Plastics Technical Briefing Note

Stand Alone Facilities for the
Conversion of Waste Plastics to Diesel Fuel

Remade Scotland

Technical Briefing Note – Stand Alone Facilities for the Conversion of Waste Plastics to Diesel Fuel

It is a commonly held view that it is desirable to recycle plastics found in domestic waste. There are many studies that assess the environmental and economic merits though it is beyond the scope of this document to review these. In brief, they are founded on determining the environmental and economic costs of conducting the complete recycling activity (over and above those encountered from other disposal routes) with the environmental and economic benefits that result.

It is apparent from this that if significant effort and expense is necessary to prepare and clean plastics so that they are in a fit condition to enter a recycling process, this can cancel out some or all of the economic and environmental benefits that would otherwise result. It is important therefore to match the recycling method with the condition and composition of the material received.

Commonly, PET (beverage) bottles and HDPE (milk) bottles are collected for recycling. These materials can be granulated, cleaned and remelted in preparation for conversion to other products.

PET bottles can be used to make a polyester fibre used for insulation (in clothing, building and automotive applications) or melted to form pellets that may be used to make other PET products. HDPE may be used to make a variety of plastic mouldings and films – the granulate from recycling may compete with some virgin HDPE material applications. Such approaches to plastic recycling are known as mechanical recycling.

For hygiene and public health reasons many consider it inappropriate to convert these materials directly back to packaging materials for food contact.

Even with the infrastructure at municipal recycling schemes targeting these bottle materials there is still significant plastic content left in the waste stream for disposal. This occurs for two reasons, firstly, there are many other plastic types and forms in the waste stream and secondly, not all of the target materials are recovered because, for example, they have not been placed into the recycling container or because they were too contaminated to be selected at sorting facilities.

There are two other broad categories of process that can be used to recycle plastics (excluding disposal methods with some recovery element such as incineration with heat recovery[1]) namely chemical recycling and feedstock recycling.

The basic explanations of these methods are presented in Box 1 below.

In addition to domestic waste sources of plastics there are others available. Commercial and industrial materials are considered for recycling as a matter of course because there is often economic justification for doing so. There are also sources that are not such attractive propositions for any recycling processes that require well prepared materials, as are, for example, waste agricultural plastics.

The use of polymer films for agricultural applications is growing steadily and destinations for post use material other than landfill or incineration are being sought.

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[1] Most waste incinerator feeds are a mixture; and much of the chemical energy content of combustible materials such as plastic can be wasted in driving off the water content and elevating the temperature of non combustible content when present. However, this can be different where refuse derived fuel is manufactured from plastics (and other combustible waste materials).

The above discussion is presented to introduce the context within which some specific feedstock recycling processes have been studied recently to update the stage of their development and value in the Scottish recycling infrastructure. This brief/bulletin focuses on a particular set of recycling techniques that can convert a range of polymer materials to fuel.

Agricultural plastics are a focus because of the relatively high levels of contamination that are likely to be encountered. If a facility were provided for this waste stream it would also be capable of accepting a fraction of the domestic waste stream not captured by the more conventional recycling supply chain.

Box 1 - Methods for Recycling Plastics

Mechanical Recycling – This is the most widespread method for plastic recycling where the material is processed to form a new product without any change in chemical composition. It usually targets only the cleaner, more readily identifiable and separable materials of restricted composition. The economics of the process are well understood. Packaging to packaging recycling can be problematic especially where food contact is involved. Normally plastics are recycled by type but there are some mixed plastic recycling routes – in such cases an acceptable blend of polymers is necessary.

The most commonly targeted materials are polyethylene (PE as HDPE and LDPE, with tolerance for polypropylene) and polyethylene terephthalate (PET).

Chemical Recycling – These processes take waste plastics and break them down into the basic building blocks required to reproduce the original material. Generally this approach is found to be more costly than production from the original raw materials but advances are being made. This type of process has the capability of solving the packaging to packaging dilemma. It is a material specific method – a separate process is required for each broad type of polymer. Sometimes additives used in the manufacture of the finished product can influence the performance of this approach. The polymer supplied needs to be clean and well prepared.

