



CONVERTING WASTE PLASTICS INTO A RESOURCE

Compendium of Technologies

UNITED NATIONS ENVIRONMENT PROGRAMME

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Compiled by



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Preface

Economic growth and changing consumption and production patterns are resulting into rapid increase in generation of waste plastics in the world. In Asia and the Pacific, as well as many other developing regions, plastic consumption has increased much more than the world average due to rapid urbanization and economic development.

The world's annual consumption of plastic materials has increased from around 5 million tonnes in the 1950s to nearly 100 million tonnes; thus, 20 times more plastic is produced today than 50 years ago. This implies that on the one hand, more resources are being used to meet the increased demand of plastic, and on the other hand, more plastic waste is being generated.

Due to the increase in generation, waste plastics are becoming a major stream in solid waste. After food waste and paper waste, plastic waste is the major constitute of municipal and industrial waste in cities. Even the cities with low economic growth have started producing more plastic waste due to plastic packaging, plastic shopping bags, PET bottles and other goods/appliances using plastic as the major component.

This increase has turned into a major challenge for local authorities, responsible for solid waste management and sanitation. Due to lack of integrated solid waste management, most of the plastic waste is neither collected properly nor disposed of in appropriate manner to avoid its negative impacts on environment and public health and waste plastics are causing littering and chocking of sewerage system.

On the other hand, plastic waste recycling can provide an opportunity to collect and dispose of plastic waste in the most environmental friendly way and it can be converted into a resource. In most of the situations, plastic waste recycling could also be economically viable, as it generates resources, which are in high demand. Plastic waste recycling also has a great potential for resource conservation and GHG emissions reduction, such as producing diesel fuel from plastic waste. This resource conservation goal is very important for most of the national and local governments, where rapid industrialization and economic development is putting a lot of pressure on natural resources. Some of the developed countries have already established commercial level resource recovery from waste plastics. Therefore, having a "latecomer's advantage," developing countries can learn from these experiences and technologies available to them.

To raise the awareness and to build the capacity of local stakeholders, UNEP has started to promote **Integrated Solid Waste Management (ISWM) system based on 3R (reduce, reuse and recycle) principle**. This covers all the waste streams and all the stages of waste management chain, viz.: source segregation, collection and transportation, treatment and material/energy recovery and final disposal. It has been shown that with appropriate segregation and recycling system significant quantity of waste can be diverted from landfills and converted into resource.

Developing and implementing ISWM requires comprehensive data on present and anticipated waste situations, supportive policy frameworks, knowledge and capacity to develop plans/systems, proper use of environmentally sound technologies, and appropriate financial instruments to support its implementation.

Many national governments, therefore, have approached UNEP, [as reflected in the decision taken by the UNEP Governing Council/Global Ministerial Environment Forum during its 25th Session in February 2009 (**UNEP/GC.25/CW/L.3**)] to get further support for their national and local efforts in implementation of the Integrated Solid Waste Management (ISWM) programme.

In response to this decision and in line with the Bali Strategic Plan for Capacity Building and Technology Transfer, UNEP has developed a programme on integrated solid waste management. This programme includes support for capacity building and technology transfer for ISWM through a number of actions:

1. Guidelines to develop ISWM System: The four sets of guidelines on ISWM covering waste characterization and quantification, assessment of current waste management system, target setting and identification of stakeholders' issues of concern for ISWM, and how to develop ISWM Plan.
2. Pilot projects on ISWM and emerging waste streams including E-waste, waste agricultural biomass, waste plastics and so on
3. Regional and sub-regional training for policy makers and experts on ISWM and emerging waste streams
4. Interactive advisory support on ISWM and emerging waste streams

To raise the awareness and to build the local capacity for the design and implementation of projects on converting waste into material/energy source, UNEP has started a compilation of guidelines for the characterization and quantification of specific types of waste, the assessment of waste management systems and compendiums of technologies for various types of wastes.

This document is a compilation of technologies for the conversion of plastics into fuel which are in commercial use, under pilot implementation and under laboratory testing. This document is

aimed to raise awareness on the available options vis-à-vis technologies as well as to assist the policy –makers and managers in the identification of appropriate technologies with respect to local economic, environmental, social and technical characteristics.

This document can also be of interest to other interested parties/organizations that aim at supporting decision-makers. They may be:

- consultants working on urban services, recycling, or waste management;
- representatives or staff of other local stakeholders including community groups, NGOs, and the private sector;
- entrepreneurs wishing to expand or strengthen their solid waste portfolios;
- academicians and scholars in urban environmental management;
- the press, especially when seeking background materials;
- donors interested in supporting future waste management activities;
- local experts interested in using or replicating the results.

This document and the information available at the website is compiled through best efforts with purpose of creating an information-base with periodic updates based on the feedback from technology experts, providers, suppliers and users. This document is not aimed to advertise or support any specific technology and errors and omissions are not intentional.

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Acronyms

ABS	Acrylonitrile-Butadiene-Styrene copolymer
BTU	British Thermal Unit
DTIE	Division of Technology, Industry and Economics
GHG	Green House Gas
IETC	International Environmental Technology Centre
ISWM	Integrated Solid Waste Management
JIS	Japanese Industrial Standards
LNG	Liquefied Natural Gas
LPG	Liquefied Petroleum Gas
NGOs	Non-governmental Organizations
PE	Polyethylene
PET	Polyethylene terephthalat
PF	Phenol resin
PMMA	Polymethyl metacrylate
POM	Polyoxymethylene
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVA	Polyvinyl Alcohol
PVC	Polyvinyl-Chloride
PVDC	Polyvinylidene chloride
RDF	Refuse Derived Fuel
RPF	Refuse-derived Paper and Plastic Fuel
3R	Reduce, Reuse and Recycle
SRF	Solid Recovered Fuel
UNEP	United Nations Environment Programme

Part I - Technologies for Converting Waste Plastics into Fuel

1. Introduction

1.1 Overview

This compendium of technologies aims to present an overview of the technologies available for converting waste plastics into a resource. It emphasizes the typical methods for converting waste plastics into solid, liquid and gaseous fuels as well as the direct combustion of waste plastics for specific applications.

The compendium is divided into two parts: Part 1 focuses on the technical aspects of the technologies and Part 2 presents technologies examples.

Within Part 1, Chapter 2 displays the plastics which are suitable for each type of fuel and the potential problems posed by contamination by undesirable materials. Chapters 3 through 5 depict flowcharts of typical production systems for solid, liquid and gaseous fuels and Chapter 6 refers to other technologies used in the steel, cement and lime manufacturers.

Part 2 presents examples of waste plastic applications in several industries.

1.2 Plastics

As a brief introduction to plastics, it can be said that plastics are synthetic organic materials produced by polymerization. They are typically of high molecular mass, and may contain other substances besides polymers to improve performance and/or reduce costs. These polymers can be molded or extruded into desired shapes.

There are two main types of plastics: thermoplastics and thermosetting polymers.

- Thermoplastics can repeatedly soften and melt if enough heat is applied and hardened on cooling, so that they can be made into new plastics products. Examples are polyethylene, polystyrene and polyvinyl chloride, among others.
- Thermosets or thermosettings can melt and take shape only once. They are not suitable for repeated heat treatments; therefore after they have solidified, they stay solid. Examples are phenol formaldehyde and urea formaldehyde.

2. Target Waste Plastics

Waste plastics are one of the most promising resources for fuel production because of its high heat of combustion and due to the increasing availability in local communities. Unlike paper and wood, plastics do not absorb much moisture and the water content of plastics is far lower than the water content of biomass such as crops and kitchen wastes.

The conversion methods of waste plastics into fuel depend on the types of plastics to be targeted and the properties of other wastes that might be used in the process. Additionally the effective conversion requires appropriate technologies to be selected according to local economic, environmental, social and technical characteristics.

In general, the conversion of waste plastic into fuel requires feedstocks which are non-hazardous and combustible. In particular each type of waste plastic conversion method has its own suitable feedstock. The composition of the plastics used as feedstock may be very different and some plastic articles might contain undesirable substances (e.g. additives such as flame-retardants containing bromine and antimony compounds or plastics containing nitrogen, halogens, sulfur or any other hazardous substances) which pose potential risks to humans and to the environment.

The types of plastics and their composition will condition the conversion process and will determine the pretreatment requirements, the combustion temperature for the conversion and therefore the energy consumption required, the fuel quality output, the flue gas composition (e.g. formation of hazardous flue gases such as NO_x and HCl), the fly ash and bottom ash composition, and the potential of chemical corrosion of the equipment,

Therefore the major quality concerns when converting waste plastics into fuel resources are as follows:

- 1) *Smooth feeding to conversion equipment:* Prior to their conversion into fuel resources, waste plastics are subject to various methods of pretreatment to facilitate the smooth and efficient treatment during the subsequent conversion process. Depending on their structures (e.g. rigid, films, sheets or expanded (foamed) material) the pretreatment equipment used for each type of plastic (crushing or shredding) is often different.
- 2) *Effective conversion into fuel products:* In solid fuel production, thermoplastics act as binders which form pellets or briquettes by melting and adhering to other non-melting substances such as paper, wood and thermosetting plastics. Although wooden materials are formed into pellets using a pelletizer, mixing plastics with wood or paper complicates the pellet preparation process. Suitable heating is required to produce pellets from thermoplastics and

other combustible waste.

In liquid fuel production, thermoplastics containing liquid hydrocarbon can be used as feedstock. The type of plastic being used determines the processing rate as well as the product yield. Contamination by undesirable substances and the presence of moisture increases energy consumption and promotes the formation of byproducts in the fuel production process.

3) *Well-controlled combustion and clean flue gas in fuel user facilities*: It is important to match the fuel type and its quality to the burner in order to improve heat recovery efficiency. Contamination by nitrogen, chlorine, and inorganic species, for instance, can affect the flue gas composition and the amount of ash produced. When using fuel prepared from waste plastics, it must be assured that the flue gas composition complies with local air pollution regulations. In the same way, ash quality must also be in compliance with local regulations when disposed at the landfill. If there aren't any relevant regulations, both the producers and consumers of the recycled fuel should control the fuel quality and the emissions at combustion in order to minimize their environmental impact.

Table 2.1 classifies various plastics according to the types of fuel they can produce. It can be observed that thermoplastics consisting of carbon and hydrogen are the most important feedstock for fuel production either in solid or liquid form.

