For Ångpanneföreningens forskningsstiftelse

och Stiftelsen Svenskt Kretslopp

Resource efficient plastic recycling

- Instruments of control and obstacles in relation to the producer responsibility

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April 2002

A21189

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1 Introduction

In Sweden, as in many other European countries, recycling of plastic packaging is a result of legislative actions pursued as part of the process of achieving a more sustainable society. Outspoken aims of the European packaging directive, which was the driving force behind the Swedish national legislation, are to:

- Reduce waste amounts
- Reduce the amount of toxic substances in waste
- Economise with energy and natural resources
- Reduce littering
- Increase recycling and reuse, as well as the use of recycled material with low environmental impact. (SOU 2001:102)

In the long run, it was the intention that the packaging directive should lead to:

- a minimisation of the direct environmental impact of the end-of-life treatment of packaging
- an increased feedback on packaging design and the promotion of less resource-consuming packaging
- creating a good example of how an individual can contribute to sustainable development (SOU 2001:102)

The producer responsibility has led to plastic packaging being increasingly treated through mechanical recycling. Still, there does not exist an absolute consensus on the direct environmental benefit of separate sorting, collection and mechanical recycling of plastic packaging. Contradictory statements both in research and in media have contributed to a picture of unclear benefits of both mechanical recycling and the recycling system as a whole. The system for separate collection of plastic packaging in Sweden has also, in the transition period, lead to inconveniences for households.

1.1 Aim, Scope, and Delimitation

Currently, there are five alternative end-of-life treatments for plastic packaging:

- Re-use
- Mechanical recycling
- Energy recovery; high-efficient and through municipal solid waste incineration
- Feedstock recycling
- Landfill

Mechanical and feedstock recycling as well as energy recovery are in included in the all-embracing term “plastic recycling” and thus involve a form of making use of used raw material, either as material or as fuel, after the product has been disposed of. However, the term plastic recyling is often used in the meaning of mechanical recycling. This makes the vocabulary somewhat ambiguous. In order to avoid confusion, the terms mechanical recycling, feedstock recycling and energy recovery will be used to distinguish what is referred to. The term plastic recycling will, when used, refer to a combination of the treatment methods, as indicated above.

The aim of this study is to define how a more resource efficient plastic recycling can be achieved in Sweden. This requires answers to the following questions:

- How can treatment methods for plastic waste be ranked with respect to resource efficiency?
- How does the present system differ from a more resource efficient system?
- How can the present system be directed towards a resource efficient system? What instruments of control can be used?

An important part of this work is to study the role of the producer responsibility for the plastic recycling in Sweden.

This study is delimited to looking at current levels of plastic consumption, areas of applications, collection systems and end-of-life treatment methods in Sweden. Other treatment methods and changes in the composition of the waste stream may be discussed where relevant. The time scope stretches from the present situation and some 20 to 30 years into the future. A time scope which is not considered to signify any major changes in plastic use, plastic waste amounts or composition.

The aim of the study is to define a plastic recycling system that is more resource efficient than the present system. An ultimately resource efficient system would not use any resources at all – this definition could also be used for a sustainable system. It is the belief of the authors that such a system is not achievable within a limited time span, and therefore the term "resource efficiency" is defined relative to the present system, and is thus more adequately described as "more resource efficient".

1.2 Method

The study was pursued both as a literature study and through contacts with relevant parties from the plastic manufacturing and recycling businesses, as well as involved legislative and governmental institutions.

In order to define resource efficient recycling, results from existing comparative research on recycling and definitions of resource efficiency are combined. The definition is argumentative rather than numerical.

A comparison of present plastic waste management and the resource efficient system is done. Through back-casting, a number of scenarios examining how the gap between existing recycling and resource efficient recycling can be bridged are defined.

A reference group consisting of Annika Helker Lundström, Återvinningsindustrierna, Maria Schyllander, Plastkretsen, and Magnus Huss, The Natural Step, has followed the research process and assisted in the creation of scenarios.

The scenarios are studied through an institutional approach, with emphasis on economic, legislative, and technical aspects.

1.3 Structure of the Report

In **Chapter 2,** resource efficient plastic recycling is discussed and defined. Previous studies on the environmental and economic effects of recycling are surveyed as a background, both for the availability of treatment options and for the definition of the resource efficient system. Criteria for resource efficient treatment are put forward.

In **Chapter 3**, the method is applied to present waste streams. This includes a mapping and characterisation of current plastic consumption and waste streams, as well as a comparison of current plastic waste treatment to the criteria for resource efficient treatment.

In **Chapter 4,** instruments for increasing resource efficiency in plastic waste management are presented. Specific scenarios for plastic fractions based on the instruments presented are outlined.

Chapter 5 discusses the results, implications, and uncertainties of the report.

Chapter 6 concludes the report.

2 Defining Resource Efficient Plastic Recycling

2.1 Definition of Resource Efficiency

Resource efficiency is defined as "material and energy productivity" in the Resource Efficiency Investigation report, SOU 2001:2. Further, from the same report :

"…it is a measure of productivity similar to labour productivity and aims to describe natural resource use per unit of production or final consumption. It is therefore basically a question of natural resource management"

"It must be emphasized that productivity measures are partial measures, and that increases in productivity for one resource does not necessarily entail increased resource efficiency on the whole" (own translation from Swedish)

"Measures aimed at reducing the use of a specific resource effects the use of other resources in the society – labour and capital as well as other natural resources" (own translation from Swedish)

Even though the resource efficiency committee mainly considers natural resource management, it does emphasize the necessity of considering other resources as well.

