, no recyclable products need to be recovered upstream of the process, although pre-sorting of non-combustibles is preferred. Downstream it is possible to recover various metals, including for instance aluminium, metals and glass.

Environmental parameters

Complies with EU directives for stack emissions.

The white bottom ash from the process is classified as non-hazardous waste, and is within the USEPA ash toxicity and leachability regulations. The ash is likely to be classified as ‘inert waste’. Metals, glass and aluminium in the ash would be available for recycling.

Residues from the Air Quality Control System bonds with the reagent (lime) making the dust relatively inert and suitable for mixing with cement.

Economic details

The costing information below is taken from Entech's costing module, and is hence **indicative**. For detailed site and waste specific information, a representative from NTech Environment should be contacted.

Selected system size: 45,000 Tonnes p/a

Key assumptions :[7]

Fuel: 100% MSW

LAND COST (Per m2)	0.00 Euro
BUILDING COST (Per m2)	175.00 Euro
CIVILS COST (Per m2)	275.00 Euro
Annual hire or lease of waste loading equipment	50,000 Euro
Auxiliary fuel: LPG. Cost:	0.20 Euro per m^3
System requires 177kWh/hr. Assumed electricity price:	0.05 Euro/kWh
Electricity sales price:	0.02 Euro
Gate fee per tonne of MSW:	0 Euro
Interest rate:	6%
Assumed overall electrical efficiency :	22-23%

Costing Module Output:

Operation Details		
Selected Annual Throughput of Waste	**45.000**	**Tonnes MSW-BioWaste only**
Entech™ RES Processing Days	**350**	**15 days downtime for maintenance**
Primary Gasification Chambers Model	**2xB**	B = PGC Model SH 7000
STANDBY PGC	**1xB**	B = PGC Model SH 7000
Design Basis		
THERMAL OUTPUT (MWt)	**15,80**	
MASS GAS FLOW (kg/hr)	**44.291**	
VOLUMETRIC GAS FLOW (Nm^3/hr)	**36.596**	
ELECTRICAL POWER OUTPUT (MWe)	**3,63**	
Footprint		
INDOOR AREA (Indoor Plant) (m^2)	**1.200**	
OUTDOOR AREA (Outdoor Plant) (m^2)	**600**	
DRIVEWAY / PARKING AREA (m^2)	**1.000**	
TOTAL LAND AREA (m^2)	**2.800**	
Labour		
PLANT OPERATING HOURS (hr/dy)	**24**	
LABOUR WORKING DAYS (dy/hr)	**365**	
NO. OF SUPERVISORS ON DUTY	**1**	
NO. OF OPERATORS ON DUTY	**1**	
NO. OF TRADESMEN ON DUTY	**1**	

[7] For simplicity not all assumptions, notes and relevant comments are mentioned here. The Entech costing module provides suggestions for all assumptions and input. For the most part these figures have not been adjusted.

Summary of the system capital cost and installation cost	
Cost of Entech™RES System	19.093.614
Estimated Cost of Delivery and installation on site	293.748
Estimated Commissioning Cost	477.966
Total Land Cost	0
Total Building Cost	210.000
Civil and site Development Cost	770.000
Enter a Contingency Fund (If required)	300.000
Enter Estimated Cost of Connection to the grid	1.000.000
Projected cost of Project	22.145.328

Financial summary:

	Entech™ RES	Site	Total
Total Capital Cost of Project	19.865.328	2.280.000	22.145.328
LESS Grant Funding	0	0	0
LESS Deposit (after grants if applicable)	0	0	0
Sub Total	19.865.328	2.280.000	22.145.328
Total Capital Cost to be Funded	**19.865.328**	**2.280.000**	**22.145.328**