As shown in Table 2.2, PE, PP and PS thermoplastics are preferable as feedstock in the production of liquid hydrocarbons. The addition of thermosetting plastics, wood, and paper to the feedstock leads to the formation of carbonous substances and lowers the rate and yield of liquid products.

Table 2.1: Polymer as feedstock for fuel production

Types of polymer	Descriptions	Examples
Polymers consisting of carbon and hydrogen	Typical feedstock for fuel production due to high heat value and clean exhaust gas.	Polyethylene, polypropylene, polystyrene. Thermoplastics melt to form solid fuel mixed with other combustible wastes and decompose to produce liquid fuel.
Polymers containing oxygen	Lower heat value than above plastics	PET, phenolic resin, polyvinyl alcohol, polyoxymethylene
Polymers containing nitrogen or sulfur	Fuel from this type of plastic is a source of hazardous components such as NO _x or SO _x in flue gas. Flue gas cleaning is required to avoid emission of hazardous components in exhaust gas.	Nitrogen: polyamide, polyurethane Sulfur: polyphenylene sulfide
Polymers containing halogens of chlorine, bromine and fluorine.	Source of hazardous and corrosive flue gas upon thermal treatment and combustion.	Polyvinyl chloride, polyvinylidene chloride, bromine-containing flame retardants and fluorocarbon polymers.

Table 2.2: Product types of some plastics pyrolysis

Main products	Type of plastics	As a feedstock of liquid fuel
Liquid hydrocarbons	Polyethylene (PE) Polypropylene (PP) Polystyrene (PS) Polymethyl metacrylate (PMMA)	Allowed. Allowed. Allowed. Allowed.
Liquid hydrocarbons	Acrylonitrile-Butadiene-Styrene copolymer (ABS)	Allowed. But not suitable. Nitrogen-containing fuel is obtained. Special attention required to cyanide in oil.
No hydrocarbons suitable for fuel	Polyvinyl alcohol (PVA) Polyoxymethylene (POM)	Not suitable. Formation of water and alcohol. Not suitable. Formation of formaldehyde.
Solid products	Polyethylene terephthalate (PET)	Not suitable. Formation of terephthalic acid and benzoic acid.
Carbonous products	Polyurethane (PUR) Phenol resin (PF)	Not suitable. Not suitable.
Hydrogen chloride and carbonous products	Polyvinyl chloride (PVC) Polyvinylidene chloride (PVDC)	Not allowed. Not allowed.

3. Solid Fuel Production

3.1 Scope of solid fuel in this compendium

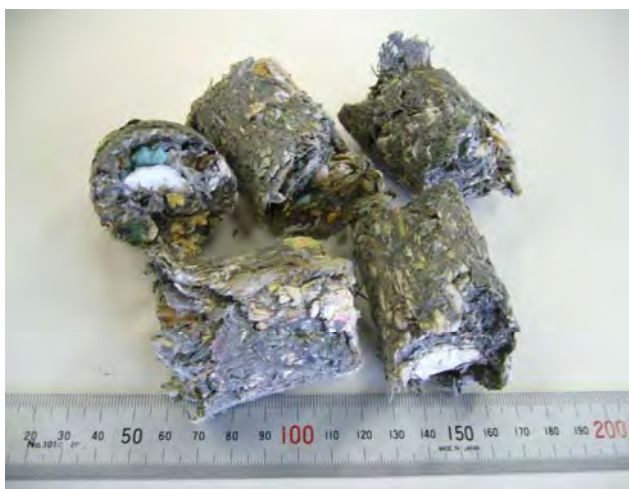


Figure 3.1: Example of RPF

Solid fuel, as referred in this compendium, is prepared from both municipal and industrial non-hazardous waste. Additionally, the solid fuel outlined here excludes coal and coal-derived fuels as well as solid biofuels such as firewood and dried manure but it may contain biofuels as a component.

This compendium differentiates two types of solid fuel: refuse derived fuel (RDF), also called solid recovered fuel (SRF) and refuse-derived paper and plastic densified fuel (RPF).

RDF is mainly produced from municipal kitchen waste, used paper, waste wood and waste plastics. Due to the presence of kitchen waste, prior to the conversion to a fuel, a drying process is required to remove the moisture from such waste to allow the solidification of the waste in suitable shapes and densities. This process is seen as a disadvantage due to the large amount of energy that the process requires. Solid recovered fuel (SRF) is defined in the European Committee for Standardization technical specification (CEN/TS 15359:2006).

On the other hand RPF (Figure 3.1) is prepared from used paper, waste plastics and other dry feedstocks. Within the plastics, the thermoplastics play a key role as a binder for the other components such as thermosetting plastics and other combustible wastes, which cannot form pellets or briquettes without a binding component. Approximately 15wt% of thermoplastics is the minimum required to be used as a binder to solidify the other components; however excessive amounts, higher than 50wt%, would cause a failure in the pellet preparation. The components of RPFs are mainly sorted from industrial wastes and are sometimes also obtained from well-separated municipal waste. This type of solid fuel is set to be standardized in the Japanese Industrial Standards (JIS).

In both cases, the plastic contents can be varied (within a range) to meet the needs of fuel users. The shape of the fuel will vary according to the production equipment (e.g. a screw extruder is often used to create cylindrical-shaped fuel with a variable diameter and length). The example of Figure 3.1 contains RPF samples 40 mm in diameter and 50 mm in length.

In the production of solid fuel, the contamination of the targeted plastics with other plastics

containing nitrogen, halogens (Cl, Br, F), sulfur and other hazardous substances may cause air and soil pollution by the flu gas emission and the incineration ash disposal (e.g. inorganic components such as aluminum in multilayer film of food packages produces fly ash and bottom ash). Other contaminants such as hydrogen chloride might cause serious damage to the boiler by corrosion.

3.2 Production method

The solid fuel production process usually involves two steps, pretreatment and pellet production:

- Pretreatment includes coarse shredding and removal of non-combustible materials.
- Pellet production comprises secondary shredding and pelletization (<200°C).

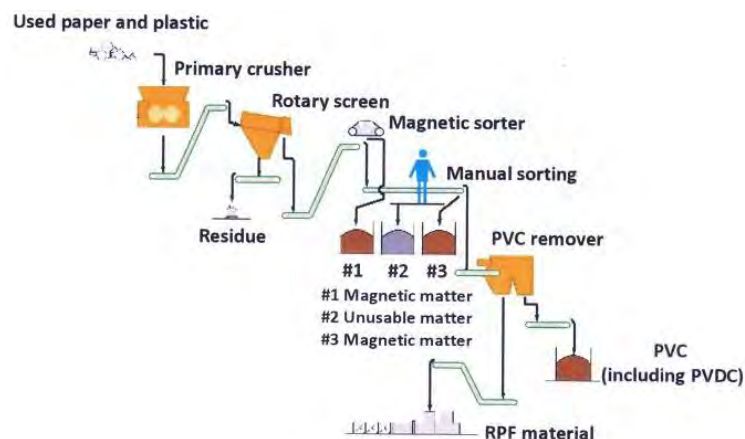
However, pretreatment is not required if the solid fuel producer can collect waste with suitable properties.

Two types of commercial production systems are described as follows. One is a large-scale model with pretreatment for the separation of undesirable contamination such as metals and plastics containing chlorine. The other is a small-scale model without pretreatment equipment.

3.2.1 Large-scale model (3 ton/hour)

Industrial waste plastics, which have been separated and collected in factories, are ideal to be used for solid fuel production.

A fuel production facility consists of a waste unloading area, stockyard, pretreatment equipment, pelletizing equipment and solid fuel storage. The pretreatment process includes crushing and sorting for the removal of unsuitable materials from incoming wastes. A schematic diagram of the pretreatment process is shown in Figure 3.2. Figure 3.3 presents a photograph of a pretreatment process.



(Copyright Japan RPF Association)

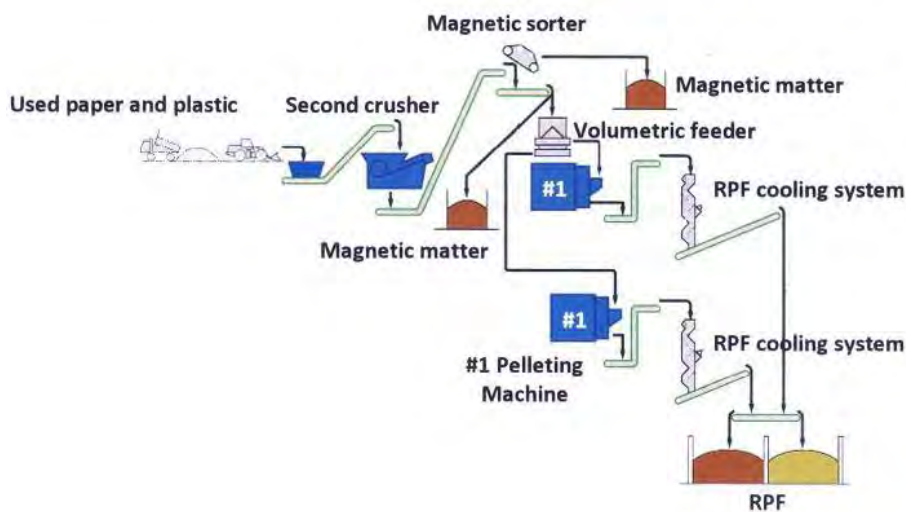
Figure 3.2: Schematic diagram of pretreatment process



(Copyright Japan RPF Association)

Figure 3.3: Example of pretreatment process (3 ton/h capacity)

After pretreatment, a suitable mixture of paper and plastics are further processed in a secondary crusher and sorting process (conveyor and magnetic separator) and the resulting mixture is pelletized to produce solid fuel. The resulting solid fuel is cooled in an air-cooling system to prevent natural ignition during storage and it is further stored for shipping. The output of the process is usually solid fuel pellets of dimensions between 6 to 60 mm in diameter and 10 to 100 mm in length. The heating value of the pellets will change depending on the content of the plastics. A mixture of paper and plastics of a 1:1 weight ratio gives a heating value of approximately 7,000 kcal/kg or higher. Figure 3.4 shows a pelletizing process and Figure 3.5 a typical pelletizing process facility with a 1 ton/h capacity.