A number of materials have been the subject for chemical recycling process developments including polystyrene, PET, nylon and polyurethane

Feedstock Recycling – Material produced from the waste plastic is usually different from the original building blocks. A portion or all of the material produced may be some type of fuel such as fuel oil, diesel, gas etc. There are restrictions on the mix of plastics that can be processed but it is normally more accommodating than both chemical and mechanical recycling. Some plastic preparation is required to achieve the mix and condition necessary.

The most common processes in this category apply to polyolefins, i.e. the polyethylene and polypropylene family of materials. They often show some tolerance to the presence of polystyrene and to a lesser degree PET.

Chemical recycling is a specific type of feedstock recycling.

See for example -
http://www.plasticsresource.com/s_plasticsresource/doc.asp?TRACKID=&CID=177&DID=490

The Processing of Waste Plastics to Produce Fuel

Feedstock Recycling

Feedstock recycling of plastics is a term that embraces a number of different process types. In essence, they involve reprocessing of the material into a valuable feedstock, the end use of which is not necessarily to produce the polymer from which it originates. The product may also be used to produce liquid fuel.

There are numerous processes for converting waste plastics into such feedstock. Commonly known examples operate at high volumes and generally would be integrated in existing petrochemical or other processing complexes (reference 1). These processes can sometimes become true chemical recycling systems when integrated with plastic manufacturing facilities. There are also examples of technologies that form smaller capacity stand-alone developments, under normal circumstances these will not have facilities for refining or for marketing a wide range of products and must aim to manufacture a narrow range of products that have high value or a ready local demand. The most common target feed material comprises polyolefins (see box) with some tolerance for the presence of other polymers.

Due to the nature of these materials the most convenient products with widespread and local market value are fuel for heating or transport. Examples of such lower scale technologies have been examined regarding their capability and outline commercial viability. They convert waste plastics into diesel fuel.

Suitable Plastics

There are many different plastic types and they have specific properties that influence their end uses when recycled and the means by which they can be reprocessed. Some processes can tolerate a certain amount of contamination by non-target plastics but a specification will always need to be met for successful operation. The feedstock recycling process used must be suitable for the types of plastic targeted.

The investigation was initiated to examine the viability of the processes in handling agricultural plastic waste. Although relatively high levels of contamination are often expected of such waste, the plastic types used for agricultural applications tend to conform to a conveniently suitable group. Contamination of the waste by non-plastic material can be removed, in principle, by a feed preparation stage.

Most agricultural plastics conform to the polyolefin group of polymers. Examples are the common materials high and low density polyethylene and polypropylene. The majority of films used will be made from polyethylene and ties and other cords frequently made from polypropylene. Most contamination from this source will be non-plastic, commonly stone and soil etc.

The example processes are suitable for polyolefins with some polystyrene. A small quantity of PET and nylon can be handled but is preferably excluded. PVC should be avoided due to its chlorine content with deleterious consequences to the equipment materials of construction and the quality of diesel that would be produced. The presence of small amounts has normally been considered by the technology developers and front end or in-process removal systems proposed.

Typical Processes

Commercial confidentiality prevents detailed revelation of the process details. However, the generic process can be described.

The waste plastic is prepared prior to supply to the process so as to remove as much contamination and non-target plastics as required. The material is fed in a dry state to a reactor where it is heated in the absence of oxygen. Above a certain temperature the chemical stability of the polymer is no longer maintained and the polymer chain begins to crack (cracking is a term applied to this phenomenon). The break up of the chain can be to a wide variety of fragment sizes meaning that a mixture of product chemicals results. Catalysts are used by some processes to tailor the resultant chemical species – that is, by confining the materials formed to a narrower range.