Projected Annual Running Cost				In your chosen currency code	Euro
Labour Cost (including holiday, NI etc) based on suggested staff levels.					343.127
Total Supplementary Fuel Selected	LPG	655.054	Cubic metres per Year		131.011
Total electrical demand	1.488.171	KWh per annum			74.409
Illustrative Cost of landfilling ash/miscellaneous and AQCS residues					229.856
General maintenance allowance					146.874
Annual allowance towards the cost of replacement refractory linings etc (Expected every 10 years)					36.718
Automatic Air Monitoring Service Contract					30.000
AQCS and Boiler Consumables					166.248
Additional cost of hire or lease of other equipment					50.000
Please enter an amount for Emission Checks (if applicable)					40.000
Please enter an amount for Permit annual fees (if applicable)					25.000
Please enter an amount for Service charges (ie: phone, office equipment etc, if applicable)					30.000
Please enter an additional annual amount that you may wish to be included into the running cost.					180.000
Est: Finance at selected rate of	6,0%	over 15 Years			2.216.141

References

Information from IET Energy and ENTECH homepages:
http://www.ietenergy.com and http://entech.net.au/ws1/

Personal communication with Roger Willmott, Business Development Director, NTech Environmental September, 2003

http://www.environmentdirectory.com.au/companies/entechgroup.htm

Usage of Entech Costing Module. Obtained from Roger Willmott, NTech Environmental Business Development Director.

Case study 7 : WasteGen, UK.

Technology supplier information

WasteGen Ltd., UK

Contact details:

WasteGen Ltd., UK

Wolvey, Hinckley
Leicestershire
LE10 3JF
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fax: +44 (0) 1455 222 749

Homepage: http://www.wastegen.com

Colin Hygate, Managing Director
Colin@wasteGen.com

Ownership details, licensees, partnerships & other relevant information:

WasteGen UK Ltd is being supported by six organisations (details on each company is obtainable from the WasteGen homepage):

Tech Trade
Galliford Try plc.
Alstom (UK) limited
Stone and Webster
Environmental Solutions

Process description

Much of the information below is based on WasteGen's reference plant in Burgau in Germany.

Description of process

The WasteGen UK Materials and Energy Recovery Plants or **MERPS**, combine pyrolysis with recycling and composting in an integrated design. It is a combination of proven technologies to enable Local Authorities and their Waste Disposal Contractors to achieve their recovery and landfill avoidance targets.

Broadly, it comprises of a Materials Recycling Facility (MRF), a pyrolysis plant and a power generation plant. The core of the design is the pyrolysis kiln, which typically would have a throughput capacity of 50,000 tonnes per annum. The modular design allows plants of various sizes to be configured, based on site space limitations and specific Authority needs.

Following pyrolysis, the producer gas is completely oxidised at high temperature. The combustion of the produced gas is through a boiler, to raise steam, or through a gas turbine. The section on the reference plant at Burgau describes in detail the proven nature at full scale of pyrolysis technology as applied to municipal wastes. This plant has operated since 1983 taking some 36,000 tonnes of municipal solid waste and converting it into gas which is burnt to produce electricity through a steam turbine.

Details on reference plant:

DESIGN

2 rotary kilns 3t/h each
2 refuse shredder 30 t/h
turbine capacity (max) 2,2 MW
flue gas quantity 25 000 m3 /h

PLANT DESCRIPTION

The two-unit plant consists of:

- Refuse treatment
- Two rotary kilns
- Dust separation
- Combustion chamber for pyrolysis gas incineration
- Waste heat boiler with turbine generator
- Bag house filter with addition of sodium bicarbonate and activated carbon
- Draught and stack

HISTORY OF PLANT

- Beginning of trial run 1983
- Commissioning up to mid 1984
- One year test run by plant supplier 1986
- Takeover by county 1987

AVERAGE ANALYSIS OF PERMANENT GAS (20 °C)