(Copyright Japan RPF Association)

Figure 3.4: Schematic diagram of a pelletizing process



(Copyright Japan RPF Association)

Figure 3.5: Typical pelletizing process facility (1 ton/h line)

3.2.2 Small-scale model (150 kg/hour)

This small-scale model is a system for solid fuel production with a 150-kg/h capacity. In this case the facility does not have a pretreatment process, (as aforementioned, a sorting process is not required if properly segregated waste can be collected) so the combustible wood, paper and plastic waste is directly fed into the crusher of the facility. This is carried out by using a handling machine as shown in Figure 3.7 where the operator must control and feed into the crusher a suitable ratio of each type of waste in order to maintain the fuel qualities such as the heating value. After crushing the materials, they are transported through a pipe conveyor and are introduced into a twin-screw pelletizer.

Figure 3.6 shows the entire process (the crusher, the pipe conveyor and the pelletizer).



Figure 3.6: Smaller RPF production facility (150 kg/h capacity)



Figure 3.7: Heavy duty machine to feed wastes

3.3 Product and byproduct

Heating value is an important characteristic of solid fuels. Some examples of heating values of several types of waste and solid fuel are listed in Table 3.1.

Table 3.1: Heating values of various fuels and wastes

Fuel or waste	Typical heating value (kcal/kg)
RDF	4000 – 5000 * ¹
RPF	6000 – 8000 * ²
Coal	6000 – 8000* ³
Heavy oil	9500
Wood/paper	4300
Plastics (polyethylene)	11000
Typical municipal wastes	1000 – 1500* ¹

*1 Depends on waste composition. *2 Can be controlled by plastic composition in fuel production process. *3 Depends on rank of coal

The heating values of solid RDFs and RPFs may vary depending on the composition of the materials they contain. Especially in RDF, fluctuations in the heating values are often observed due to changes in the composition of the municipal waste (which is difficult to control) and according to the degree of drying of the municipal waste used in the production process.

RPF heating values can usually be controlled easily due to the use of dry and sorted plastics, paper and other combustible waste, which have been collected from companies.

Other important features of the solid fuels are its content of ash, moisture and the content of potential hazardous substances like nitrogen, chlorine, sulfur and heavy metals.

Fuel suppliers should have an agreement with fuel users regarding the solid fuel qualities.

Special attention is required in order to avoid self-ignition and methane evolution during the RDF storage

4. Liquid Fuel Production

4.1 Scope of liquid fuel in this compendium

Liquid fuel within this compendium is defined as plastic-derived liquid hydrocarbons at a normal temperature and pressure. Only several types of thermoplastics undergo thermal decomposition to yield liquid hydrocarbons used as liquid fuel. PE, PP, and PS, are preferred for the feedstock of the production of liquid hydrocarbons. The addition of thermosetting plastics, wood, and paper to feedstock leads to the formation of carbonous substance. It lowers the rate and yields of liquid products.

Depending on the components of the waste plastic being used as feedstock for fuel production, the resulting liquid fuel may contain other contaminants such as amines, alcohols, waxy hydrocarbons and some inorganic substances. Contamination of nitrogen, sulfur and halogens gives flu gas pollution. Unexpected contamination and high water contents may lower the product yields and shorten the lifetime of a reactor for pyrolysis

Liquid fuel users require petroleum substitutes such as gasoline, diesel fuel and heavy oil. In these fuels, various additives are often mixed with the liquid hydrocarbons to improve the burner or the engine performance. The fuel properties such as viscosity and ash content should conform to the specifications of the fuel user's burners or engines. No additives would be needed for fuel used in a boiler. A JIS technical specification was proposed for pyrolytic oil generated from waste plastic for use as boiler and diesel generator fuel (TS Z 0025:2004).

Skillful operators and a well-equipped facility are required due to the formation of highly flammable liquids and gases.

4.2 Production method

The production method for the conversion of plastics to liquid fuel is based on the pyrolysis of the plastics and the condensation of the resulting hydrocarbons. Pyrolysis refers to the thermal decomposition of the matter under an inert gas like nitrogen.

For the production process of liquid fuel, the plastics that are suitable for the conversion are introduced into a reactor where they will decompose at 450 to 550 °C. Depending on the pyrolysis conditions and the type of plastic used, carbonous matter gradually develops as a deposit on the inner surface of the reactor. After pyrolysis, this deposit should be removed from the reactor in order to maintain the heat conduction efficiency of the reactor.

The resulting oil (mixture of liquid hydrocarbons) is continuously distilled once the waste

plastics inside the reactor are decomposed enough to evaporate upon reaching the reaction temperature. The evaporated oil is further cracked with a catalyst. The boiling point of the produced oil is controlled by the operation conditions of the reactor, the cracker and the condenser. In some cases, distillation equipment is installed to perform fractional distillation to meet the user's requirements.

After the resulting hydrocarbons are distilled from the reactor, some hydrocarbons with high boiling points such as diesel, kerosene and gasoline are condensed in a water-cooled condenser. The liquid hydrocarbons are then collected in a storage tank through a receiver tank. Gaseous hydrocarbons such as methane, ethane, propylene and butanes cannot be condensed and are therefore incinerated in a flare stack. This flare stack is required when the volume of the exhaust gas emitted from the reactor is expected to be large.

Figure 4.1 presents a schematic diagram of a liquid fuel production plant.

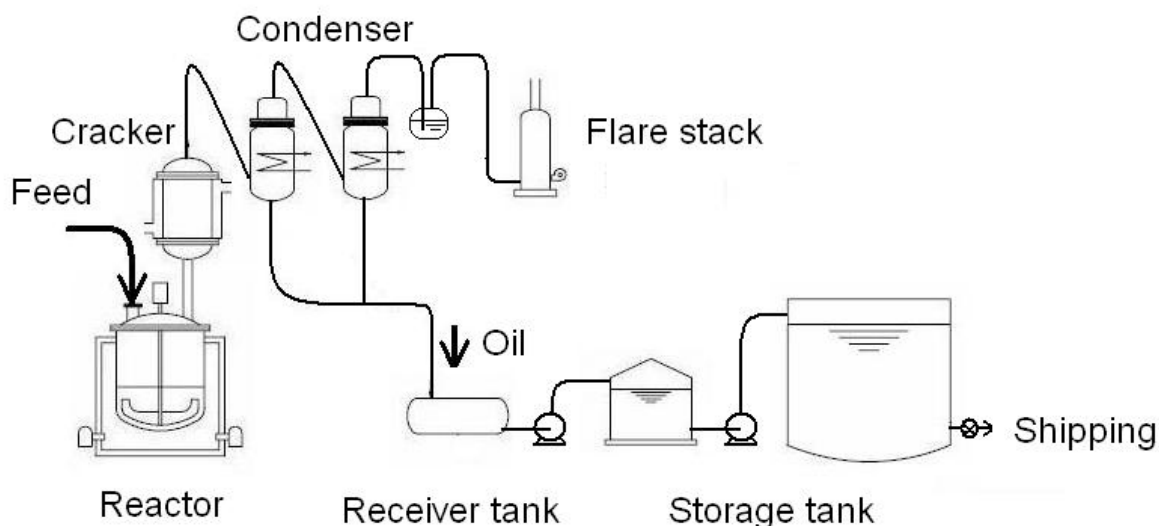


Figure 4.1: Schematic diagram of a production plant of plastics-derived fuel

There may be variations in the feeding methods used depending on the characteristics of the waste plastic. The easiest way is to simply introduce the waste plastics into the reactor without any pretreatment. Soft plastics such as films and bags are often treated with a shredder and a melter (hot melt extruder) in order to feed them into the reactor because otherwise they would occupy a large volume of the reactor.

There are also different types of reactors and heating equipment. Both kiln-type and screw-type reactors have been proposed, while induction heating by electric power has been developed as an alternative to using a burner.

Due to the formation of carbonous matter in the reactor, which acts as a heat insulator, in

some tank reactors the stirrer is used to remove the carbonous matter rather than for stirring. After the liquid product of the pyrolysis is distilled, the carbonous matter is taken out either with a vacuum cleaner or in some cases reactors are equipped with a screw conveyor at the bottom of the tank reactor to remove the carbonous matter.

Operators should understand the relationship between the amount and composition of the waste plastics as well as the operating conditions. Energy consumption and plant costs relative to the plastic treatment capacity are the typical criteria for evaluating the plant performance. Operating skill and safety considerations are important in this type of chemical conversion due to the highly flammable liquid fuels which are formed.

4.3 Products and byproducts

Liquid fuel is used in burners or engines as a substitute for liquid petroleum. Table 4.1 presents the properties of waste plastic-derived fuel and petroleum fuels. Samples A and B are a whole distillate and middle distillate of waste plastic pyrolytic oil respectively. After considering the burner or engine operating stability, it is possible to mix plastics-derived oil with petroleum fuel.

Table 4.1: Typical properties of waste plastics-derived fuel and petroleum fuels

Category	Sample A (whole distillate)	Sample B (middle distillate)	Diesel fuel	Heavy oil
Specific gravity (15 °C), g/cm ³	0.8306	0.8430	0.8284	0.8511
Flashing point (°C)	-18 (PM)	68.0 (Tag)	69.0 (Tag)	64 (PM)
Kinetic viscosity (30 °C/50 °C, mm ² /s)	1.041/-	-/1.73	3.822/-	-/2.29
Carbon residue on 10% bottoms; wt%	-	0.85	0.01	0.46
Ash weight (%)	0.00	<0.001	-	0.006
Gross heating value (cal/g)	11294	10746	-	10708
Total chlorine (wt ppm)	47	10	<1	1.6
Nitrogen (wt%)	0.14	0.033	-	0.015
Sulfur (wt ppm)	100	910	310	0.41 %
Cetane index	27.0	42.9	58.4	46.3
Distillation temperature (°C)				
Initial	47.0	180.0		164
10%	69.0	199.0		195
50%	148.0	233.0		276
90%	294.5	323.5	344.0	347
End	374.0	351.5		370<

Some plastics yield residual substances such as carbonous matter and other inorganic matter during pyrolysis. Carbonous matter can be used as a feedstock for solid fuel. Aluminum foil or other inorganic substances may be contained depending on the level of waste composition so suitable management is required.

