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ISWA International Solid Waste Association
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Promoting sustainable waste management worldwide

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High-temperature gasification

The Thermoselect process

Gasification conserves the chemical energy of waste in the syngas produced. One technology giving good results has been developed by Thermoselect of Switzerland. The process accepts a wide range of waste, and produces purified syngas as well as granulate metals and minerals that can be used in industry and construction.

While a large number of different gasification systems have been developed over the past two decades, only a few have reached technical maturity. One of these is the Thermoselect process, which transforms waste into usable end products without the need for pre-treatment. The system offers an almost complete diversion of waste from landfill, and offers the possibility of using hydrogen technology or fuel cells for sustainable energy production. The process also avoids the formation of dioxins, furans and other organic compounds.

Three large-scale Thermoselect plants are in operation in Germany and Japan; another plant was in operation in Italy during 1992–1998 (see Table 1). Various kinds of wastes have been successfully treated, including mixed commercial streams, mixed plastic wastes, automotive shredder residues (ASR) and municipal solid waste (MSW). Five more large-scale plants are under construction in Japan during 2004 (see Table 2). By the end of 2005, the total capacity of plants using this process will reach 2700 tonnes per day. (As the article 'Gasification and pyrolysis' by Alexander Klein and his colleagues, in *WMW* September–October 2004, pointed out, it is in Japan that most of the global activity in gasification of waste has been taking place, and where the technology has become mainstream. One motivation has been the shortage of landfill space, but the desire for more advanced technology has also been important.)

The process

The Thermoselect gasification process recovers synthesis gas, usable vitreous mineral substances and iron-rich materials from various kinds of wastes such as MSW and

TABLE 1. Thermoselect plants in operation so far

	Fondotoce, Italy	Mutsu, Japan	Karlsruhe, Germany	Chiba, Japan
Plant capacity	1 line, 96 tonnes/day	2 lines, 140 tonnes/day	3 lines, 720 tonnes/day	2 lines, 300 tonnes/day
Operation	Demonstration plant in operation 1992–1998; not in regular operation since 1998	Since January 2003	Since January 1999; commercial operation since January 2002	September 1999
Constructor	Thermoselect srl	Mitsubishi Materials	Thermoselect SA	Kawasaki Steel Corp. (now JFE Engineering)
Operator	Thermoselect srl	Mitsubishi Materials	EnBW (TESS)	JRC (Japan Recycling Corporation)
Feedstock	MSW and industrial wastes	MSW	MSW	Industrial waste
Syngas use	Power generation by gas engines	Power generation by gas engines	Steam turbine and district heating	Export to steel works

TABLE 2. Thermoselect plants under construction in Japan during 2004

	Nagasaki	Kurashiki	Yorii	Tokushima	Izumi
Plant capacity[a]	3 lines, 300 tonnes/day	3 lines, 555 tonnes/day	2 lines, 450 tonnes/day	2 lines, 120 tonnes/day	1 line, 95 tonnes/day
Constructor	JFE Eng.	JFE Eng.	JFE Eng.	JFE Eng.	Kyokuto Kaihatsu
Owner	Municipality	Mizushima Eco Works	Yorii Orix Eco Service	Municipality	Clean Stage
Feedstock	MSW	MSW and industrial waste	Industrial waste	MSW	Industrial waste
Syngas use	Power generation by gas engines	Export to steel works	Boiler/steam turbine and power generation by gas engine	Power generation by gas engine	Boiler/steam turbine

[a] The capacity of a thermal line varies from 60 to 225 tonnes per day depending on input and availability requirements.

commercial or industrial wastes. An uninterrupted process simultaneously gasifies organic waste fractions and melts down inert materials (see Figure 1).