The discipline of economics is defined as "the study of the allocation of scarce resources", here referring to anything that holds a positive value, be it land or any other natural resource, labour, or capital (Turner et al, 1994). Plastic waste management does not only affect natural resources and energy use. Often, the economic aspects of waste management systems are relevant, as well as the labour demanded from households with sorting and cleaning waste fractions and psychological effects, such as the good example described in the introduction. Therefore, we consider it relevant for this study to define resources as widely as is done in economics. Examples of resources affected by plastic material use and recycling are:

Natural resources (including energy resources)

- Oil, both as a resource for the plastic material, and as a resource for energy used in production and transportation
- Additives in the plastic materials
- Materials and energy replaced by the recycled plastic
- For packaging plastics, net effect on the packaged materials (e.g. reduction or increase in food destruction because of packaging)

Carrying capacity of nature (i.e. capacity for emission assimilation)

- Global warming
- Eutrophication
- Acidification

Health:

- Emissions of e.g. toxic substances from production or waste management
- Impurities in e.g. food packaging that may contaminate its contents
- Poorly packaged food may increase risk of contamination

Capital

- Economic resources in terms of costs associated with recycling compared to a linear use of plastic material

Labour

- Labour used in production, i.e. paid labour. (This labour is usually included in the capital resource as labour is bought for capital)
- The resources in terms of leisure time spent by households in the pretreatment (sorting, cleaning and transporting) of plastic waste for recycling

Environmental awareness

- Plastic recycling may trigger environmental awareness in individuals, i.e. a positive effect
- The free time and effort spent by an individual on environmental issues may be considered a limited resource, i.e. a negative effect

The resources above are only examples, and so are the ways to measure them. For example, for emissions it is maybe rather the effect of emissions (such as loss of biodiversity, damage to ecosystems) that are to be considered as resources. This distinction will not be relevant for this study. In theory, resource efficiency would imply an *efficient use of all the resources described above*. This means a minimum input of the resources for a given amount of output. However, as pointed out by the resource efficiency committee, reducing the use of one specific resource often entails increases in the use of others, i.e. trade-offs between resources have to be made. Recycling plastics may for example reduce the consumption of oil, but may also entail increased labour efforts from households. Therefore, in order to define resource efficiency, the resources have to be weighted against each other, e.g. how much labour effort by households is similar to a 1-litre reduction of oil use in a given circumstance. This weighting should then be based on valuations of the scarcity and relative importance of the resources.

In practice, the weighting between the resources proves to be difficult, if not impossible, to carry out without normative elements. The weighting, or valuation as it is sometimes called, requires the use of political, ideological and/or ethical values. Not only the weighting factors, but also the choice of weighting method, and the choice of using a weighting method at all, are influenced by fundamental ethical and ideological valuations (Finnveden, 1997). Apart from this, there are major uncertainties involved in defining the scarcity of resources: uncertainties concerning the resource stock, future needs and prices, etc. There are even value choices present in what is normally considered traditional, value-free natural sciences (Finnveden, 1998): the choice of classification and characterisation methods for LCA use are examples of this. The effects on capital and labour are easier to quantify and assess as their effects are more naturally included in the economic system, and as their time frames are more centred round the present day. But even here there are discrepancies in the opinion on how to value the efforts made outside the system of a national economy, such as the spare time and money spent by households on recycling. As no objective weighting can be achieved, and as a consensus as to what normative weighting should be used does not exist, the idea of a scientific weighting between resources seems inconceivable.

In this study, strict weighting between resources would lead to very situation specific results, strongly anchored in present technology. As the aim is to look at a time period of 20-30 years ahead of us, during which time substantial technological development may take place, such strict weightings should be avoided.

One approach in the defining of resource efficiency is to work from the concept of sustainability as is done within the framework of The Natural Step. The Natural Step defines sustainability as being subject to four system conditions: nature's function and diversity may not systematically be subject to:

1. *increased concentrations of substances extracted from the Earth's crust*,

2. *from substances produced by society*, or

3. *from the physical impoverishment by over-harvesting or other forms of ecosystem manipulation*.

The fourth condition is a prerequisite to the above conditions and states that

4. (natural) *resources should be used fairly and efficiently in order to meet the basic human needs world wide*.

Standing alone, these principles of sustainability give little guidance as to what direction development should move in order to approach sustainability, why the Natural Step has produced some principles of sustainable development as well. These comprise of:

- a step-by-step approach (in order to outsource the relevant questions upstream on the path to fulfilling the system conditions),
- a flexible platform for future activities (in order to answer the questions and take steps towards action in fulfilling the system conditions) and
- an economic link between long term and short term (in order to identify the activities that can save resources and at the same time render a fast enough return on financial investments).

The above principles of sustainability and sustainable development together constitute the framework of the Natural Step. The Natural Step works with the whole concept of sustainability, integrating economy, ecology and social progress. Thus, it covers all of the resources relevant for plastic recycling. However, the principles do not give concrete guidance as to how to weigh resources when necessary. The pricniples are good guidelines for long-term strategies, but we do not find the achievable within a limited time scope. Therefore, the principles are not rejected as such, but we find that more concrete toos needs to be developed.

Yet another approach in the defining of resource efficiency is to work with the concept of eco-efficiency (WBCSD, 2000). Eco-efficiency is a management philosophy that encourages business to search for environmental improvements that yield parallel economic benefits. Eco-efficiency may be achieved by "the delivery of competitively priced goods and services that satisfy human needs and bring quality to life, while progressively reducing ecological impacts and resource intensity throughout the life-cycle to a level that at least is in line with the Earth's estimated carrying capacity". In short, eco-efficiency aims to create more value with less impact. The concept has three broad objectives; reducing the consumption of (natural) resources, reducing the impact on nature, and thirdly, increasing product or service value. Eco-efficiency may thus be represented by the ratio of product or service value divided by environmental influence. It does not specifically define what ratio that is optimal, but rather constitutes a framework for developing indicators that can be studied in time trends. Therefore, eco-efficiency does not give the guidance needed for weighting in this study.

2.1.1 Conclusions and implications

The concepts presented above give an implication of how difficult it is to weight resources and define resource efficiency, and as a consequence of this, to define resource efficient plastic recycling. There will always be trade-offs between different types of resources. In order to be able to proceed with an analysis of how a more resource efficient plastic recycling may be achieved, all of the resources defined above are considered. However, spending an equal and sufficient amount of time and effort analysing all resources involved would, apart from being an enormous task, be an implicit weighting that all resources are equally important. The definition of resource efficiency when two or more resources are involved invariably involves elements of normative nature, as it builds upon direct weighting of the resources to be analysed, regardless of how it is done. Therefore, in order to be able to proceed with the study, a normative decision has been made that the resources that will be considered as most important in this analysis are the environmental resources (natural resources and the carrying capacity of nature). Consideration will also be given to economic resources and social aspects such as the effort in sorting and cleaning waste fractions by households, and the environmental awareness of the consumers.

In order to keep the weighting relatively flexible and manageable, the intention is to develop a comparative ranking of available plastic waste management strategies, where criteria for the efficiency of a specific treatment can easily be compared to plastic waste streams. The ranking will be based on previous studies, with emphasis on environmental resources as discussed above. This method does not give the level of detail and reliability as for example an LCA, but does on the other hand provide some flexibility for the analysis of possible technological development of the studied systems.