Pyrolysis of mixed plastics with nitrogen-containing plastics produces the corresponding liquid fuel with nitrogen compounds, which in turn produces nitrogen oxide in the flue gas at combustion. Similarly, liquid fuel derived from waste plastics containing chlorine will cause corrosion to the reactor and burner and it will form hydrogen chloride and dioxins. Flue gas treatment should therefore be considered to avoid the potential risks that those chemicals pose to workers and local residents.

5. Gaseous Fuel Production

5.1 Scope of gaseous fuel in this compendium

The gaseous fuel described in this report refers to the flammable gas obtained from the thermal treatment of waste plastics. There are two types of gaseous fuel:

- *Gaseous hydrocarbon*: hydrocarbons that are in a gaseous state under normal temperature and pressure (0 °C, 1 atm).
- *Synthesis gas or syngas*: mixture of hydrogen and carbon monoxide

In the conversion of plastics to gaseous fuel, the waste plastics undergo thermal decomposition in a tank reactor, resulting in the formation of liquid fuel as the main product and gaseous fuel up to about 20 wt%, as the minor product. Gaseous hydrocarbons become the main product after residing in the reactor for an extended time at a reaction temperature under controlled decomposition conditions and the use of a specific reactor. Under specific conditions, carbon and carbohydrates can be used as feedstocks for the production of gaseous fuel like methane and hydrogen.

5.2 Production method

The gasification process includes a series of steps such as pretreatment, gasification, gas cleaning and storage.

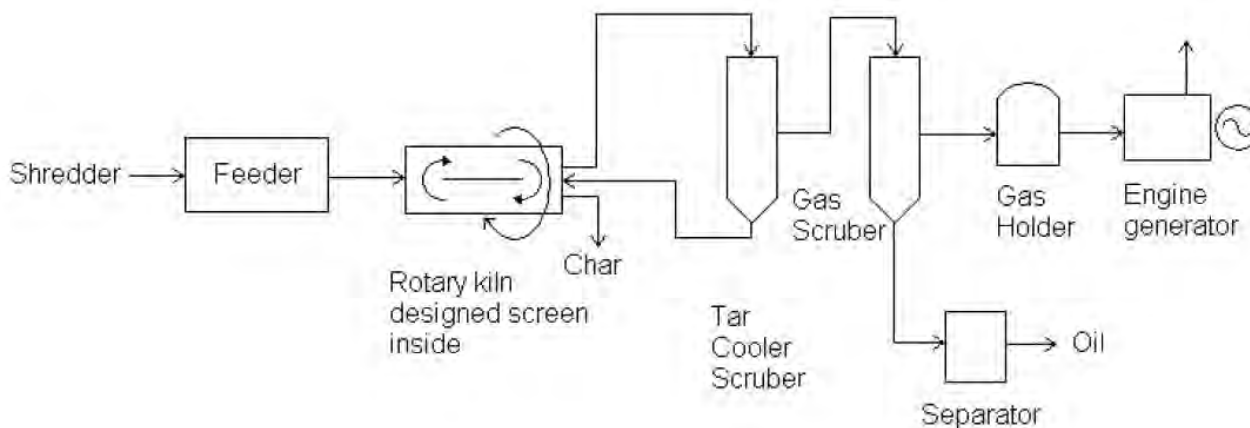


Figure 5.1: Schematic diagram of a production plant of plastics-derived gaseous fuel

Polyethylene and polypropylene thermally decompose at temperatures up to about 700 °C and under an inert atmosphere to form a mixture of gaseous hydrocarbons, methane, ethane, ethylene, propane, propylene, and various isomers of butane and butane¹. On the other hand, most of the organic substances undergo gasification yielding syngas².

¹ Kodera, Y., Ishihara, Y., Kuroki, T.; *Energy Fuels*, 20, 155-158, 2006.

² Gebauer, M., Stannard, D.; *Gasification of Plastics Wastes*, In *Recycling and Recovery of Plastics*, Ed. by Brandrup, J., Bittner, M.,

Gasification proceeds at elevated temperatures, higher than 800 and practically 1000 °C. Depending on the types of reactors and reaction conditions, carbonous matter and carbon dioxide are formed, and nitrogen from the air is contained in the product gas.

The gasification reactors to be used are moving-bed, fluidized-bed and entrain-bed reactors.

If the product is to be stored, a large gas holder is to be required.

The gasification technique is already used commercially for coal and there are several examples of commercial operations using biomass and waste plastics to produce low- and medium-BTU gas.

Several manufacturers have proposed small-scale gasification systems. Careful cost analysis is important with respect to the amount of collected waste, the transportation distance and the commercial value of the resultant products such as electricity and gaseous fuel.

In any case, this technology requires skillful operators and careful handling to avoid hydrogen explosion

Table 5.1 summarizes the gasification methods which yield flammable gas.

Table 5.1: List of various gasification methods

Type of gasification	Conditions	Typical products
Pyrolysis	>700 °C under inert atmosphere	Gaseous hydrocarbons from aliphatic hydrocarbons including polyethylene and polypropylene.
Partial oxidation	>1000 °C under oxygen or air	Carbon monoxide from carbon, hydrocarbons and carbohydrates including wood. Hydrogen also forms from hydrocarbons and carbohydrates.
Steam gasification	>800 °C under oxygen or air	Methane, carbon monoxide and hydrogen
Hydrogasification	Around 500 – 600 °C under hydrogen	Methane, carbon monoxide and water

5.3 Product

As afore mentioned, there are two types of pyrolysis products in the gasification process. One is a mixture of gaseous hydrocarbons such as methane and ethylene while the other is synthetic gas – a mixture of hydrogen and carbon monoxide. Table 5.2 shows the type of waste and its typical products.

Michaeli, W., Menges, G, pp. 455, Hanser Publishers, Munich, 1996.

Table 5.2: Wastes and typical products

Type of waste	Pyrolysis conditions	Typical products
Polyethylene, polypropylene	Inert atmosphere, 700 – 800 °C	High-BTU gas (e.g. 9000 kcal/Nm ³); Hydrocarbon gas like Methane and ethylene. Liquid hydrocarbon like benzene and toluene.
Aromatic polymer, carbonous substances, carbohydrates like wood in addition to the polymers above.	Air, steam atmosphere, above 1000 °C	Low-BTU gas (e.g. 800-1800 kcal/Nm ³); Hydrogen, carbon monoxide, carbon dioxide and nitrogen. Methane formation increases the heating value to give medium-BTU gas.

Cf. Higher heating value: hydrogen 3050 kcal/Nm³ (0°C, 1atm).

The heating values of the gaseous products will vary according to the type of waste used, the contamination of nitrogen from the air and/or other reasons. However it can be said that the calorific value of Syngas ranges between the calorific value of biogas and LNG/LPG.

6. Other Technologies

Instead of installing a new waste plastic conversion facility, some types of industrial infrastructure provide optional methods for using waste plastics as fuels. Some use solid fuel prepared from waste plastics and other combustible wastes while others involve placing the waste plastics into conversion equipment without pelletization.

Some applications in the steel, lime and cement manufacturing industries are as follows:

In the steel industry, some countries commercially treat waste plastics in blast furnace and coke ovens. Pioneering work has been done in the area of blast furnace treatment in the UK and Germany³. Currently, some steel manufacturers adopt similar treatment methods⁴. The key aspects of the technology are the preparation of the waste plastics pellets at a constant quality and subsequent injection of the pellets into a blast furnace. Contamination by chlorine-containing plastics and some other materials is prohibited in order to prevent any adverse effects to the steel quality.

Lime is used for steel production and solid fuel from waste plastics is used as fuel in lime kilns. Preparation of solid fuel (RPF) with a heating value of 8000 kcal/kg and a method for injecting it into a kiln have been developed and commercially utilized in Japan.

In cement production, shredded waste plastics are injected into a cement kiln for use as fuel. Chlorine-containing plastics should be removed prior to the injection so as to maintain cement quality⁵.

In all the lime, cement and steel production processes, the dechlorination of chlorine-containing mixed plastics is an essential pretreatment process. In some cases this pretreatment is carried out using an extruder or screw-type equipment at about 350 °C.

For specific types of plastics, compaction and volume reduction can also be important. Volume reduction of expanded polystyrene is performed by thermal melting or by a solvent dissolution method. The resulting ingot is a raw material for recycled resin production. Such pretreatment technologies contribute to the reduction of transport costs and improvement of processing efficiency by increasing the feeding rate. Similarly, granulation of plastics such as films

³ For Review, A. Tukker, Plastic Wastes – Feedstock Recycling, Chemical Recycling and Incineration, vol. 13 (4), p. 9, Smithers Rapra publications, 2002.

⁴ Y. Ogaki, K. Tomioka, A. Watanabe, K. Arita, I. Kuriyama, T. Sugayoshi, NKK Technical Review, No. 84, p.1 (2001); http://www.jfe-steel.co.jp/archives/en/nkk_giho/84/pdf/84_01.pdf

⁵ For Review, A. Tukker, Plastic Wastes – Feedstock Recycling, Chemical Recycling and Incineration, vol. 13 (4), p. 20, Smithers Rapra publications, 2002.

and bags using a granulator can be an essential tool to improve transport efficiency, feeding to equipment and processing.

Coke oven treatment was developed by a Japanese steel manufacturer⁶. Agglomerated plastics are charged into cokes ovens together with coal at around 1 %, resulting in the formation of gaseous products and other chemicals under pyrolytic conditions. These products are used within steel works or by chemical companies. Similar to blast furnace treatment, chlorine-containing plastics are not allowed into the mix. Under actual operation, the agglomerate charged into the coke oven contains about 3% chlorine but, unlike in blast furnaces, the amines from the coal seem to neutralize the hydrogen chloride released from waste plastics without affecting the coke quality.

Heat recovery using municipal waste incinerators is also a valuable option for the users who require heat supply. In this case, the waste in its original form, or crushed, is introduced in an incinerator or a boiler aiming to obtain the heat of combustion of such waste as a form of steam or hot water. It must be highlighted that this is a non-storable heat source and therefore the supply of such hot water or steam is to be for the industry itself or to nearby users.

This technology requires a large stock yard for the bulkiness of the waste and attention to potential fires and odor issues due to the stock of waste should be paid. Operation schedule should also be carefully planned due to the fluctuations of the waste generation, their calorific value and to match the heat demand of the users with the supply hours to the users.