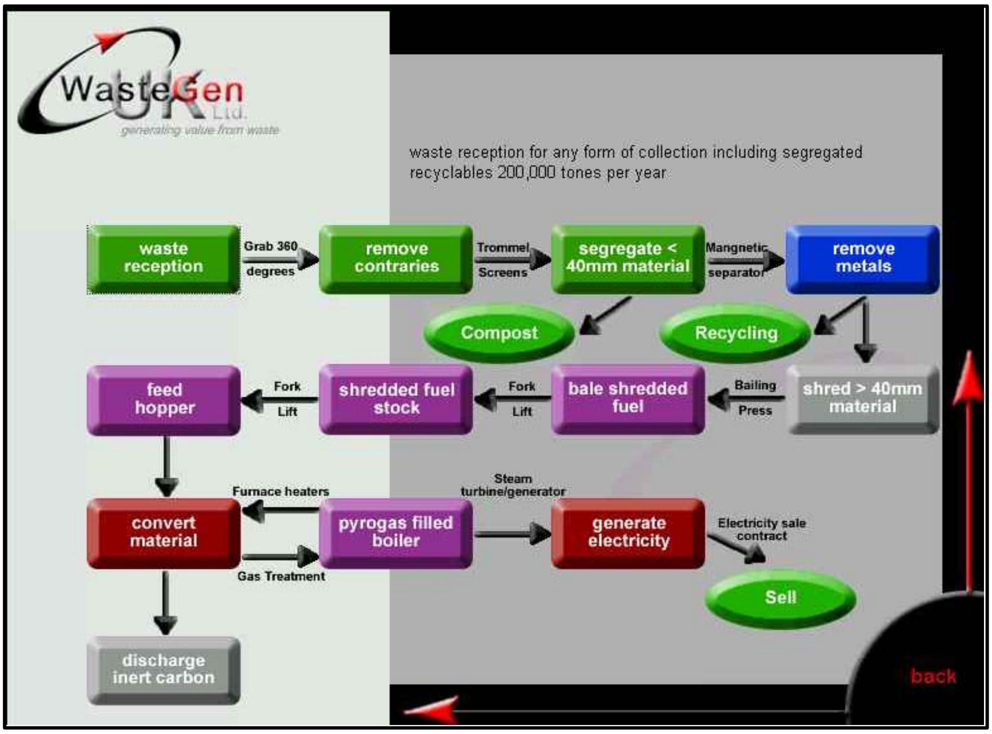
Hydrogen : 15%
Carbon monoxide: 20%
Carbon dioxide : 39%
Methane : 12%
Hydrocarbons : 13%

Under operating conditions (500 °C), the pyrolysis gas furthermore contains 40 to 60 % of steam and approximately 15 % of organic condensation products (tar, oil, etc.).

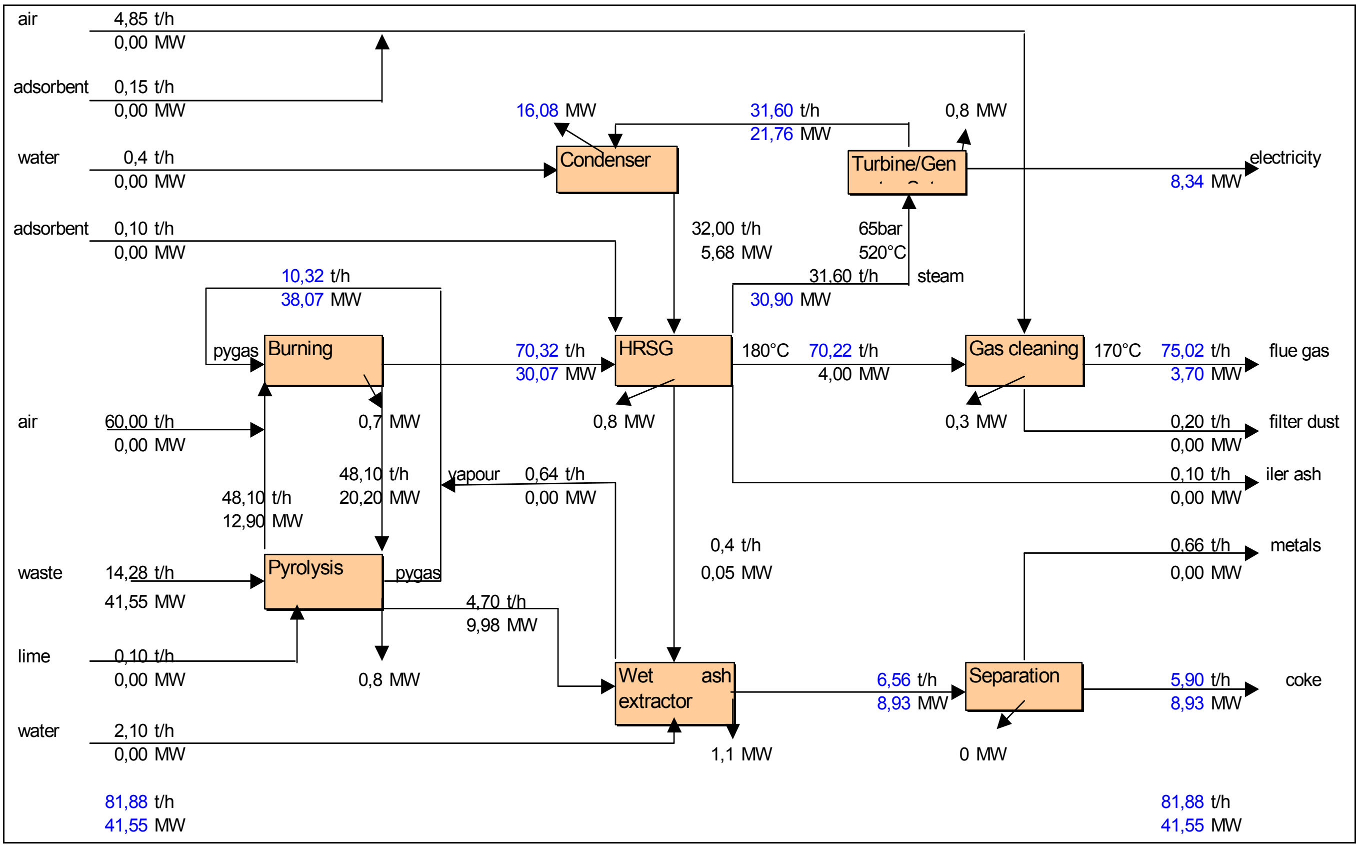
Quantity of pyrolysis gas : 700 m^3/tonne of refuse
Caloric value : 10 000 to 14000 kJ/m3
Density : 0,8 to 1,2 kg/m^3