2.2 Previous Studies on Waste Management of Post-consumer Plastic Packaging

Plastic waste can be treated in several ways:

- **Waste minimisation.** The ultimate way to solve the waste problems is of course to minimise the generation of waste at its source, i.e. a resource efficient use of the product material and energy resources from the start. If no waste arises, there will be no ensuing environmental impact. If less plastic is consumed and thus less plastic waste is produced, there will be less ensuing environmental impact to deal with.

- **Re-use**. The plastic product can be part of a return-system and thus be reused in its original application over and over again. Examples of such products are PET refill bottles, transport trays, crates and pallets.

- **Mechanical recycling**. Separately collected plastic can be re-melted and formed into new products. Virgin plastic material is substituted by preference, but the substitution of other materials, for example concrete and impregnated wood, exist as well.

- **Feedstock recycling**. Separately collected plastic is broken down into its original components, and substitutes other fossil resources in several feedstock applications, but not as an energy source. Various methods are still at a pilot stage. However, there are also processes that are in operation, e.g. the use of plastic waste in blast furnace and in a gasification process to produce systhesis gas. In both cases other fossil resources (mainly coal) are substituted.

- **High-efficient energy recovery.** A separately collected fraction of plastic packaging can be used as a fuel e.g. in cement kilns, substituting other fossil fuels. The process is characterised by a high thermal efficiency.

- **Energy recovery from incineration of municipal solid waste**. Plastic packaging can be incinerated in combination with other solid waste with energy recovered as a side activity. In this way other primary energy carriers are substituted in the production of heat or electricity. The thermal efficiency is moderate to high.

- **Landfill.** Plastics are dumped, separately or mixed with other waste, at a landfill, with the intention of letting it remain there indefinitely. Landfilling is mainly considered a means for getting rid of waste, rather than using inherent resources still imbedded in the material.

Several studies have been conducted to assess the environmental performance, the costs, as well as the socio-economic consequences associated with different end-of-life treatments of plastic packaging. The aim and scope of the studies vary with application, but a few common denominators are observed.

There is an inclination in literature to see reuse as more resource efficient than mechanical recycling (SOU 2001:102). If nothing else differs between the systems (separate sorting and collection), reuse usually entails less energy consumption (water and detergents for cleaning) than mechanical recycling (which consists of a re-melting process).

Landfill is consistently ranked as the last alternative with respect to environmental effects (Bäckman et.al., 2001; Eggels et.al., 2001; Finnveden et.al., 1999; Sundqvist et.al., 1999; Öhlund & Ericsson, 1998;) as well as economic effects (Bäckman et.al., 2001; Eggels et.al., 2001; Sundqvist et.al., 1999). The main contributor to this conclusion is the fact that landfilling natural resources already introduced into the technosphere leads to an inefficient use of resources. This in turn results in an increased consumption of natural resources to produce anew the functions (e.g. plastic material and heat) provided in the processes of mechanical recycling and energy recovery.

Eggels et al. (2001) makes a distinction between the two alternative methods of energy recovery – ER_{MSWI} (municipal solid waste incineration with energy recovery) and ER_{HIGH} (high efficient energy recovery). The methods are in that study compared under average European conditions. The results indicate the superiority of ER_{HIGH} for some of the environmental effects (impact categories) due to the fact that it substitutes coal as opposed to a mixture of energy carriers for average European heat/ electricity production.

Previous research has showed that ER_{MSWI} is better with respect to environmental effects compared to both mechanical recycling and landfill under the assumption that the recovered energy substitutes fossil fuels (Finnveden et.al., 1999; Sundqvist et.al., 1999; Öhlund & Ericsson, 1998). The economic costs associated with ER_{MSWI} are lower than those of mechanical recycling (Bäckman et.al., 2001; Sundqvist et.al., 1999).Under the assumption that renewable energy resources are substituted mechanical recycling is, however, more beneficial with respect to environmental effects than ER_{MSWI}. This is under the additional assumption that the recycled plastic substitutes virgin plastic. (Bäckman et.al., 2001; Sundqvist et.al., 1999)

When recycled plastics substitute materials other than virgin plastic (e.g. impregnated wood or concrete, the environmental benefit of mechanical recycling versus ER_{MSWI} decreases (DKR, 2000; Eggels et.al., 2001; Finnveden et.al., 1999). The costs increase even more (Eggels et.al., 2001).

Plastic is an organic material that degrades over time (mainly through exposure to ultraviolet radiation and heat). This implies that both normal use and the recycling process degrade the material. And for this reason it cannot be mechanically recycled Therefore, it cannot be infinitly treated through mechanical recycling. It has been calculated that plastic material can be used and recycled between 3-10 times, depending on the sort of plastic, before the material shows severe signs of degradation (Jansson, 2000). This limits both reuse and mechanical recycling of plastics.

2.2.1 Feedstock Recycling

According to a comparative study performed by Tukker et.al. (1999) on different chemical recycling alternatives under European conditions, the two alternatives that are already in operation on a small scale and therefore closest at hand to consider in the near future are the use of plastic waste as a replacement of other fossil resources (coke, coal or heavy oil) in blast furnaces of steelworks, and in a gasification process like the one operated by Sekundärrohstoff Verwertungs Zentrum (SVZ) “Schwarze Pumpe” in Germany.

Compared to ER_{MSWI} the blast furnace has clear environmental benefits, under average European conditions, as the plastic material is utilized to 100 %. This is assumed to be true under the conditions that separate collection, cleaning and agglomeration accounts for relatively low consumption of energy. Compared to ER_{HIGH} the method should render rather similar scores with regards to environmental benefits (Tukker et al, 1999). When it comes to the economic aspect of the method, it is not as favourable as ER_{MSWI}. The method has been successfully implemented in Germany mainly due to legislative instruments in favour of it. Germany has set very high recycling targets and the possibility for the treatment plants to be guaranteed large volumes of waste exists (Tukker, et.al., 1999).

The other alternative of feedstock recycling that has been well implemented in Germany is the gasification process of the Sekundärrohstoff Verwertungs Zentrum (SVZ), “Schwarze Pumpe”. This plant processes waste materials (e.g contaminated wood, sludge paperfractions and plastics) together with lignite and oil to produce synthesis gas (hydrogen and carbon monoxide), and further to mainly methanol and electricity. According to Tukker et.al. (1999) this process renders similar results compared to the blast furnace. The results are however dependent on what allocation procedure is applied. The SVZ-plant was originally designed for coal gasification, and if it is assumed that the plastic waste substitutes coal, the results are comparable to the blast furnace. That is, under average European conditions, SVZ gasification and the blast furnace lead to a more resource efficient use of fossil energy carriers and thus a lower global warming impact compared to ER_{MSWI}.