Synthesis gas is the main product of the process. Gasification transforms all organic materials in the waste into a synthesis gas, with a composition that reflects the thermodynamic equilibrium of the temperature at the top of the reactor – approximately 1200°C. The high-temperature, oxygen-free environment, and the residence time of more than two seconds in the upper part of the reactor, ensures that the prime constituents of the exiting syngas only occur as the smallest possible molecular species in the form of H_2, CO, CO_2 and H_2O. At a gas outlet temperature of 1200°C, the synthesis gas thus obtained from the organic fraction of MSW typically comprises (by volume) 25%–42% H_2, 25%–42% CO, 10%–35% CO_2, 2%–5% nitrogen, up to 1% methane, H_2S at trace amounts, and other impurities.[1–4]

Subsequent purification of this synthesis gas and the process water yields by-products in the form of salt, zinc concentrate and sulphur. Since this process does not deposit ash, slag, chars or filter dusts, no secondary treatment is required. The synthesis gas can be converted into electrical energy with a high efficiency, or it can be used in its basic molecular form.

Syngas can be converted into electricity at a high efficiency

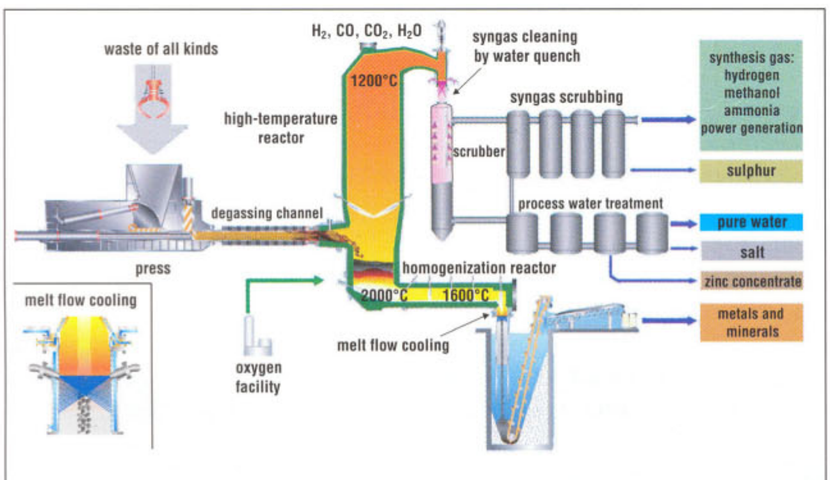


FIGURE 1. The Thermoselect resource recovery process

Melting of inorganic materials

All metallic and mineral components are melted down in the lower part of the reactor (see Figure 1, inset). The mineral and metal melts are then collected in the lower homogenization reactor, which is heated with natural gas and oxygen. In this reactor, the minerals and metals automatically separate into a two-phase flow as a result of their differences in relative density. Any residual carbon in the melt is further converted to syngas. The molten substances are subsequently granulated by water quenching, and are extracted from the quench basin using a bucket elevator.

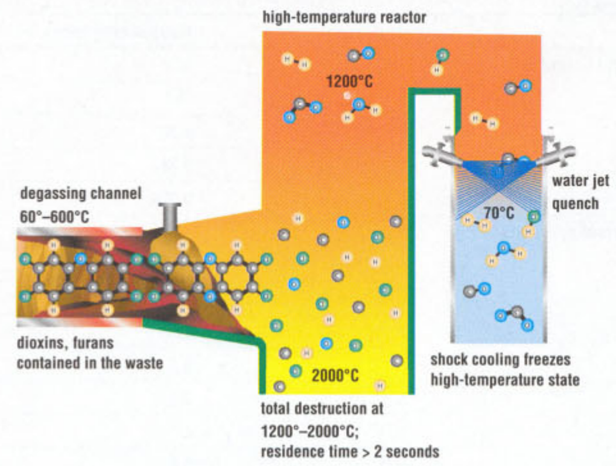
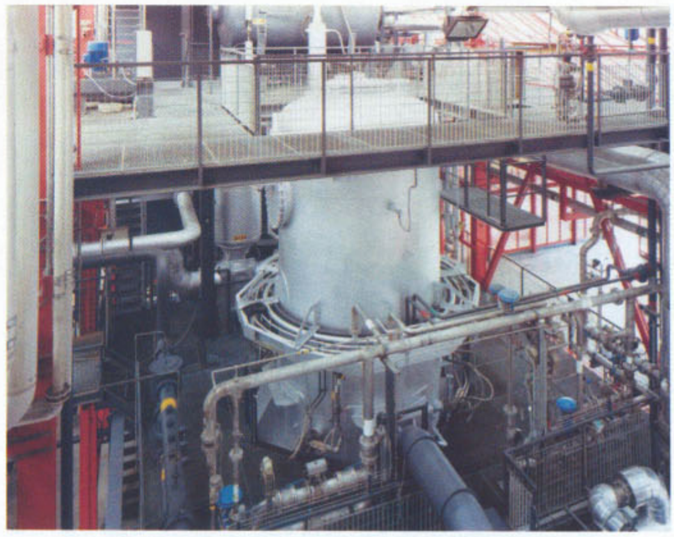