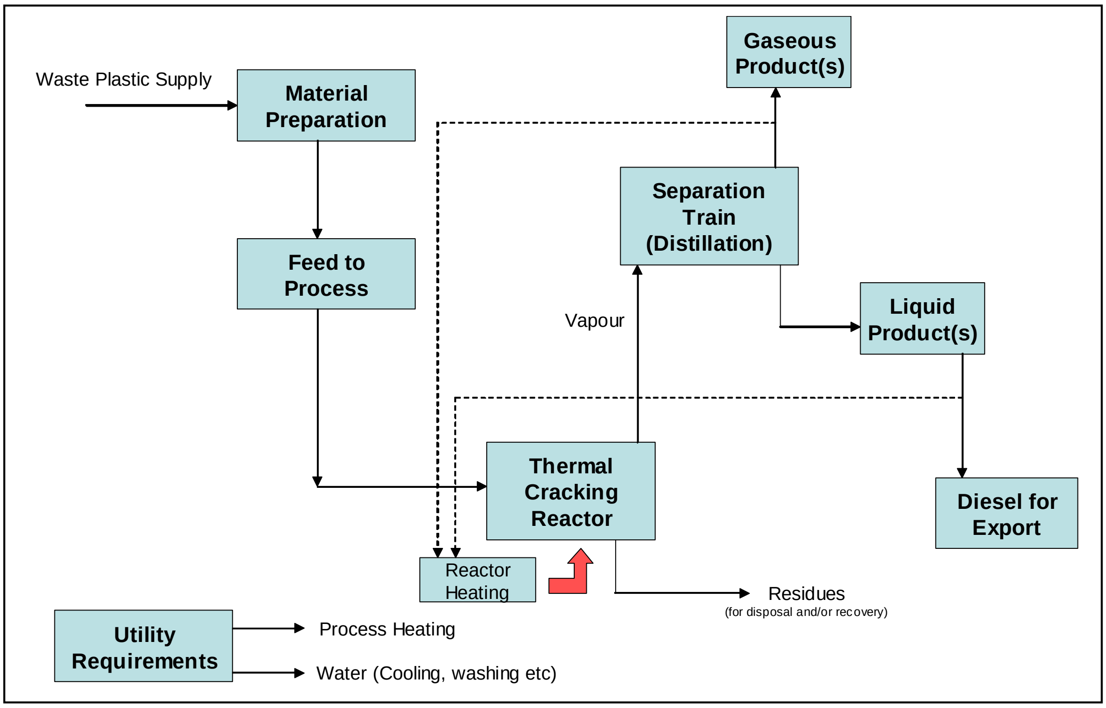
Even where catalysts are employed the conversion to desired product will not be complete. The more specific processes aiming at diesel production typically convert just over 80% of the incoming plastic to this fuel. The remainder of the product will be non-target materials such as lighter petroleum gases, gasoline etc. A residue is formed by material that cannot be converted to vapour. Materials not found in the product stream will comprise other process residues including fillers used in the original plastics and any contamination that entered with the feedstock. Disposal of this will be necessary but it will be a small fraction of the original plastic waste.

Due to the thermal nature of the method, process heat is required for the initial cracking stage and for the separation of products - this can be provided directly from the products and by-products.

The equipment required for each system is suitable for exploitation on a small scale with moderate inventories of raw material and diesel product. There are examples of exploitation that indicate their technical viability.

Figure 1 illustrates a typical process; a description of each process stage is presented below.

Figure 1 – Typical Process Arrangement



Material preparation – In some cases material may be received that is of a composition and in a form suitable for direct addition to the cracking reactor. If this is the case the initial feed preparation would not be necessary. Normally this would not be the case and it will be prudent to include a material preparation step. The design of this will be based on the range of material mixes anticipated. The chief purpose will be to reduce contamination to an acceptable level and put the supply to the reactor in a suitable form. For example, the stage may wash the feed material, remove PVC plus any included soil and stones and then shred to a form that is appropriate for the reactor feed system.

Feed to process – there are a number of options for delivery materials to the reactor, this is an important step because the reaction must occur in the absence of oxygen and good heat transfer properties will be desirable.

Thermal cracking reactor – this is the vessel within which the plastic is heated to the necessary temperature for the reaction to occur. As discussed above this is conducted in the absence of oxygen, which would otherwise influence the reaction products and present a fire hazard. There is only one exit for desired products and that is as a vapour exiting the vapour space in the reactor. Other materials remaining in the reactor will be residues and will be continuously or periodically extracted. The product vapours pass overhead to a separation train where they will be refined. Some processing of reactor residues may be possible dependent on the details of the individual process.