2.3 Ranking the treatments from a resource efficiency perspective

The literature study above gives relatively good support for a relative ranking between the environmental performance and in some cases economic performance of the available treatment methods. Based on the discussion in 2.1.1, the ranking and weighting metod will be developed as follows:

- A hierarchy of the treatment options will be established mainly on the basis of their relative environmental performance, which in turn will be based on previous studies. Other resources will be considered where relevant.

- Additional prerequistites that need to be fullfilled in order for each treatment option to be considered resource efficient will be listed. If these prerequisites are not met for a particular plastic waste fraction, the treatment may be considered non-applicable, which implies that the more resource efficient treatment option may be found a step down in the hierarchy.

2.3.1 Reuse

As pointed out in section 2.2 reuse may be considered more resource efficient than mechanical recycling, and will therefore be so for the purpose of this study. The recent evalutation of the Swedish producer responsibility assumes this to be the case and in the ongoing discussions, on a European level, on the renewal of the EU packaging directive targets for reuse are considered (SOU 2001:102). These two facts show the relevance of the alternative.

2.3.2 Mechanical recycling

Mechanical recycling has shown to be more beneficial with respect to environmental effects than $ER_{MSWI,}$ under the certain conditions, namely when recycled plastic substitutes virgin plastic and when the substituted energy carrier is biofuel. Carlsson (2001) has shown that some 7 % of the total amount of recycled plastic packaging in Sweden substitutes other materials, mainly impregnated wood. In this case mechanical recycling still holds environmental benefits.

The costs of mechanical recycling relative to energy recovery are generally considered to be higher. A part of the high costs stems from the low value of the recycled plastic material. The process of mechanical recycling has been known as long as the process of energy recovery. However, it is only in the last decade that it has been used more extensively for the treatment of post-consumer plastic packaging. It may therefore be argued that mechanical recycling will experience decreased costs after additional years of operation and refinement, as has been the case for energy recovery in Sweden (Bäckman et.al., 2001).

When considering both environmental and economic resources, the relative ranking between mechanical recycling and energy recovery is somewhat dubious. For the purpose of this study, where the superiority of environmental resources has been decided upon mechanical recycling is ranked as a more resource efficient treatment method for plastic waste than energy recovery, i.e. the second best alternative next to reuse.

2.3.3 ER_{MSWI}

In Sweden energy recovery is practised almost exclusively through ER_{MSWI}. This alternative is used for the treatment of around 40 % of the Swedish household waste

(RVF, 2001) and district heating is produced to 96 %. Furthermore, in average, district heating in Sweden is produced by renewable biofuels to more than 50% (STEM, 2001). Due to this and the fact that ER_{MSWI} does not result in an as large environmental benefit compared to mechanical recycling when renewable energy resources are substituted, ER_{MSWI} it is often ranked lower than mechanical recycling.

2.3.4 Landfill

From the studies presented in the previous section (*2.2*) it is concluded that landfill is not a resource efficient alternative for the treatment of plastic packaging, except for under very special circumstances. Landfilling may be relevant for the end-of-life treatment of certain non-packaging products that, due to additives (e.g. plastic caps of certain electric or electronic devices that contain hazardous flame-retardants), are not suited for incineration or recycling.

2.3.5 Feedstock recycling and ER_{HIGH}

Feedstock recycling has until this day not been practised in Sweden. It has been dispatched as non-feasible due to high investment costs, considering the relatively small amounts of post-consumer plastic available for the process (Naturvårdsverket, 1996). However, in a cost-benefit analysis of Plastkretsen's current operation, Pilz (2001) suggested that an application of the process in Sweden should be further evaluated.

As pointed out in the literature study there are two chemical recycling alternatives that are interesting for Swedish waste management in the near future – the blast furnace and the gasification process of SVZ "Schwarze Pumpe". In the study of Tukker et.al. (1999) it is concluded that both these alternatives as well as ER_{HIGH} may have environmental advantages compared to ER_{MSWI}, mainly due to the higher efficiency. However, the study is pursued under average European conditions and the Swedish conditions for ER_{MSWI} are more favourable than the European (Bryman, personal communication). Sweden has an extended network for district heating (basically all major urban settlements have district heating) and thereby has a stable market for the heat that is generated. On average, the efficiency lies around 90 % and in some of the newer plants it may even rise above 100 %. There currently does not exist any comparative studies that include these three treatment alternatives under Swedish conditions and therefore it is difficult to rank them in the resource efficiency hierarchy of plastic recycling.

2.3.6 Conclusions

For the reasons presented above, it is concluded that, under Swedish conditions, reuse is to be considered the most resource efficient form of plastic recycling. Secondly, mechanical recycling is to be considered more resource efficient than ER_{MSWI}. ER_{MSWI} is still regarded as a resource efficient treatment method, and it is underlined that this method does constitute an important complementary alternative to mechanical recycling. This conclusion correlates well with the conclusion drawn in the evaluation of the producer responsibility (SOU 2001:102) In this study, mechanical recycling, at current recycling rates, is concluded to be more beneficial with respect to the environment than ER_{MSWI} (or landfill). It is, however, underlined that the current system may be further developed with respect to the roles of the involved actors, their responsibilities and co-operation, participation of consumers, costs and issues that wrongfully increases competition of businesses that do not take their responsibility according to the law. For the purpose of this study, the EU waste hierarchy is re-confirmed:

1. Reduction
2. Reuse
3. Mechanical recycling
4. Energy recovery (ER_{MSWI})
5. Landfill

This hierarchy is valid under certain conditions, which will be more closely defined in the next section (*2.4*). Feedstock recycling and ER_{HIGH} are left out of the hierarchy due to the facts presented earlier in *section 2.3.6*.

2.4 Criteria for resource efficiency of treatment options

In addition to the conditions presented in the previous section (*2.3*) there are certain criteria that need to be met in order for the different treatment alternatives and the system as a whole to be more resource efficient. In the following sections those criteria are set for each specific treatment. The criteria have been developed through adapting the conditions in the literature studied in section 2.2, and through interviews with actors involved in plastic recycling in Sweden. If the conditions for a treatment option are not fulfilled for a specific plastic waste fraction, the most resource efficient treatment option would be the one a step down in the waste hierarchy. Thus, beginning at the topmost step (reuse), reconfirming the conditions, the most resource efficient treatment available for each plastic fraction can be defined.