FIGURE 2. **Syngas cleaning by water quench**



The process simultaneously gasifies organic waste fractions and melts down inert materials

Syngas cleaning

The synthesis gas passes through several stages for cleaning: water quench, acidic scrubber, alkaline scrubber, dust removal, desulphurization and gas drying (see Figure 2).

The crude synthesis gas first leaves the reactor at approximately 1200°C and flows into a water jet quench that almost instantaneously cools the syngas down to about 70°–90°C. According to computational fluid dynamics calculations, the quench takes about 30 milliseconds, and the total residence time in the quench apparatus is about 300 milliseconds.

This rapid cooling prevents syngas constituents from recombining into higher organic molecules, and separates the entrained dust or semi-liquid particles from the gas stream. According to measurements, dioxins and furans in the synthesis gas are virtually non-existent,[5] as is also the case for existing coal-gasification processes.

Syngas has been used to produce hydrogen at the Chiba facility in Japan

TABLE 3. Typical composition of metal and mineral granulates (% by mass)

		Composition (mass %)
Metal granulate	Fe	83.8
	Cu	12.7
	Ni	0.38
	Cr	0.28
	Zn	0.059
Mineral granulate	SiO_2	45
	Fe_2O_3	17
	CaO	14
	Al_2O_3	12
	Na_2O	5.7
	MgO	2.4
	K_2O	1.1
	P_2O_5	0.8
	TiO_2	0.9

Syngas utilization

There are multiple applications for the utilization of the purified synthesis gas:

- hydrocarbon production – e.g. methanol
- hydrogen in fuel cells – as used in the Chiba facility in Japan – and carbon monoxide in solid-oxide fuel cells
- ammonia production – e.g. fertilizers
- electricity – e.g. gas engines, steam boiler and turbine for combined-cycle options, and gas turbines. The choice of power-generating equipment depends on the price of power. Higher power-generating efficiency would need to be supported by higher electricity prices.

Environmental benefits

The Thermoselect resource recovery process was conceived for recovering the maximum possible benefit from various types of wastes that cannot be recycled by conventional methods. With Thermoselect, these wastes are continuously processed, with the primary goal of achieving the highest possible yield of high-quality recyclable products at the lowest possible level of pollution, as well as the simultaneous utilization of the chemical energy contained in the waste. The by-products of the process can be used as:

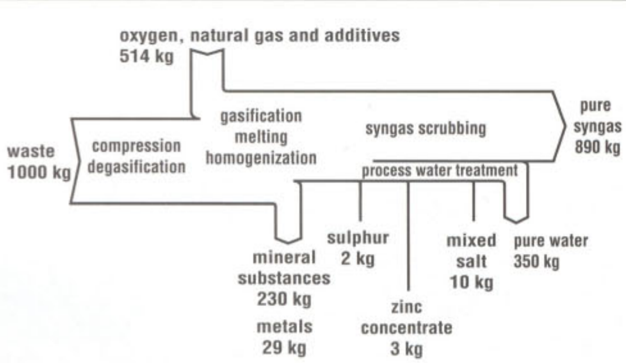


FIGURE 3. Mass balance of the Thermoselect process

- mineral granulate – reused as gravel substitute in concrete, as shot blast or as road-bed
- metal granulate – recycled into the metal industry
- sulphur – reused in sulphuric acid and in the fertilizer industry
- zinc concentrate – reused for zinc recovery
- salt – reused in the chlorine manufacturing industry
- water – reused in the process itself
- synthesis gas – converted either into further chemicals or power.