Process flow diagram & plant pictures

Process schematic



Process flow diagram -- 100,000 tonnes per year plant (source: WasteGen quote P03-22-00, see references)



Typical plant size and intended fuels

residual domestic waste
commercial waste
bulky waste
sewage sludge

Size based on modular design: 50,000 to 200,000 tonnes per year.

Feedstock preparation details, feed requirements, and typical feed characteristics

Information on waste feedstock at the reference plant in Burgau:

Area of refuse collection: County Gunzburg, 762 km2
Number of inhabitants: 120 000
Waste quantity: 35 000 tonnes per annum

Types of waste:
residual domestic waste
commercial waste
bulky waste
sewage sludge

Calorific value of waste: average 8500 kJ/kg (5000-14,000 kJ/kg)

Raw waste composition:
25 % moisture
30 % inorganic waste
45% organic waste

Method of thermal conversion

Rotary kiln pyrolysis unit:
Number of rotary kilns - 2
Capacity - 3 tonne/h
Number of revolutions of kiln - 1,5 rpm
Size - 0 2,2 m x L 22 m
Wall thickness - 25mm
Material - AC66

Method of power production

ENERGY GENERATION

Flue gas temperature before boiler - 850°C
Flue gas temperature behind boiler - 350°C
Electricity generation (steam turbine) (max) - 2,2 MW
Steam parameters - 350°C 125 bar

Downstream clean-up systems

From reference plant:
• Addition of lime during refuse feeding in order to bind pollutants already present within the kiln
• SNCR measurements for NOx removal and
• Addition of sodium bicarbonate and activated carbon to the flue gas behind the boiler and separation of the reaction products in a baghouse filter

Reference plants

Plant	Date operational	Fuel	Fuel Consumption	Comments
Burgau	1983	MSW	36,000 tpa	generates 2,2MWe

Mass and energy balances:

See process flow diagram above.