It is important to keep in mind that what treatment alternative may be considered resource efficient is very dependent on what plastic waste fraction it is applied to.

2.4.1 Resource Efficient Reuse

As discussed in the previous section reuse is considered more resource efficient than all other end-of-life treatments. The following criteria need to be fulfilled for a resource efficient reuse:

- The transportation or collection system should involve a minimal effect on fuel consumption (compared to other tretament options).
- The cleaning system should involve a minimal effect on energy consumption (compared to other tretament options).
- The system products should make allowances for degradation in the plastic durability due to exposure to heat and ultraviolet radiation, or naturally replace a product when it has been in use long enough to inhibit its function.
- Legal hygienical demands should be met (e.g. concerning food packagings)
- Plastic fractions should be large in volume, providing for cost-efficiency in both collection and processing.
- A demand for the reused plastic goods must exist.

2.4.2 Resource Efficient Mechanical Recycling

The resource efficient mechanical recycling of plastics should ideally eventually contribute to a common market for virgin and recycled plastic, where materials of adequate combinations of virgin and recycled granulated plastics suitable for the application are sold. The achievement of this market requires a more resource efficient mechanical recycling system than what is presently used. This system involves a limited number of plastic material waste streams to be recycled, a cost-efficient collection and sorting system that generates homogeneous fractions of plastic material and a complication-free processing to high quality regranulate comparable with, and fully substituting, granulate produced from virgin material.

Broken down into fundamental components, the resource efficient mechanical recycling system should involve the following:

- Plastic fractions that are large in volume. This provides for cost-efficiency in both collection and processing.
- Plastic materials that are well defined and marked. This provides for homogeneous fractions to be obtained for processing through sorting and collection.

- Plastic fractions that are clean in the sense that they are free of non-plastic materials. This allows a complication-free processing.
- Plastic fractions that are relatively free of additives, that may otherwise contribute to complications in the processing of a high quality output.
- The system products should make allowances for degradation in the plastic durability due to exposure to heat, ultraviolet radiation and recycling, or naturally discard a product when it has been in use long enough to inhibit its function.
- A demand for the recycled granulate must exist.

2.4.3 Resource Efficient Energy Recovery

The evaluation of the producer responsibility (SOU 2001:102) concludes that in the case where the packaging material cannot be reused or mechanically recycled, the energy content should be utilised through incineration with energy recovery. Energy recovery can therefore be considered a resource efficient alternative when;

- Combustion of the plastic does not lead to unmanageable emissions (personal communication, Håkan Stripple, IVL)

2.4.4 Resource Efficient Landfilling

This is the bottom step of the waste hierarchy. Although this is the least resource efficient treatment method it may still be the only option left for certain plastic waste fractions, if the criteria cannot be fulfilled for any other treatment method. In these cases, landfilling is available option.

3 Applying the Concept to Current Waste Streams in Sweden

3.1 Plastic consumption and recycling

The Association of Plastics Manufacturers in Europe (APME) estimates an annual consumption of plastic to 90 kg/ European. The yearly consumption of plastic in Sweden would then be approximately 800,000 tons, which according to Plast- och Kemibranscherna (2001) is the only existing estimation today. At the same time it is admitted that this figure is somewhat high for Sweden, as the consumption of bottled water is considerably lower in Sweden than in Europe on average. In Sweden, plastic packaging accounts for almost 40 % of the total plastic consumption. Another 40 % is accounted for by the building-, vehicle- and electronic industries (PIR, 2001). According to the Swedish Environmental Protection Agency (Naturvårdsverket, 2001) the total amount of post-consumer plastic packaging arisen in Sweden in 1999 was about 180,000 tons (see *table 3.1*). This does not correlate well with the estimations made by APME as it corresponds to 25 % of the total plastic consumption, rather than 40 %. *Table 3.1* also shows the recycled amounts of significant plastic packaging materials in the same year.

Table 3.1. Total amounts of plastics in Sweden in 1999 according to some estimations (Carlsson, 2001)

		Amounts according to Naturvårdsverket (tonnes)	Amounts according to Swedish APME (tonnes)
Total amount of plastic consumption			**800 000**
Of which:	**plastic packagings**		**320 000**
	building,vehicle,and electronics		**320 000**
Total amount of plastic packaging available for recycling		**176 568**	
Responsibility of Plastkretsen		**123 000**	
Recycled amounts through mechanical recycling		24 400	
of which	*LDPE*	*14 700*	
	HDPE	*6 600*	
	PP	*2 510*	
	PET	*590*	
	EPS	*380*	
Energy recovery		23 600	
PET recycling		**26 188**	
Refill (reuse)		18 212	
Mechanical recycling		5 650	
OTHER (reuse)		**27 000**	

The post of reuse in *table 3.1* accounts for transport trays, crates and pallets that are usually business specific reuse schemes. This figure is highly dependent on how calculations are made. There are many business specific systems that are not accounted for in the figure (Schyllander, personal message). 1999 was the last year that recycled amounts where estimated and presented as specific material flows such as HDPE and PET (Schyllander, 2001). The recycling rates have remained fairly stable during the past two years (Jacobsson, personal message). In addition to the amounts presented in the table around 40,000 tons of mixed plastic waste where incinerated as part of municipal solid waste with energy recovery as a side activity.

3.1.1 Legislation

The treatment of plastic packaging is regulated in two laws – the law on certain beverage packaging (SFS 1991:336) and the regulation on producer responsibility of packaging waste (SFS 1994:1235). SFS 1991:336 regulates beverage packaging made of PET, both recyclable and refillable. It states that any importer or producer of a PET-bottled beverage is obliged to assure that the used bottles are part of a recycling system. Current recycling targets are set at 90 % material utilisation, i.e. reuse or mechanical recycling.

SFS 1994:1235 regulates all other plastic packaging in accordance with the EU packaging directive. It states that packaging should be produced in such a way that their volume and weight is reduced to the minimum level needed to secure a feasible safety and hygienic level. In this sense packaging should be designed, produced and marketed in such a way that it can be reused or recycled so that the environmental impact at its end-of-life treatment is limited. The current recycling targets are set at 70 % of which 30 % should be material utilisation (i.e. 40% of the packagings can be incinerated and still be counted towards the recycling goals).

The recycling of plastic packaging in Sweden is subsequently divided into two areas of responsibility (see also *table 3.1*):

- **The recycling of PET bottles**. AB Svenska Returpack PET (the Swedish PET recycling organisation) administrates the recycling of one-way PET bottles (mechanical recycling). Svenska Bryggareföreningen (The Swedish Brewery Association) administrates the recycling of PET refill bottles, which is a form of reuse.