Figure 3 shows the by-products of the gasification process in proportion to the waste input.

Solid residues

Unlike incineration processes,[6, 7] Thermoselect does not produce any chars, oils or ash that need subsequent treatment or disposal.[8] Rather, the mineral granulate is inert and vitreous, as it has been melted down at a high temperature (> 1600°C). The leachability of the mineral granulate (according to the German regulation DEV S4) is negligible; a typical composition is shown in Table 3.

The emission values measured are at least 90% lower than the permitted maximum

Air emissions

The primary emissions to air are made up of the exhaust gases from the power-generating unit which utilizes the synthesis gas. These emissions have been extensively tested and are monitored continuously for compliance. Content of heavy metals, cadmium/thallium and dioxins and furans is measured twice every year in the Karlsruhe

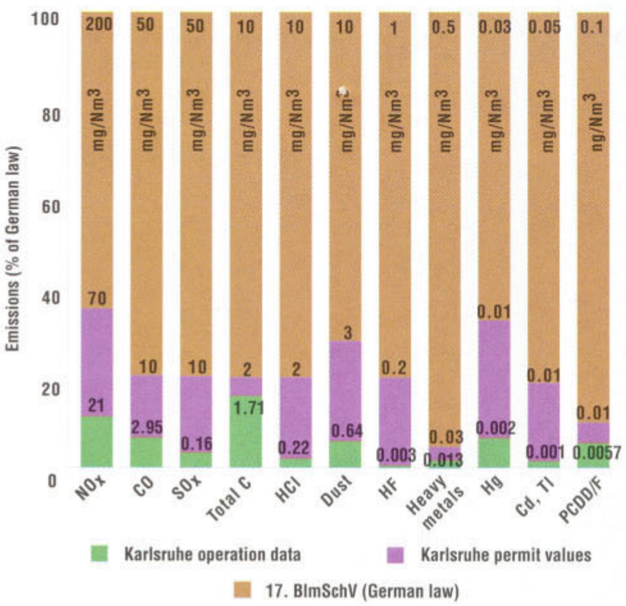


FIGURE 4. Air emissions from the Thermoselect facility at Karlsruhe – daily average values

Air emissions monitored at the facility at Karlsruhe, Germany, are significantly lower than German statutory limits

plant in Germany. Figure 4 indicates emission levels obtained there, and compares them with the permitted values issued by the local authority (Regierungspräsidium Karlsruhe), as well as the stringent emission limits according to the German Law (17. BImSchV). The permitted values are at least 70% lower than the current law, and the actual measured emission values are at least 90% lower than the permitted values.

The demonstration plant in operation during 1992–1998 at Fondotoce, Italy, accepted MSW and industrial wastes, and used the resulting syngas for electricity production

Raw and hazardous waste

The process can handle raw waste without prior treatment. It can also treat waste streams considered as hazardous, since the inherent conditions for process operation fully comply with the European Community Directive 2000/76/EC on the Incineration of Waste. This Directive states that 'if hazardous wastes with a content of more than 1% of halogenated organic substances ... are incinerated, [then] the temperature has to be raised to 1100°C for at least two seconds'. As Thermoselect's high-temperature reactor is designed to guarantee gas residence times of at least two seconds at temperatures exceeding 1200°C, it is therefore suitable for treating MSW. It is also suitable for the treatment of commercial and industrial waste streams as well, whether they are mixed together or separate.

Flexibility: waste inputs

This process can handle a wide range of wastes. These include wastes with a lower calorific value, in the range of 6–18 MJ/kg, and with a moisture content of approximately 10%–60%. Liquid wastes such as sewage sludge can also be processed.

Automotive shredder residue (ASR)

The process can also be used to recycle shredder dust from end-of-life vehicles and other post-consumer waste such as electronic devices. For example, in a three-day trial operation in the Karlsruhe plant in November 2002,[9] ASR (with a chlorine content of up to 3.5%, a heating value of 10–17 MJ/kg, and high heavy metal contents), was fed through in fractions of 45%–55% in mixture with domestic waste – all without affecting normal disposal operations.