Environmental parameters

Stack emissions from reference plant:

Contaminant	Limit Valu 11% O_2		Burgau Emissions
Total Dust / Particulates	10 mg/Nm^3	Daily average	1.4 mg/Nm^3
Total Dust	30 mg/Nm^3	100% ½ hourly average	1.7 mg/Nm^3
Total Dust	10 mg/Nm^3	97% ½ hourly average	
Total Organic Carbon (Gaseous and vaporous organic carbon)	10 mg/Nm^3	Daily average	
Total Organic Carbon (Gaseous and vaporous organic carbon)	20 mg/Nm^3	100% ½ hourly average	1.6 mg/Nm^3
Total Organic Carbon (Gaseous and vaporous organic carbon)	10 mg/Nm^3	97% ½ hourly average	
HCl	10 mg/Nm^3	Daily average	5.1 mg/Nm^3
HCl	60 mg/Nm^3	100% ½ hourly average	7.5 mg/Nm^3
HCl	10 mg/Nm^3	97% ½ hourly average	
HF	1 mg/Nm^3	Daily average	Below detection limits
HF	4 mg/Nm^3	100% ½ hourly average	
HF	2 mg/Nm^3	97% ½ hourly average	
SO_2	50 mg/Nm^3	Daily average	8.0 mg/Nm^3
SO_2	200 mg/Nm^3	100% ½ hourly average	20.0 mg/Nm^3
SO_2	50 mg/Nm^3	97% ½ hourly average	
NOx expressed as NO_2	200 mg/Nm^3	Daily average	166.9 mg/Nm^3
NOx expressed as NO_2	400 mg/Nm^3	100% ½ hourly average	274 mg/Nm^3
NOx expressed as NO_2	200 mg/Nm^3	97% ½ hourly average	
CO	50 mg/Nm^3	Daily average	<10
CO	150 mg/Nm^3	100% ½ hourly average	<10
CO	100 mg/Nm^3	97% ½ hourly average	<10
Cadmium and Thallium (Cd and Tl)	0.05 mg/Nm^3		0.006 mg/Nm^3
Mercury (Hg)	0.05 mg/Nm^3		0.011 mg/Nm^3
	Total 0.5 mg/Nm^3		Monitored readings expressed in mg/Nm^3
Arsenic (As)			0.008
Lead (Pb)			0.024
Chromium (Cr)			0.011
Cobalt (Co)			0.001
Copper (Cu)			0.002
Manganese (Mn)			0.003
Nickel (Ni)			0.002
Vanadium (V)			0.003
Dioxins and Furans	0.1 ng/Nm^3		0.001 ng/Mm^3 .4

Economic Details

None available

References

Information WasteGen homepage: http://www.wastegen.com/template.htm

Personal communication with Colin Hygate, CEO, WasteGen. September, 2003

WasteGen UK quote P03-22-00: Thermal Waste Treatment Plant for 100,000 tonne / year. May 2002.

Case study 8 : TPS, Sweden

Technology supplier information

TPS Termiska Processer AB

Contact details:

TPS Termiska Processer AB
Studsvik, 611 82 NYKÖPING, Sweden
Tel: +46-(0)155-22 13 00
Fax: +46-(0)155-26 30 52
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Mr. Michael Morris [michael.morris@tps.se] ph: +46 155 22 13 72

Ownership details, licensees, partnerships & other relevant information:

TPS Termiska Processer AB was originally a division of the publicly owned Studsvik group. In 1991, the Swedish State Power Board (Vattenfall) took over the ownership of Studsvik and as a result the Thermal Processes laboratory of Studsvik became a separate company in July 1992. It was named TPS Termiska Processer AB and was at that time owned by the Swedish producers of district heat and biomass fuel (51%), the employees of the company owning the remaining 49%.

In September 1999 there was a further change in ownership, and now the company is owned mainly by present and ex--employees and members of the board.

TPS Termiska Processer AB has 40 employees in the main company, whilst the 100% owned TPS-CP Energi AB employs 20 people.