Additionally, due to the variety of feedstock that can be used, flue gas quality should be controlled and incineration ash should be well managed.

⁶ K. Kato, S. Nomura, K. Fukuda, H. Uematsu, H. Kondoh, Nippon Steel Technical Report, No. 94, p. 75 (2006); <http://www.nsc.co.jp/en/tech/report/pdf/n9413.pdf>

Part II - Technology Examples

7. Solid Fuel Production Examples

7.1 Earthtechnica's commercial plant for solid fuel production

Main features	
Feed	Combustible waste including plastics, wood, and paper
Processes	Separation and pelletization
Main equipment	Sorter, separator, shredder and ring-die pelletizer
Special features	Continuous feeding
Main product	Solid fuel

Technical description

1. Outline of our solid fuel production facility

- 1) Solid fuel is produced from waste plastics, used paper and waste wood as substitutes for coal and heavy oil. This system effectively converts waste plastics of low specific gravities such as films and sheets into solid fuel which is suitable for various solid fuel boilers. It contributes to the conservation of resources and reduction of CO₂ emissions.
- 2) This system has newly-designed pretreatment equipment which enables effective separation of PVCs, metals and other substances which are unsuitable in solid fuels.
- 3) Combustion heat can be controlled by varying the ratio of plastics to paper and wood.
- 4) Solid fuel can be produced with the dimensions of 6 – 20 mm diameter x 10 – 40 mm length.
- 5) Our system is the most popular solid fuel production system in Japan. In 2000 we received the Nikkei Superior Products and Services Award.

2. Typical features of the solid fuel production facility

- 1) The "GULIVER" and "MULTIROTOR" primary and secondary crushers have large hoppers which are suitable for feeding bulky feedstock. Soft plastics, paper and wood are effectively crushed. The crusher structures are well designed for easy maintenance.
- 2) The "AIRJET SEPARATOR," high-performance air separator removes heavy impurities such as iron fragments, and contributes to the stable operation of the facility.
- 3) The "MULTI SORTER" plastic separator detects PVCs and PVDCs and lowers the chlorine content of the feedstock.
- 4) The "MULTI PRESS" pelletizer does not require any external heating because pellets are

prepared using frictional heat inside the ring-die.

- 5) This production system is equipped with a pellet cooler which cools the solid fuel to room temperature using air.

Table 7.1 summarizes the technical descriptions of the solid fuel production facilities.

Table 7.1: Solid fuel production facility specifications

Type	Treatment capacity (tons/hour)	Installation area (W x L x H) (m)
RP050	0.5	7 × 23 × 8
RP100	1.0	7 × 24 × 8
RP200	2.0	8 × 30 × 10
RP400	4.0	8 × 40 × 10
RP500	5.0	10 × 45 × 12

Ref. Technical brochure by Earthtechnica.

Supplier: Earthtechnica Co., Ltd., Japan

<http://www.earthtechnica.co.jp/>

<http://www.earthtechnica.co.jp/english/> (Website in Japanese and English)

7.2 Fujitex's commercial plant for solid fuel production

Main features	
Feed	Combustible wastes including plastics, wood and paper
Processes	Separation and pelletization
Main equipment	Sorter, separator, shredder and ring-die pelletizer
Special features	Continuous feeding
Main product	Solid fuel

Ref. Technical brochure by Fujitex.

Technical description

Fujitex supplies solid fuel production systems with a treatment capacity ranging from 200 to 1500 kg/h. The specifications of a typical system are shown in Table 7.2.

Table 7.2: Specification of EF-500-15

Type	EF-500-15
Pelletizer	Flat die (55kW)
Size of solid fuel (mm)	D15 × L50
Shredder	Single rotor (55kW) Rotor size: D400×L1500 mm
Dimensions	9000 L × 2350 W
Power consumption (kW)	130.32 kW

(Copyright Fujitex)

Supplier: Fujitex Co., Ltd., Japan

http://www.fjtex.co.jp/profile/new_products.html (in English)

<http://www.fjtex.co.jp/kankyo/12other/rpf.html> (in Japanese: includes video of solid fuel production)

8. Liquid Fuel Production Examples

8.1 Environment System's commercial plant for liquid fuel production

Main features	
Feed	Thermoplastics waste (excluding chlorine-containing plastics)
Processes	Pyrolysis
Main equipment	Tank reactor
Special features	Continuous feeding of scrap film by using an extruder.
Main product	Hydrocarbon oil

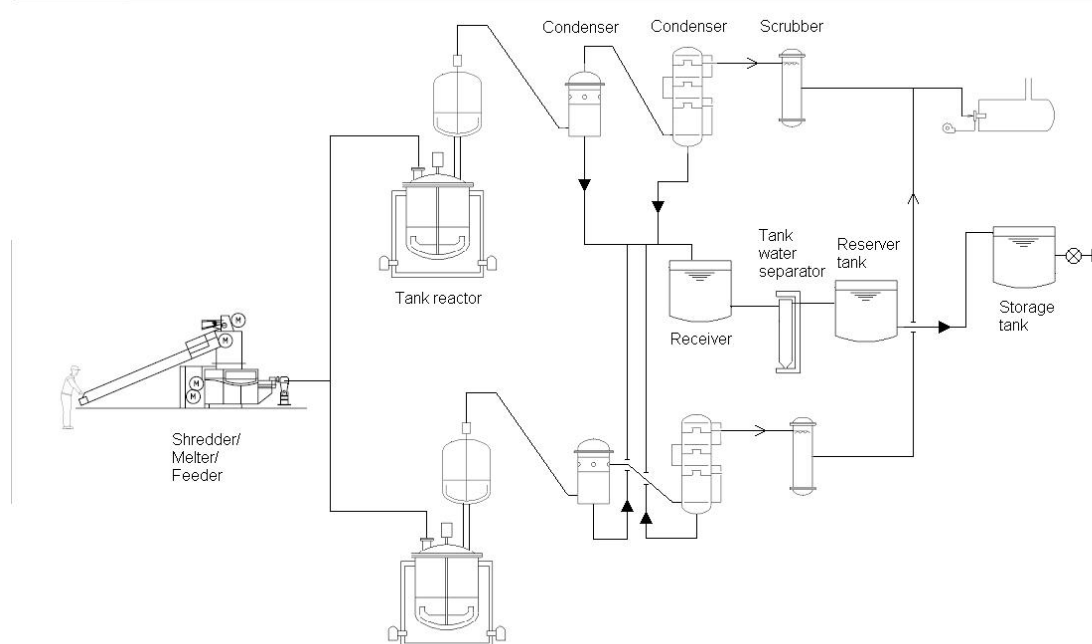
Image of a typical commercial plant



Figure 8.1: Fuel Oil Production Plant at a packaging manufacturer in Gunma Prefecture.

Technical description

A schematic diagram of a typical plant is shown in Figure 8.2.



(Copyright Environment Technology)

Figure 8.2: Schematic diagram of a typical plant

A standard specification is shown in Table 8.1.

Table 8.1: Specification of oil production plant

Type	ES-1000	ES-1500
Treatment method	Batch	Batch
Tank volume	1.0 m ³	3.3 m ³
Treatment capacity (Bulk specific weight of sample; 300 kg/m ³)	300 kg/batch	1000 kg/batch
Oil yield	300 L (ca 80 wt%)	1000 L (ca 80 wt%)
Utility	3-Phase 200V, 15 kW Nitrogen gas, water	3-Phase 200V, 25 kW Nitrogen gas, water
Weight	Ca 15 ton	Ca 26 ton
Material	SUS310S/SUS304/SUS316/SS	

Ref. Technical brochure by Environment Technology.

Supplier: Shonan Trading Co., Ltd., Japan

<http://www.shonantrading.com/machine/?id=1227664212-334647> (Website in Japanese)

Manufacturer Environment System Co.,Ltd., Japan

8.2 Mogami Kiko's commercial plant for liquid fuel production

Main features	
Feed	Thermoplastics waste
Processes	Pyrolysis
Main equipment	Tank reactor
Special features	Batch operation Dehydrochlorination process
Main product	Hydrocarbon oil

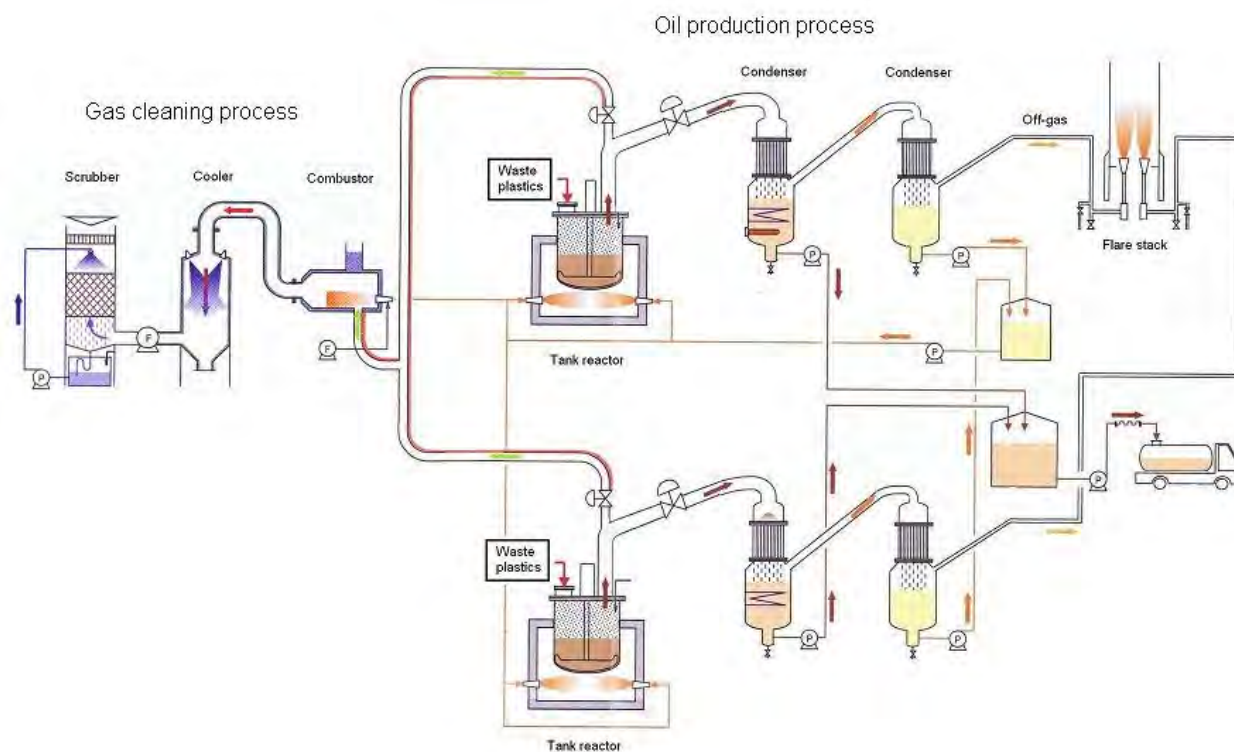
Image of a typical commercial plant



Figure 8.3: Fuel Oil Production Plant in Yamagata Prefecture

Technical description

Figure 8.4 shows a flow diagram of the fuel production plant at Mogami-Kiko Co., Ltd. in Yamagata Prefecture. Two tank reactors are installed. Upon primary thermal treatment of waste plastics containing PVC at 400 °C, hydrogen chloride is released into a combustor followed by an absorber. After the primary treatment, the reactor temperature is raised to 500 °C and thermal decomposition is performed for 12 to 15 hours. After cooling, the decomposition residue is removed with a vacuum cleaner.