- **The recycling of all other plastic packaging from both households and businesses**. Plastkretsen (the organising body for the compliance with the producer responsibility on packaging) administrates the recycling of these waste fractions.

3.1.2 The PET recycling organisations

Swedish PET recycling is, as mentioned before, administrated by two organisations, namely the Swedish PET recycling company and the Swedish Brewery Associaton. The breweries own the Swedish PET recycling company to 49 % and Rexam, a packaging producing company that produces packaging in various materials, owns an additional 49 %. The Swedish breweries, i.e. the fillers of the packaging, own the Swedish Brewery Association that administrates the recycling system for PET refill bottles.

In the year of 1999 the one-way PET bottles were recycled to a rate of 74 %, and the refill bottles were reused to a degree of 98 %. The PET recycling system was implemented after persistent public opinion in the early nineties, before the producer responsibility came in question on a European level. It is a deposit-refund system and the bottles are collected at grocery stores, where the collection system is co-ordinated with the distribution system in the sense that the empty space of the distributing trucks is filled with returned bottles on the return. In this way the collection has a marginal effect on the fuel consumption.

According to the evaluation of the producer responsibility the actors of the system are, all in all, satisfied with the system. According to the study, there is no reason to change a winning concept. These “brewery bottles” seem to be of high priority for consumers: the system has a high degree of service that generates certain credibility with the customers, as they know that the bottles they recycle are assured a proper treatment. All involved actors would probably regard an abolition of the system as negative.

3.1.3 Plastkretsen

Plastkretsen AB is the organising body for the compliance with the producer responsibility on plastic packaging. Plastkretsen is owned to 60 % by PIR – Plastinformationsrådet, the advising committee on plastic information (owned by actors in the polymer producing industry – the Plastics and Chemical Federation), to 10 % by SPI – Svenska Petroleum Institutet, the Swedish Petroleum Institute (owned by various oil companies), and to 30 % by business sector organisations for commerce and fillers of packaging.

Plastkretsen contracts entrepreneurs that collect plastic packaging and recycling companies that recycle the material. The collected material can be divided into different fractions, with respect to waste source and material sort. Plastic packaging is collected from both households and businesses. From households two material flows are separated – a “hard fraction”, consisting mainly of HDPE and PP, and a “soft fraction”, consisting of LDPE. From businesses, three major flows are separated – a hard fraction, again consisting mainly of HDPE and PP, and a soft fraction, consisting of LDPE (“shrink-and-stretch” film) and “other plastic packaging”. The hard fractions are mechanically recycled to palisades, pallets, etc. The soft fraction from households, either separately collected or as part of the rest fraction of households, is almost exclusively treated through incineration with energy recovery. The soft fraction from businesses is recycled to plastic bags.

The household fraction has until now for the most part been collected through a bring system, although in some municipalities the option of kerbside collection is available. In 1999, between 20-25 % of the total amount of plastic waste recycled through Plastkretsen originated from households.

For businesses, 30 so-called “receiving sites”, where the separately collected fractions can be exchanged for a refund, have been set up across the country. The major part, 75-80 %, of the total amount of plastic wastes recycled in 1999 originated from businesses. For the most part, around 80 %, this fraction consists of LDPE.

Unlike recycling systems for other packaging materials, the system of plastic recycling does not return the recycled material to the original polymer producers. The recycling companies are small in size (often family businesses) and they use the plastic waste as input material in new processes to produce products that are either designed to be suited for recycled material or compete with similar products of virgin plastic material. Thus, different actors produce virgin plastic products and recycled plastic products, even though they sometimes share a common market.

3.1.4 The Agricultural Sector

The plastic waste that is generated within the agricultural sector consists to the main part of LDPE. Between 11-12,000 tons of plastic waste is currently generated on a yearly basis. About 8,000 tons consist of ensilage plastic, which until now has not been regarded as a form of packaging, but rather as a part of the agricultural production process. Therefore, the producer responsibility has not been applied to this fraction.

However in the evaluation of the producer responsibility this fraction is considered. In some parts of the country there currently exists systems for collection of ensilage plastic, but they are far from nation-wide and it appears to have been difficult to find incineration plants that are willing to treat the waste. The ensilage plastic is rather polluted by its contents, and therefore it has until now mainly been treated through energy recovery. However, there seems to be a demand from businesses that pursue mechanical recycling, as the waste fraction is still fairly easily treated (SOU 2001:102).

Interests within the agricultural business sector have voluntarily agreed to build up a nation wide system for the collection and recycling of the main part of the generated plastic waste. The recycling goals are in line with the goals set up by Plastkretsen, namely 30 % mechanical recycling by the year 2004. The fraction that is not recycled mechanically should be treated through energy recovery. Initially the system will be financed by funds from the members and in the long run by recycling fees. Membership is open to anyone that has an obvious connection to the business sector. The initial interests are different plastic converters, Svenska Foder AB and Lantmännen (i.e. producers, importers and suppliers of ensilage plastic). The recycling and collection system is under construction, but in structure it will not differ much from the present system of Plastkretsen. The collection will therefore in as much as possible be co-ordinated with other sites for receiving separately collected waste fractions.

3.1.5 Non-packaging

This is a large and very heterogeneous area of plastic applications, stretching from building materials over automobile parts, electronic equipments, to toys. The composition of the plastics, and the additives used in the plastics, vary as much as the applications: e.g. in casings for electronic goods, flame retardants are often used, while for PVC tubing, softeners provide the plastic with the desired qualities. Normally, the time period between production and discarding of the plastic products are much more prolonged than for plastic packagings, as the products themselves are capital goods.

In the recent evaluation of the producer responsibility in Sweden (SOU 2001:102) the product group toys was evaluated with respect to its potential of being included in the extended producer responsibility regulation in the future. It was concluded that this group of products will most probably not be included in the legislation, as it would be difficult to motivate the producers to accept the restrictions that follow with a national law (Sweden only accounts for 5 % of the worlds total toy consumption). The electronic toys are, already included in the producer responsibility (SFS 2001:102). Furthermore, toys have varying lifetimes: some may be passed on from generation to generation, in which case it may be difficult to assure economic guarantees for recycling or set up recycling schemes that need to be active over such prolonged time periods. From a pedagogical perspective, there may of course be a point in including toys in the extended producer responsibility, to teach children their responsibility in a sustainable society. However, the producer responsibility evaluation concludes, there exist product groups other than toys that should be prioritised in the extension of the producer responsibility.