Separation train – the vapours exiting the reactor are mixed hydrocarbons varying from heavy and diesel oils through gasoline to petroleum gases - many of the components can be selectively condensed by controlled cooling. At its most sophisticated this separation train will comprise a distillation system employing heating and cooling to enable well defined separations. Heavier vapours will condense first and some may not be readily condensed at all, these 'lighter' materials will be product gases. It is control of this stage that will determine the blend of materials making up each reactor product. The gases remain an overhead product and have fuel value for heating or electrical generation.

Liquid products – The performance of the reaction will determine the relative quantities of the different products exiting the reactor as vapour. Once condensed, liquid products can be easily stored to await on site use or distribution. The separation train will direct the liquid products to separate storage as appropriate. Typical liquid product categories would be fuel oil, diesel oil and gasoline. The objective is to produce the maximum quantity of the target product.

Utility requirements – Utilities are the services used by the facility and will include electricity and water. The reactor has a heating requirement as will most separation systems. Further requirements may be dictated by the approach taken for the preparation stage.

Example Processes

Marketed by Ozmotech the Thermalysis process has three examples of implementation in Japan, orders for installations are claimed for several locations in Australia and one in Spain. The PO Process which was developed and is marketed by Smuda Technologies Inc. has relatively large reference plants in Poland and several smaller scale units in South Korea, an installation is also currently under construction in Hanford, CA in the United States.

The latter process makes a further claim that vegetable oils can also be converted to diesel. Both can process waste or off-specification mineral oil.

Process Economics

The economics of such processes can be strongly distorted by local environmental practices and legal instruments. It is therefore important to be cautious about transferring technology to the European or UK commercial environment simply because it may be commercially successful elsewhere. Local attitudes to the techniques, taxes, duties and financial instruments to encourage recycling can contribute to enhance or diminish the commercial viability. Recent increases in crude oil prices have tended to make these developments more attractive.

The economics are best assessed by estimating the overall price of production for a unit of product. In this case a cost per litre of diesel is a convenient measure. The price should be built up from contributions from all relevant costs incurred including;

The capital cost of the plant and equipment including engineering and construction

The cost of plant commissioning

Staffing costs and overheads

Cost of raw materials and additives etc

Utility costs including heat, power, lighting, water and fuel

Maintenance costs

Overhead costs such as rental, rates, licences to operate etc.

The first two cost types are generally referred to as capital costs and need to be spread over the operating life of the facility either via suitable write off period or an interest payment approach. These are then added to the other operating costs. When compared with a realistic sale price the economic justification for establishing such a facility can be assessed. In examining the economic justification for any planned facility it is also important to make allowance for the funds necessary to prepare feasibility studies etc since these sums are at risk should the project be abandoned.

Figures derived in this way may appear attractive when compared with fuel pump prices as there is a significant tax content in the price paid by the final consumer. It is important to understand the method of application of this taxation to ensure that a fair comparison is made with other sources of fuel.

In the UK the manufacture of diesel fuel (and other fuel types) is subject to excise duty. Hence a duty becomes payable to HM Customs and Excise when the fuel is manufactured (rather than when it is sold or transferred). The producer needs to recover the cost of production and this excise duty when the fuel is sold. VAT will also be charged on the sale price (currently 17.5%). At present the manufacture of diesel from renewable resources such as vegetable oils attracts less excise duty than from traditional raw material. The definition of materials that qualify for this lower rate is restrictive and currently only certain processes with specific product qualities are eligible.

(See Box 2 – Customs and Excise Issues)

The full economic potential needs to be considered including the material collection, preparation and product distribution aspects. Plant location will usually have a significant effect as will the quality of product achievable.

Box 2 – Customs and Excise Issues

Three main elements of taxation need to be considered in the manufacture and sale of hydrocarbon fuels. These are excise duty, value added tax (VAT) and climate change levy (CCL). The following describes the excise duty element in some detail. VAT is a relative well known and understood form of taxation and is not discussed. CCL is unlikely to apply in the circumstances described though this should be confirmed on a case by case basis.