(Copyright Mogami-Kiko)

Figure 8.4: Schematic diagram of a fuel production plant in Yamagata Prefecture

Two tank reactors are installed at Mogami Kiko’s facility. Mixed plastic containers and packaging from household waste are thermally decomposed to produce 50 to 90 wt% of hydrocarbon oil. When using mixed plastics of bulk density 300 kg/m³, the performance is 1.5 t per day per reactor. Typical results are shown in Table 8.2.

Table 8.2: Typical results of mixed plastics pyrolysis*

	Component	Amount: kg (Yield: wt%)
Feed	Used mulching film (PE)	205
	Used flexible container (PP)	410
Product	Hydrocarbon oil	484 (79)
	Solid residue	88 (14)
	Off-gas	43 (12)

*Yield of individual products will vary depending on composition of waste plastics
Ref. Technical brochure by Mogami-Kiko.

A standard specification is shown in Table 8.3.

Table 8.3: Specification of fuel production plant

Type of feedstock	Thermoplastics contaminated with PVC and PET
Feeding method	Charging waste plastics in a flexible container
Removal of pyrolysis residue	Vacuum cleaner
Operating mode	1 batch/day.
Performance	See Table 8.2
Typical facility configuration	Two 5.6-m ³ tank reactors (effective volume about 5.0 m ³)
Fuel for pyrolysis	Waste plastics-derived oil
Installation	Indoor Flare stack and chlorine treatment equipment are installed in outdoors.

Ref. Technical brochure by Mogami-Kiko

Supplier: Mogami-kiko Co., Ltd., Japan

<http://www.mogami-kiko.co.jp> (Website in Japanese)

8.3 MCC's commercial plant for liquid fuel production

Main features	
Feed	Thermoplastics waste (excluding chlorine-containing plastics)
Processes	Pyrolysis
Main equipment	Tank reactor
Special features	Induction heating for pyrolysis
Main product	Hydrocarbon oil

Image of a typical commercial plant

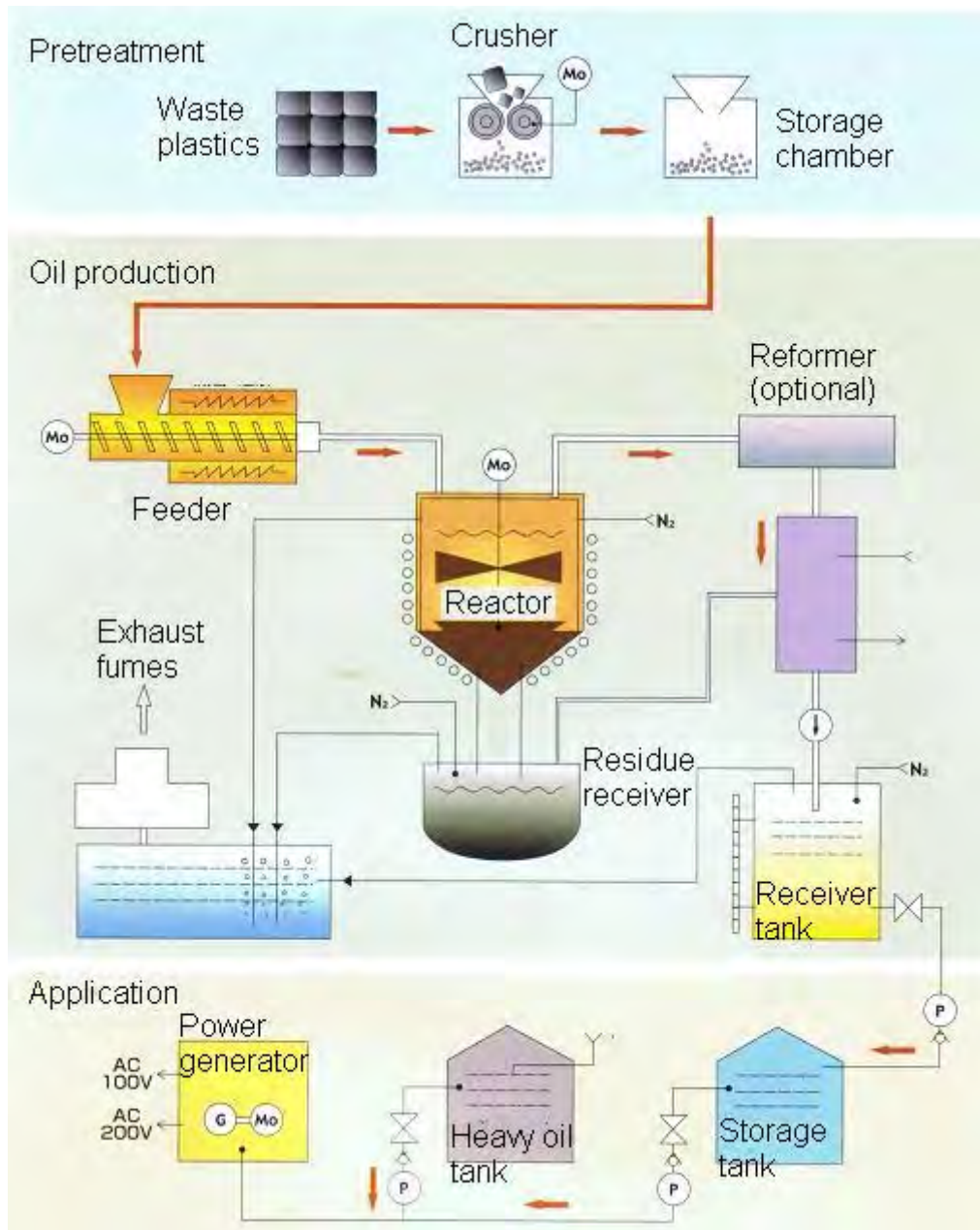


(Copyright MCC)

Figure 8.5: Fuel Oil Production Plant YUKAKI MYF125

Technical description

System flow is shown in Figure 8.6.



(Copyright MCC)

Figure 8.6: Schematic diagram of fuel oil production system

Batch (B) and continuous (C) operation is equipment with a capacity of 30 (B), 50 (C), 100 (C), and 200 (C) kg/h is available.

Supplier: MCC Co., Ltd., Japan

<http://www.janis.or.jp/users/totalmcc/new1.htm>

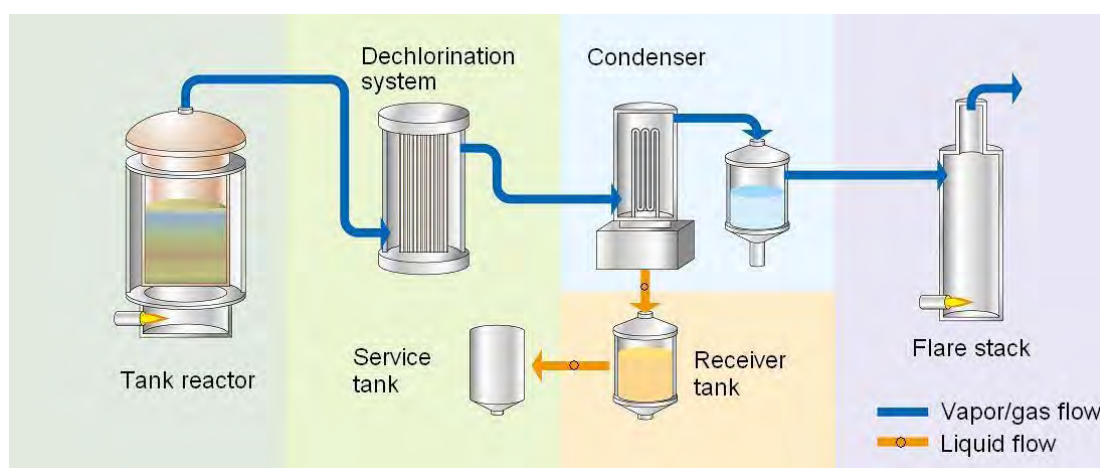
(Website in Japanese)

8.4 Altis's commercial plant for liquid fuel production

Main features	
Feed	Mainly mixed plastics; current commercial operation is for medical waste
Processes	Pyrolysis
Main equipment	Tank reactor
Special features	Removable inner reactor vessel
Main product	Hydrocarbon oil

Technical description

A schematic diagram of a typical plant is shown in Figure 8.7.



(Copyright Altis)

Figure 8.7: Schematic diagram of a plant for medical wastes

Upon pyrolyzing chlorine-containing plastics, hydrocarbons and hydrogen chloride are formed. After removal of hydrogen chloride in a dechlorination system, volatilized hydrocarbons are condensed with a condenser. The resulting liquid hydrocarbons are stored in a service tank for use. Gaseous components are incinerated in a flare stack to yield a flue gas without hydrocarbon contamination.