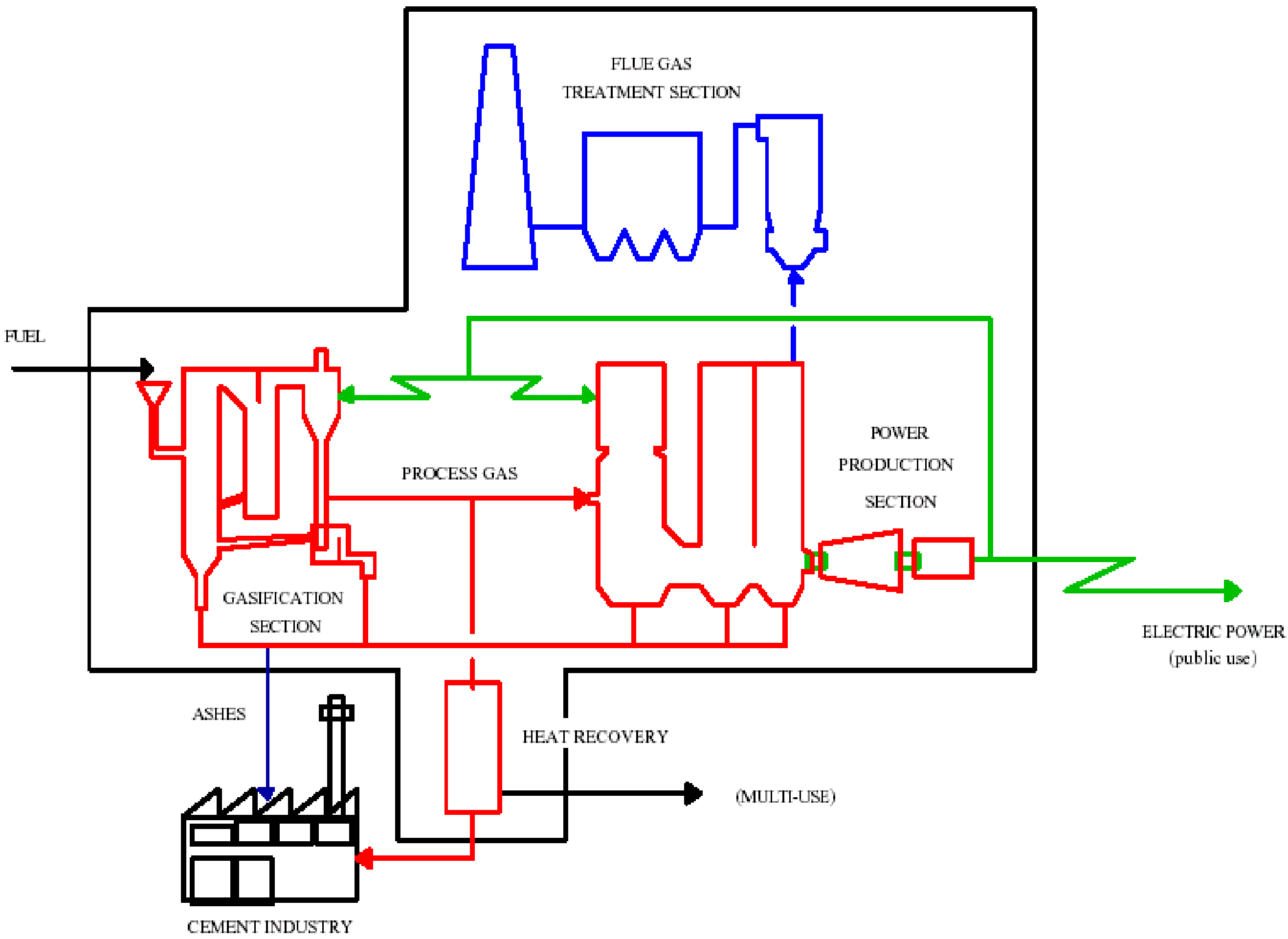
Process description

Description of process

TPS systems are mainly CFB gasifiers for biomass, however TPS have also done extensive work on solid waste fired gasifiers. In the early 1990s TPS sold a license to Ansaldo of Italy for 2 RDF fuelled CFB gasifiers for a plant in Greve-in-Chianti, Italy. The information in this case study is based on the Italian gasifier project Greve-in-Chianti.

Each gasifier is of 15MWth capacity and the Greve-in-Chianti plant processes about 200 tonnes of RDF a day (or about 75,000 tonnes a year). The 2 CFB gasifiers operate under atmospheric pressure at about 850°C, employing air as the gasification/fluidising agent. The fuel gas is not required to be cleaned, as the gas is fed to either adjacent cement furnaces or to a boiler, that generates steam for a 6.7MWe condensing steam turbine. The specially designed combustor/boiler has a 2s residence time to destroy potential pollutants. The flue gas exiting the boiler is cleaned in a three-stage dry scrubber system before being exhausted through the stack.