HM Customs & Excise definition of excise duty is

> *"A UK duty charged on both UK produced and imported goods. Goods subject to excise duty include beer, wine, spirits and other alcoholic drinks; hydrocarbon oils (including fuel oil); and tobacco goods. The rate of duty is set separately for each product. Excise duty also applies to gambling activities."*

Excise duty becomes due as the fuel is produced and is set according to a duty structure related to the fuel composition and end use. Although fuel duty increases were to be made from 1st September 2004 these were not applied and so the rates remain at the following levels:

Heavy (gas) oils	**Pence per litre**
Ultra-low sulphur diesel (ULSD)	47.10
Sulphur-free-diesel	47.10
Heavy oil which is not ULSD (i.e. conventional diesel)	53.27
Marked gas oil and ULSD oil not for road fuel use	4.22
Light oil delivered to an approved person for use as furnace fuel	3.82
Fuel oil	3.82
Fuel substitutes	
Biodiesel for use as a road fuel	27.10
Biodiesel used otherwise than as road fuel	3.13

Biodiesel is defined as diesel quality liquid fuel produced from biomass or waste cooking oil where the ester content of which is not less than 96.5% by weight and the sulphur content of which does not exceed 0.005% by weight, or is nil

Other fuel substitutes	If the fuel is substituting for petrol, assume that it would be taxed at the ULSP rate. If it is substituting for diesel, assume that it would be taxed at the ULSD rate.

ULSP – Ultra low sulphur petrol

Manufacture of diesel for road fuel use from the type of facility discussed in this document would be charged an excise duty of 47.1 pence per litre (a). If set aside for off-road use as a rebated gas oil a lower figure of 4.22 pence per litre is due. To conform as such it needs to be marked with Euromarker dye (reference 2) and in order to perform this internally the operator needs to be approved as an oil producer. Otherwise the diesel would have to be forwarded to approved marking premises after payment of the full excise duty for road fuel use – following the marking of the fuel the operator could reclaim the difference in the excise duties for road fuel and off-road use subject to satisfactory documentation.

There is an exemption from duty where the producer is a refiner who uses a portion of oil manufactured for producing oil. That is, excise duty may be expected to be avoided on the portion of product used to provide process heat (reference 3). A detailed examination of circumstances and discussions with HM Customs and Excise would be necessary prior to confirmation.

Duty would be payable on any of the fuel used to produce electricity either by raising steam or using a diesel generator. These rates would correspond to those assigned to light oil for use as a furnace fuel or fuel oil, currently the same rate at 3.82 pence per litre.

Following investigation it is not believed that Climate Change Levy would be payable in operating such a facility, though it would be advisable to make contact on this subject with HM Customs and Excise for each development.

a - Assuming that the standards for ultra low sulphur content were met.

Routes to Development

Technical reference and outline economic data are becoming available and a series of activities would be necessary to ensure any development proposed progresses with due diligence.

Technical performance claims should be investigated through reference visits, sample processing and analysis on host equipment.

Technical and economic performance guarantees should be obtained from the technology providers.

Sharing of financial risk with the technology providers should be explored

Identify the waste source, collection schemes and probable material preparation methods

Propose candidate participants and draft contractual relationships

Consider local planning and community issues and select candidate locations

Investigate all planning and licensing issues and assess implications

Location specific proposals should be conducted to provide feasibility studies

The feasibility study should include economic evaluations, environmental impact assessments, and health and safety considerations etc

Following this preliminary type activity, a decision on the desirability of proceeding to implementation would be made. Given a positive decision, the next stage will require that a full cost estimate be derived by initiating a design activity. The mode of conducting this will be influenced by the involvement of technology providers and other third parties. All stages of the material supply chain will need to be considered and effort will be required to define the various companies and organisations that will conduct activities along it. Suitable contractual relationships and undertakings should be established.

References

1. Plastics Waste – Feedstock Recycling, Chemical Recycling and Incineration – A. Tukker TNO – Rapra Review Reports Volume 13, Number 4, 2002
2. Hydrocarbon Oil (Designated Markers) Regulations 1996 and the Hydrocarbon Oil (Marking) Regulations 2002
3. Section 19A of the Hydrocarbon Oil Duties Act 1979 and Public Notice 179 Appendix K

Glossary

HDPE	High density polyethylene
LDPE	Low density polyethylene
LLDPE	Linear low density polyethylene
PE	Polyethylene
PET	Polyethylene terephthalate
VAT	Value added tax