Supplier: Altis Co., Ltd., Japan

<http://www.Altis.ne.jp> (Website in Japanese)

8.5 Kankyo Technology's commercial plant for liquid fuel production

Main features	
Feed	Thermoplastics waste (excluding chlorine-containing plastics)
Processes	Pyrolysis
Main equipment	Tank reactor
Special features	Continuous feeding
Main product	Hydrocarbon oil

Technical description

The PLALIS-600 tank reactor has a 6.15 m³ capacity. Performance is dependent upon bulk specific weight as shown in Table 8.4. Fuel consumption is reported as 0.25 L (0.2 kg) per 1-kg feed.

Table 8.4: Performance of the PLALIS-600 reactor

Bulk specific weight (g/cm ³)	0.2	0.5
Feeding weight per day (kg)	1110	2770
Oil yield in kg (L)	887 (1108)	2217 (2771)
Fuel consumption in kg (L)	222 (277)	554 (693)
Net oil yield in kg (L)	666 (833)	1662 (2077)

Typical oil yield is 80 wt%. Specific gravity of the oil is 0.8 g/cm³.

A standard specification is shown in Table 8.5.

Table 8.5: Specification of PLALIS-600

Type of feedstock	Thermoplastics excluding those without hydrocarbon oil. Halogen contamination is not allowed.
Feeding method	Charging of waste plastics in a flexible container or using a feeder
Removal of pyrolysis residue	Vacuum cleaner
Operation pattern	1 batch/day. Operation period is within 12 h.
Performance	See Table 8.4
Dimension	W 8.5m x L 11m x H 7.5m
Total weight of facility	35 tons
Equipment materials	SUS310S, SUS316, SUS304, SS, Copper
Fuel for pyrolysis	Waste plastics-derived oil
Fuel consumption	30 to 60 L/h
Utilities	Electricity (100 and 200V), nitrogen gas, fuel gas, sodium hydroxide & water
Installation	Indoor

Supplier: Kankyo Technology Co., Ltd., Japan

<http://www.kankyotec.com>

(Website in Japanese; plant brochure available in English, Korean & Chinese)

9. Liquid and Gaseous Fuel Production Examples

9.1 Toshiba's commercial plant for liquid and gaseous fuel production

Main features	
Feed	Thermoplastics waste and/or biomass (excluding chlorine-containing plastics)
Processes	Pyrolysis
Main equipment	Rotary kiln with external heating
Special features	Continuous feeding
Main product	Liquid and gaseous hydrocarbon

Image of a typical commercial facility

A typical commercial oil production facility is currently operating in Sapporo, Japan (Figure 9.1).



(Copyright Altis)

Figure 9.1: Oil production facility for separated plastics from municipal waste

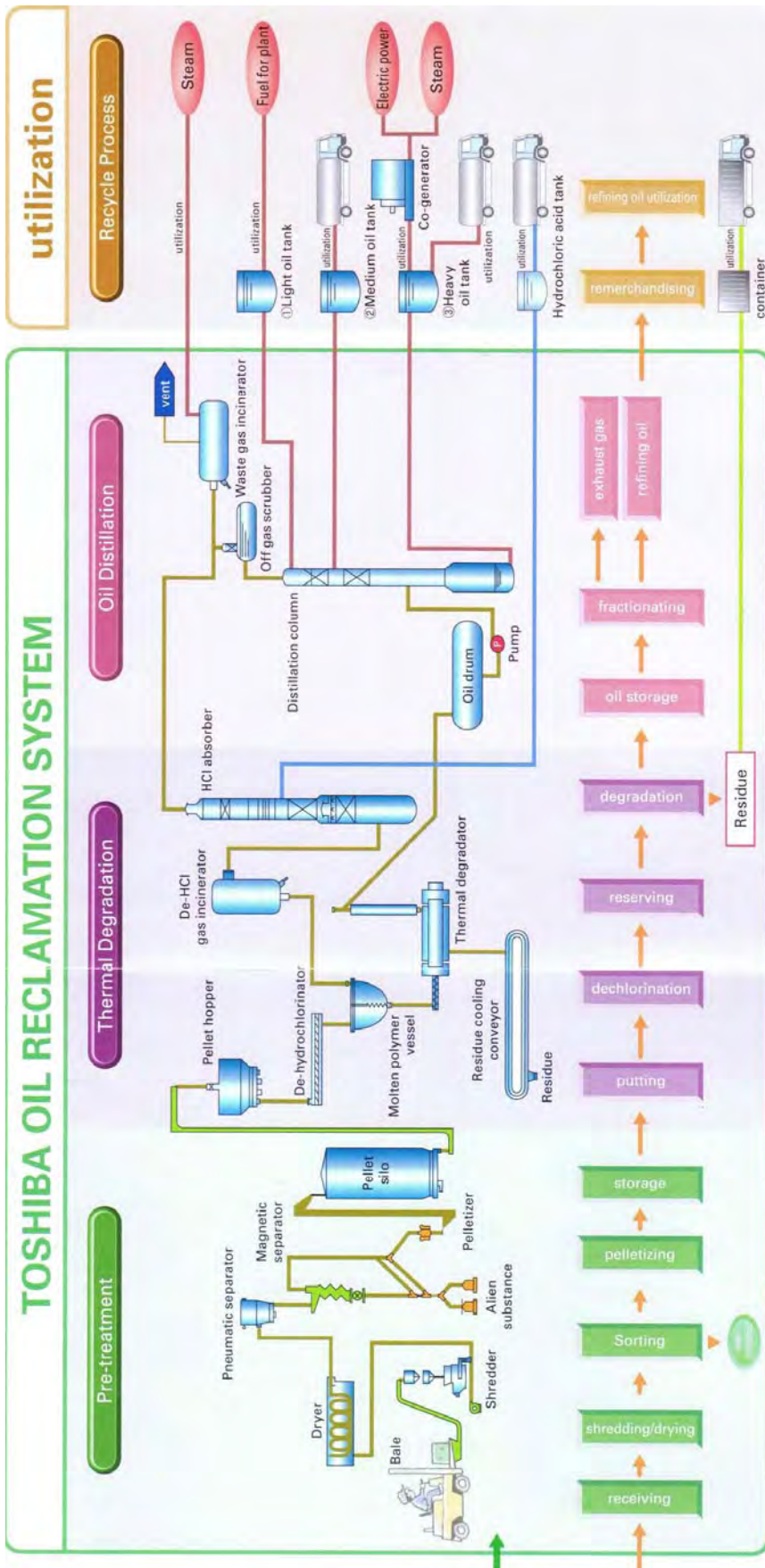
Technical description

Process characteristics

- Treatment of municipal waste plastics containing PVCs.
- Catalyst-free process
- Easy operation & maintenance due to atmospheric pressure process
- Energy recovery use of product oil, waste gas and residue
- Chlorine recovery in PVC as 20 wt.% hydrochloric acid
- Product oil usage for furnaces in plant as well as co-generator as fuel
- Fewer emissions into the air and water
- Full automatic operation using computer-controlled system

Plant site:	Total area	15,000 m ²
	Constructed area	7,324 m ²
Plant capacity:	Pre-treatment	43.5 tons/day as bale (21.75 t/d x 2 lines)
	Thermal degradation	40 tons/day as pellets (20 t/d x 2 lines)
	Co-generation	4,000kW (2,000 kW x 2 lines)

Figure 9.2 shows a schematic flow of a fuel production process by Toshiba.



Copyright Toshiba

Figure 9.2: Schematic flow of fuel production process by Toshiba

Supplier: Toshiba Corporation Social Infrastructure Systems Company, Japan

http://www3.toshiba.co.jp/snis/ovs/index_e.htm (Website in English)

9.2 Ostrand's commercial plant for liquid and gaseous fuel production

Main features	
Feed	<ol style="list-style-type: none">1. All plastics (thermoplastics, thermosetting, halogen-containing)2. Plastics contained with biomass, metal, asbestos, bacteria etc.3. Biomass
Processes	Pyrolysis
Main equipment	Rotary kiln designed with screen solid circulation.
Special features	Continuous operation & rapid heating by internal circulating of solids. External or internal heating by heating medium.
Main product	Liquid and gaseous hydrocarbons

Image of a typical commercial plant

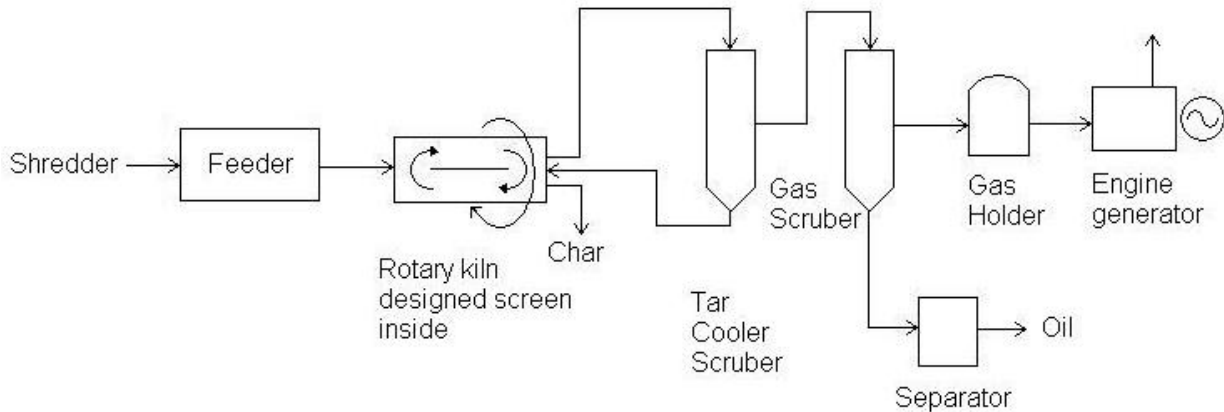


(Copyright Ostrand)

Figure 9.3: Gasification Plant in Iwaki City

Technical description

As shown in Figure 9.4, our system of thermal treatment for organic waste consists of a hopper, feeder, rotary kiln, condenser, gas refiner, oil (gas) storage tank and dual fuel engine generator.