Process flow diagram & plant pictures



Gréve-in-Chianti Plant Process Schematic

The 2 gasifiers at Gréve-in-Chianti

Typical plant size and intended fuels

Each of the 2 CFB gasifiers have a capacity to consume 100t.day of RDF pellets, equivalent to about 15MWth each.

There are preferred characteristics of the RDF pellets utilised at the plant. See fuel characteristics below.

Feedstock preparation details, feed requirements, and typical feed characteristics

Typical composition of fuel (RDF pellets):

Compound	Value	Unit
C		wt.%
H		wt.%
N		wt.%
O		wt.%
S	0,05 - 0,30	wt.%
Cl	0,4 - 0,8	wt.%
Zn	200 - 300	mg/kg
Pb	50 - 150	mg/kg
Cd	1 - 2	mg/kg
Hg	0,1 - 1	mg/kg
Ash	9 - 16	wt.%
Moisture	5 - 10	wt.%
Bulk density	500 - 700	kg / m3
HHV	16 - 21	MJ/kg
Ash melting temperature	>1150	°C
Further details :	RDF pellets dimension: d=10-15mm L=50-150mm Ni: 5-20mg/kg, Cu: 50-100mg/kg, Cr: 50-200mg/kg	

Method of thermal conversion

Air blown gasification

Typical syngas composition (Gréve-in-Chianti plant, vol. basis):

H_2O: 9,5%
CO: 8,8%
H_2: 8,6%
CO_2: 15,65%
N_2: 45,8%
CH_4: 6,5%
C_xH_y: 4,9%
H_2S: 48,6ppm

Method of power production

Condensing steam turbine (steam pressure 40 bar, temperature 374°C. Electric power: 3,7MW)

Syngas is also used for cement furnaces

Downstream clean-up systems

Three-stage dry scrubber for removal of SO_2, HCl, heavy metals, particles (dust), HF and HBr.

Commercial status

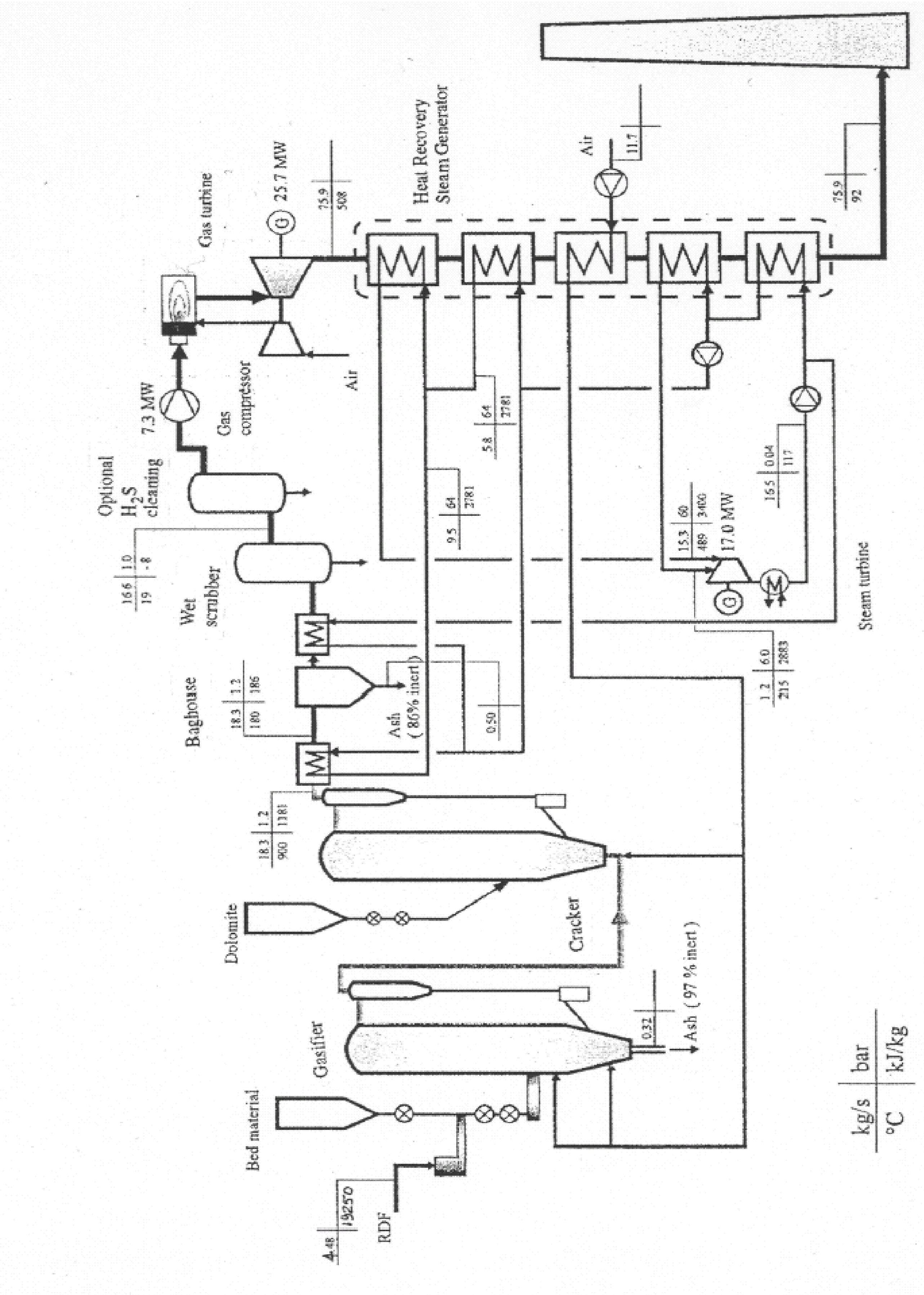
The CFB technology is fairly well proven at commercial scale for biomass fuels. TPS is (probably) prepared to offer guarantees for the gasifier itself, in terms of producing a specific gas of certain quality, given a predetermined (and consistent) quality of RDF pellets.