3.1.6 Summary

In table 3.2, a summation of main current treatment methods for the plastic waste in Sweden is presented.

Table 3.2 Main current waste treatments for plastic waste in Sweden

Plastic flow	Main current treatment
Households	
PET	MR
HDPE	Mechanical recycling, energy recycling, and landfill
PP	Mechanical recycling, energy recycling, and landfill
LDPE	Energy recycling and landfill
Businesses	
HDPE	Mechanical recycling and energy recycling
PP	Mechanical recycling and energy recycling
LDPE	Mechanical recycling and energy recycling
Agriculture	
LDPE	Energy recycling and landfill
Non-packaging	
LDPE, HPDE,PP, PET	Energy recycling and landfill

3.2 Potential improvements in resource efficiency of plastic recycling

In this section the treatment of current plastic waste fractions are analysed from a resource efficiency perspective. Starting at the top of the hierarchy of treatment methods, the characteristics of each individual waste fraction are compared to the criteria for resource efficiency of each treatment. This is an iterative process that is concluded when the plastic waste fraction characteristics meet the criteria of resource efficiency for the treatment method. The evaluation is presented in table 3.1-3.3, where a "✓" indicates a problem, and a (✓) indicates a potential problem. A "?" indicates no information on the subject is available. The analysis has been confirmed in a workshop with the reference group to the study.

Due to the fact that information about the feasibility of treating a certain plastic waste fraction in a certain way is highly dependent on today's system, the results may only be verified for existing treatment options. Therefore, it is easy to be misled to the conclusion that the present system is the most resource efficient one. However, there are a number of treatment options that cannot be entirely ruled out, even though they are not practised today. Firstly, several plastic fractions have the potetial of being reused, namely HDPE and PP packagings from both businesses and households. Development concerning homogeneity of containers, identification, sorting, etc. are necessary for this to be possible, but there is nothing inherent in these waste fractions that prohibits reuse. As for mechanical recycling, basically all monomaterial plastic packaging has the potential of being subject to this treatment. At present problems that concern volume, homogeneity of fractions and additives arise, but in theory these problems can be avoided through e.g. better sorting techniques, voluntary or legislative regulations on additives, etc. For these reasons there is possibly a large potential for the collected end-of-life treatments of plastic packaging to develop towards higher resource efficiency. It is nevertheless important to consider all types of resources when making this calculation. It may well be that costs and household efforts for higher levels of reuse and mechanical recycling outweigh the savings on environmental resources. As for non-packaging plastics, too little is known about composition, amounts, etc. in order to conclude what treatment option would be the most resource efficient one.

Table 3.1. Characterisation of material flows of plastics for reuse

Plastic flow	Reusability	Collection and transport	Energy consumption	Volume	Market
Households					
PET					
HDPE	✓	✓		✓	✓
PP	✓	✓		✓	✓
LDPE	✓	(✓)		(✓)	(✓)
Businesses					
HDPE	(✓)				(✓)
PP	(✓)				(✓)
LDPE	✓				(✓)
Agriculture					
LDPE	✓				✓
Non-packaging					
LDPE, HDPE, PP, PET	?	?	?	?	?

Reusability	It should be practically possible to reuse the goods
Collection and transport	collection and transport of the fraction if reused should not be remarkably higher than for mechanical recycling of the same fraction
Energy consumption	energy consumption for washing etc. of the fraction if reused should not be remarkably higher than for mechanically recycling the same fraction
Volume	the fraction should be large enough in volume to enable cost-effective handling
Market	there should be a market for the reused goods

Table 3.2. Characterisation of material flows of plastics for mechanical recycling

Plastic flow	Volume	Homogeneity in material	Cleanness, no laminates	No additives	Market
Households					
HDPE	(✓)	(✓)	(✓)	(✓)	
PP	(✓)	(✓)	(✓)	(✓)	
LDPE	(✓)	(✓)	(✓)	(✓)	
Businesses					
HDPE	(✓)	(✓)	(✓)	(✓)	
PP	(✓)	(✓)	(✓)	(✓)	
LDPE	(✓)	(✓)	(✓)	(✓)	
Agriculture					
LDPE	(✓)				
Non-packaging					
LDPE, HDPE, PP, PET	?	✓	✓	✓	?

Volume	refers to the total amount of recycled material of a particular flow
Homogeneity in material	refers how homogeneous the separately collected fraction is with respect to the sort of plastic

Cleanness	refers to how clean the fraction is with respect to materials other than plastic
Amount of additives	refers to the amount of addititves that, due to specific applications, are contained in the material

Table 3.3. Characterisation of material flows of plastics for energy recovery

Plastic flow	Manageable emissions	Market
Households		
PET		
HDPE		
PP		
LDPE		
Businesses		
HDPE		
PP		
LDPE		
Agriculture		
LDPE		
Non-packaging		
LDPE, HDPE, PP, PET	?	

As can be seen in tables 3.1 – 3.3, the largest uncertainty, and thus the largest potential improvement in resource efficiency, probably lies in the area of non-packaging plastics. This fraction accounts for a large part of the total plastic consumption and as the current treatment option is a mixture of landfill and energy recovery the end-of-life treatment of the waste fraction has a substantial potential to improve. In order for more specific evalutations of the waste fraction to be made, however, more research has to be pursued within the field.

As for plastic packaging, a comparison of the main current treatment and a potential resource efficient treatment of the individual waste fractions (table 3.4) shows that there is some potential to increase the reuse of certain fractions. However, the largest potential to increase resource efficiency lies in the overall reduction of plastic packaging to landfill.

Table 3.4. Treatments of different plastic flows

Plastic flow		Main current treatment	Potential resource efficient treatment*
Households	PET	Reuse, mechanical recycling	Reuse (and mechanical recycling)
	HDPE	Mechanical recycling, energy recovery, and landfill	Reuse, mechanical recycling (and energy recovery)
	PP	Mechanical recycling, energy recovery, and landfill	Reuse, mechanical recycling (and energy recovery)
	LDPE	Energy recovery and landfill	Mechanical recycling (and energy recovery)
Businesses	HDPE	Mechanical recycling, energy recovery, and landfill	Reuse, mechanical recycling (and energy recovery)
	PP	Mechanical recycling, energy recovery, and landfill	Reuse, mechanical recycling (and energy recovery)
	LDPE	Mechanical recycling, energy recovery, and landfill	Mechanical recycling (and energy recovery)
Agriculture	LDPE	Energy recovery and landfill	Mechanical recycling (and energy recovery)
Non-packaging	LDPE, HPDE,PP, PET	Energy recovery and landfill	?