(Copyright Ostrand)

Figure 9.4: Schematic diagram of a typical plant

Specification of pyrolysis plant

Treatment capacity	200 kg/h
	Mixture of plastics (30.7%), biomass (60.8%) and others (8.5%)
	Bulk density 500 kg/m ³
Dimensions	Inner vessel 1000 mm outer diameter x 3540 mm length
	Outer vessel 1382 mm outer diameter x 2600 mm length
Inner vessel	Equipped with solid circulation system installed.
Feed	Screw feeder 200 mm outer diameter x 1300 mm length
	Water-cooled; nitrogen-gas sealed
Outlet	Char: double dumper
	Gaseous products: fed to a scrubber
Utility	Power: 5.7 kWh/h
	Nitrogen gas: 20 Nm ³ /h for sealing at dumper and screw feeder
	Chilled water: 50 L/h
Performance of pyrogas production	
Gaseous products	80 – 100 Nm ³ /h; 5000 – 6000 kcal/Nm ³
Tar	30 – 40 kg/h
Char	20 – 30 kg/h

Typical operating results based on a pilot plant

Mixed plastics and municipal waste were pyrolyzed at the pilot plant shown in Figure 9.5. The components of mixed plastics used as feedstock and the typical operating results are shown in Tables 9.1 and 9.2 respectively. Operating conditions included a temperature of 700°C and feeding rate of 20 kg plastics/h.



(Copyright Ostrand)

Figure 9.5: Pyrolysis gasification pilot plant

1. Operation #1, Mixed plastics (Higher heating value 9519kcal/kg-dry base)

Here an example of gasification using mixed plastics is described. The characteristics of a feed are summarized in Tables 9.1 and 9.2. Table 9.3 shows a typical result of gasification of the feed.

Table 9.1: Content of three elements of mixed plastics

	Moisture	Ash	Combustibles	Total
Yield (wt%)	1.04	2.19	96.77	100

Table 9.2: Element of Combustibles (Dry base)

Ash	Combustibles	Elemental analysis						Total
		C	H	N	O	S	Ce	
2.21	97.79	73.8	12.9	1.11	9.86	0.03	0.09	100

Table 9.3: Output: Gas, oil & char (by pilot plant 20kg/hr)

	Yield (wt%)	Remarks
Gas	87.9	Heating value: 10.630kcal/Nm ³
Heavy tar	5.8	Boiling temp: >150°C
Light tar	4.6(3.3*)	Boiling temp: 150-50°C
Char	1.7	
Total	100.0	

*water content

2. Operation #2, Municipal waste

Typical examples of gasification of a sample of municipal waste are described here.

Table 9.4: Contents of municipal solid waste (original sample)*

	Water	Ash	Combustible	Total
Yield (wt%)	45.8	5.6	48.6	100

*Higher heating value 2,790 kcal/kg-wet base; 5,148 kcal/kg-dry base

Table 9.5: Contents of municipal solid waste prepared as RPF (dried sample)*

	Water	Ash	Combustible	Total
Yield (wt%)	2.9	13.1	83.9	100

*Higher heating value 4,777 kcal/kg-dry base

Table 9.6: Elemental composition*

Analytical results of six elements (wt%)						Subtotal	Other	Total
C	H	N	O	S	Cl			
44.7	6.7	0.9	31.9	0.0	2.6	86.9	13.1	100

*High heating value: 4,777 kcal/kg-dry base

Table 9.7: Output: Gas, Oil, Char (by pilot plant 20kg/hr)

	Yield (wt%)	Remarks
Gas	52.5	5,679kcal/Nm ³
Heavy tar	2.8	
Light tar	29.1(14.9*)	
Char	15.6	Organic: 3.3; Inorg: 12.3
Total	100	

*Water content

Supplier: Ostrand Corporation, Japan

e-mail: hatta@ostrand.co.jp

<http://www.ostrand.co.jp/index.html>

http://www.ostrand.co.jp/newtech_01.html

(Website in Japanese)

Annexure 1: List of Technology Providers

A list of plant manufacturers and consultants is provided below. Note that some companies may have limited ability to communicate with overseas customers without the assistance of experienced trading companies and may have changed their products from those currently advertised on the internet or ceased to sell waste plastic conversion technologies for business reasons.

Some companies supply smaller equipment for thermal decomposition of waste plastics with a capacity of less than 100kg/h. However, waste plastic conversion using these micro-reactors requires special business and economic feasibility considerations.

Solid, liquid and gaseous fuel production system technology providers

Technology	Company, URL and Contact
Solid fuel (RPF)	Earthtechnica Co., Ltd., Japan http://www.earthtechnica.co.jp/ http://www.earthtechnica.co.jp/english/ (website in Japanese and English)
Solid fuel (RPF)	Fujitex Co., Ltd., Japan http://www.fjtex.co.jp/profile/new_products.html (in English) http://www.fjtex.co.jp/kankyo/12other/rpf.html (in Japanese with access to video of solid fuel production)
Solid fuel (RPF)	Kyokuto Kaihatsu Kogyo Co.,Ltd. (Jpn) http://www.gec.jp/JSIM_DATA/WASTE/WASTE_2/html/Doc_397.html http://www.kyokuto.com/product/kankyo/sisetu/sisetu_05.shtml Contact http://www.kyokuto.com/cgi/form_en.cgi
Solid fuel (RDF)	O.Kay Engineering Services Limited (UK) http://www.okay.co.uk/okay/index.htm Contact postbox@okay.co.uk http://www.okay.co.uk/okay/contact_main.htm
Solid fuel (RDF)	Mayo Vessels & Machines (India) http://www.mayovessels.com/technology.html Contact response@mayovessels.com http://www.mayovessels.com/contact_us.html
Solid fuel (RDF)	eFACTOR3 (USA) http://www.efactor3.com/products.php Contact hbendfeldt@efactor3.com http://www.efactor3.com/contact.php
Solid fuel (RDF)	Visno (Netherland) http://www.visno.nl/pages%20UK1.1/refuse_derived_fuel_uk_a.htm Contact info@visno.nl http://www.visno.nl/pages%20UK1.1/addresses_uk_a.htm

Liquid fuel	Kankyo Technology Co., Ltd., Japan http://www.kankyotec.com (website in Japanese; brochures in English, Korean, Chinese available for plants)
Liquid fuel	Dealer: Mogami-kiko Co., Ltd., Japan http://www.mogami-kiko.co.jp (website in Japanese) http://www.mitumine-kk.co.jp (website in Japanese)
Liquid fuel	Dealer: Shonan Trading Co., Ltd., Japan Manufacturer: Environment System Co.,Ltd., Japan* http://www.shonantrading.com/machine/?id=1227664212-334647 (website in Japanese)
Liquid fuel	MCC Co., Ltd., Japan http://www.janis.or.jp/users/totalmcc/new1.htm (website in Japanese)
Liquid fuel (Dry distillation of medical wastes)	Syo • A Co., Ltd., Japan http://www.cpri.co.jp/index.html (Web in Japanese) http://www.cpri.co.jp/English%20ver/E_Hospital%20waste_top.html (Web in English) http://www.cpri.co.jp/VIDEO_1E.html (Video presentation about the plant in English)
Liquid fuel (Dry distillation of medical wastes)	Altis Co., Ltd., Japan http://www.Altis.ne.jp (website in Japanese)
Liquid fuel	Splainex Ecosystems Ltd (Netherland) http://www.splainex.com/waste_recycling.htm Contact page http://www.splainex.com/contact_en.htm
Liquid fuel	Northern Technologies International Corporation (USA) http://www.polymerenergy.com/ Contact page http://www.polymerenergy.com/contact
Liquid fuel	Gossler Envitec GmbH (Germany) http://www.gossler-envitec.de/index.html http://www.gossler-envitec.de/GEN_Flyer_EN_03-11-2008-B.pdf Contact envitec@gossler.de
Liquid fuel	Alphakat GmbH (Germany) http://alphakat.de/index.php?option=com_content&task=blogcategory&id=37&Itemid=63 Contact mail@alphakat.de
Liquid fuel	Changing World Technologies, Inc. (USA) http://www.changingworldtech.com/
Liquid fuel	TA Technology (China) http://tyrerecyclemachine.com/ Contact jamesng2020@hotmail.com
Liquid and gaseous fuel	Toshiba Corporation, Social Infrastructure Systems Company, Japan http://www3.toshiba.co.jp/snis/ovs/index_e.htm (website in English)
Liquid and gaseous fuel	Ostrand Corporation, Japan http://www.ostrand.co.jp/index.html http://www.ostrand.co.jp/newtech_01.html (website in Japanese) Contact hatta@ostrand.co.jp

About the UNEP Division of Technology, Industry and Economics

The UNEP Division of Technology, Industry and Economics (DTIE) helps governments, local authorities and decision-makers in business and industry to develop and implement policies and practices focusing on sustainable development.

The Division works to promote:

- > sustainable consumption and production,
- > the efficient use of renewable energy,
- > adequate management of chemicals,
- > the integration of environmental costs in development policies.

The Office of the Director, located in Paris, coordinates activities through:

- > **The International Environmental Technology Centre** - IETC (Osaka, Shiga), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.
- > **Sustainable Consumption and Production** (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.
- > **Chemicals** (Geneva), which catalyzes global actions to bring about the sound management of chemicals and the improvement of chemical safety worldwide.
- > **Energy** (Paris), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
- > **OzonAction** (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
- > **Economics and Trade** (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies.

*UNEP DTIE activities focus on raising awareness,
improving the transfer of knowledge and information,
fostering technological cooperation and partnerships, and
implementing international conventions and agreements.*

For more information,
see **www.unep.fr**

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The world's annual consumption of plastic materials has increased from around 5 million tonnes in the 1950s to nearly 100 million tonnes; thus, 20 times more plastic is produced today than 50 years ago. Plastic waste recycling is one of the most established recycling activities in economically developed countries. In most of the situations, recycling of waste plastics is becoming viable in developing countries as well, as it generates resources and provides jobs. The recycling of waste plastics also has a great potential for resource conservation and GHG emissions reduction, such as producing diesel fuel from plastic waste. As raw materials, wastes plastics have attractive potentials for large-scale industries and community-level enterprises. For efficient and effective conversion of waste plastics into a resource, appropriate selection of technologies is one of the vital pre-conditions. This compendium is compiled to assist in the selection process for those technologies. The geographical scope of the compendium is global. Thus, technologies listed range from highly sophisticated equipment from industrialized countries to simple technologies from the developing countries. Technologies listed in the Compendium are limited to the information which could be generated within available time and budget.