Figure 5 compares the permitted air emission values with the average yearly air emissions of the Karlsruhe facility and those during operation with ASR. Comparison of the average values for 2002 with measurements taken during the ASR test shows that changing the input composition of the processed waste has no impact on the air emissions of a Thermoselect plant. The gas-cleaning train and its control concept is therefore robust enough to compensate for changes in waste composition.

According to results of the trial operation, the Thermoselect process is able to process ASR, producing synthesis gas which can be used as a chemical feedstock. This qualifies the process as a 'recycling process' under European legislation.

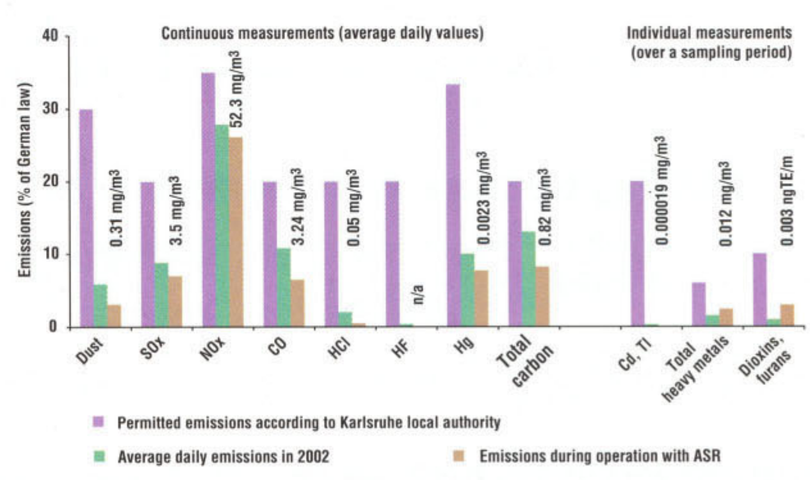


FIGURE 5. Average daily air emissions at the Karlsruhe facility – comparison of MSW and ASR results

Refuse-derived fuel (RDF)

Mechanical–biological treatment plants produce about 20%–40% of RDF from their input. Due to its high calorific value and therefore high carbon content, landfilling of RDF is no longer allowed in Germany as of 2005 according to TASi (Technische Anleitung Siedlungsabfall) regulation. In the other EU countries, similar regulations are expected to come into force as a result of Directive 1999/31/EG.

Thermoselect has successfully processed RDF. In a trial at the Karlsruhe plant, nearly 200 tonnes of RDF (excluding any MSW) was fed to the gasifiers during one continuous production. A very rich syngas of high calorific value was produced, yielding approximately 65% higher thermal output from the gasifiers as compared with MSW operation. The plant processed this high-calorific material without any problems, and emissions remained at the same low level as during the processing of MSW.

Selling syngas to a chemical plant yields higher income than using it for electricity generation

Benefits and future possibilities

This high-temperature gasification process has now been scaled up successfully to full commercial scale: because it allows the combined processing of industrial wastes and MSW in a single plant, it is proving to be commercially competitive with other thermal treatment methods. Furthermore, the technology is entitled to public sector support programmes in some countries. For example, it qualifies as renewable energy for the UK's Renewable Obligation Certificates, and Italy's 'Certificati Verdi' scheme.

Integrating a Thermoselect plant into a chemical facility, which uses the resulting syngas as an important feedstock, is economically even more interesting. Selling syngas to a chemical plant yields higher income than using it for producing electricity for the grid. In addition, the equipment needed for syngas export – a compressor alone – is much simpler than that for electricity production. This saves on investment and capital costs (when power is needed at the plant, it will be imported). Therefore, integrating a gasification plant into a chemical facility is even more economically advantageous. In this case, the plant does not only fulfil the requirements of a recycling plant, but also can offer a significant increase in profits.

According to large-scale plant tests, RDF and ASR have no negative effects on air emissions nor on granulate quality – showing that the process has potential for recycling these types of residues as well.

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Notes

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