Reference plants

TPS have various gasifiers installed around the world, however, only 1 plant runs on waste (RDF).

Plant	Date operational	Fuel	Fuel Consumption	Comments
Gréve-in-Chianti plant	1992	RDF	75,000 tonnes per year	Thermal capacity approx. 2 x 15MW = 30 MW. Electricity generation: 6,7MWe

Mass and energy balance [Granatstein 2003]:



Environmental parameters

Stack emissions (blanks indicate that data has not been made available for this study)

Compound / Item	Value	Unit
Flue gas temperature	130	°C
CO		mg/Nm3
Particles / dust (TSP, Total suspended particles)	5 - 10	mg/Nm3 dry @10% O2
HF + HBr	2	mg/Nm3 dry @10% O2
HCl	3-20	mg/Nm3 dry @10% O2
SO2	5-15	mg/Nm3 dry @10% O2
NOx	200-300*	mg/Nm3
Pb	2	mg/Nm3 dry @10% O2
Cr		mg/Nm3
Cu		mg/Nm3
Mn		mg/Nm3
Cd	0,1	mg/Nm3 dry @10% O2
Hg	0,1	mg/Nm3 dry @10% O2
Ni		mg/Nm3
As		mg/Nm3
TOC (Total Organic Compounds)		mg/Nm3
Dioxins		ng TEQ/dry Nm3
Total heavy metals:	3	mg/Nm3 dry @10% O2

* The reason for the high NOx emission is the supply of nitrogen for cooling of the bottom section of the gasifier in combination with the high air consumption.

Economic details

Reported costs [Granatstein, 2003] for the original configuration are equivalent to US$4666/kW (6.4MWe net), however it is noted that there were mitigating considerations for this high figure. TPS themselves have estimated US$2812/kW for a 1200t/d RDF (1600t/day MSW) plant, with a net output of 60.7MW. Anticipated O&M is US$35.6M/yr. These capacities exceed the intended scope of this study.

References

Information from TPS homepage: http://www.tps.se

Personal communication with Michael Morris, TPS. September, 2003

Case study on waste-fuelled gasification project Greve in Chianti, Italy, for IEA Bioenergy Task 36, DL Granatstein, Aug 2003