*subject to conditions defined in 3.2 – 3.5

4 Instruments and scenarios

In this chapter, instruments and their relevance in achieving an overall resource efficient plastic recycling system are developed. The major instruments of importance are discussed in detail. Scenarios are used to examplify how a resource efficient plastic recycling can be achieved. The scenarios cover improvements mechanical recycling and feedstock recycling. The scenarios develop the concepts of the producer responsibility and IPP, but also other instruments, such as the deposit/refund-system.

4.1 Instruments

Instruments can be defined as anything that increases incentives in accordance with a desired goal. Instruments are thus aimed at altering the rules on the market. They can be divided into the following categories:

- **Strategic instruments**. This group encompasses strategic policies aimed at environmental concerns, such as the fifteen Swedish environmental goals.

- **Fiscal or economic instruments**. These instruments are intended to give a direct economic incentive to act in accordance with the goal, e.g. a tax on energy use in order to reduce energy consumption. Fiscal instruments can also be subsidiary, such as investment subsidies for bioenergy production facilities, or a deposit-refund system.

- **Regulatory or legislative instruments**. These measures range from instruments aimed directly at improving e.g. environmental performance through emission standards, to instruments that operate more broadly, such as legislative demands for environmental consideration in public procurement.

- **Other instruments**, including voluntary agreements, education and information, and research and development. There is no apparent reason to group these instruments other than that they often are not seen as isolated instruments but rather complementary to the above stated groups.

Instruments do not have to be regulated by the authorities: they can also be used within or between business sectors or between producers and consumers. Normally, a combination of instruments is used in order to achieve a goal. Plastic waste is influenced more or less by several instruments. Some examples are:

- Swedish environmental goals influence the long-term planning on resource use, recycling, etc (strategic)
- Producer responsibility more directly influences the level of recycling (mainly legislative)
- The law on certain beverage packagings affect PET reuse systems and levels (also legislative)
- Environmental taxation, such as energy tax, landfill tax, influence the relative economic performance of treatment options (fiscal)
- Plastkretsen and others have information campaigns on how to sort waste (information instrument)
- This study is an example of research done in order to improve the environmental performance of plastic waste management (research and development)

Several other instruments could be added to the list. The use of instruments depends on what actors and what behaviours are identified as important to influence: the production process, what kind of products thata are produced, consumer choice, etc.

There are two significant instruments regarding plastics, presently and potentially, namely the producer responsibility and the Integrated Product Policy approach. In order to better place these instruments into a context, they are developed below.

4.1.1 The Producer Responsibility

The evaluation of the producer responsibility concludes that the existing producer responsibility is both environmentally and socio-economically justified. It should therefore continue to substantially apply in its present form. However, as the recycling systems have not existed for a very long period, there are yet many problems related to competition, the roles of participants and the efficiency of the systems that need to be handeled. It is also concluded that these ordinances need to be combined with financial instruments that serve as driving forces for increased recycling. (SOU 2001:102)

The evaluation also concludes that there is no clear justification for statutory producer responsibility for other products than those in effect today. There are a number of reasons for this: a large part of the products in question have long life spans, an expansion of the statutory responsibility would mean overlapping of existing ordinances, where other instruments are already in operation for products. Therefore, the evaluation recommends permits to develop voluntary undertakings rather than statutory ones. There are some other recommendations:

- The clarity of the intention and objectives of the producer responsibility must be improved
- The incentives for increased use of recovered raw material should be increased
- The recycling systems' consumer contacts should be improved
- Monopoly effects should be reduced
- Tools for reducing product environmental performance should be developed
- Supervision and monitoring of the compliance of the producer responsibility should be improved

Specifically for plastic packagings, the following recommendation is given:

- Plastkretsen should increase its efforts, both concerning information and activities, in order to achieve the recycling goals.

(SOU 2001:102)

The evaluation of the producer responsibility does not try to evaluate whether or not recycling is better than other options, but rather how efficient the producer responsibility is in fulfilling recycling goals.

4.1.2 Integrated Product Policy (IPP)

The European Commission has presented a so-called Green Paper on Integrated Product Policy. A White Paper on IPP is expected in the summer of 2002. In an extended timeperiod the White Paper may lead to a EU directive on IPP, and if it reaches this stage, IPP will probably be more concrete and more easily analysed than presently. However, IPP has achieved a major response on the environmental arena, and therefore demands a separate analysis.

The strategy of the Integrated Product Policy is to "complement existing environmental policies and legislation by using so far untapped potential to improve a broad range of products and services throughout their life cycle from the mining of raw materials to production, distribution, use, and waste management. Its central element is the question how the development of greener products and their uptake by consumers can be achieved most efficiently". Thus, IPP is not a well-defined single instrument but rather a "mix of instruments that needs to be carefully used and fine-tuned to ensure a maximum effect".

The idea behind the IPP is that once a product reaches the market, there is relatively little that can be done to improve its environmental characteristics. Therefore, the IPP approach will primarily focus on eco-design of products, and the creation of information for an informed consumer choice and incentives for an efficient take-up and use of greener products, and the polluter-pays-principle in product prices. The name IPP stems from:

Integrated: consideration of the entire life cycle of products in the minimization of environmental impact, as well as to a broad approach integrating various instruments to achieve the goal of greening products.

Product: in principle, all products and services are included in the scope of this policy. Focus lies mainly on certain products selected on the basis of their importance and scope of improvement. Although services should not be excluded, they are not the primary focus.

Policy: referring to that the role of public authorities within the IPP approach shall be one of facilitation rather than direct intervention.

Thus, legislation is not the main focus of the IPP, but it may be used as part of a mixture of instruments when appropriate. The pillar of its success is voluntary action by both producers and consumers. Market forces should be used to the largest possible extent. The Green Paper presents several examples of how the IPP may be implemented:

- Get the prices right through Polluter Pays Principle
- Increasing Green Demand
- Supply Side Measures

There is some development of these concepts in the Green Paper, but the idea of IPP is not very concrete at this stage in the process. A major cause for its popularity is the idea of voluntariness: the market would rather regulate itself than let it be done through imposed legislation, the same is true for the administration.

According to its rather vague description, basically any initiative in the environmental field can be labelled as IPP, as long as it is voluntary.

In the producer responsibility report (SOU 2001:102) it is concluded that it may be an advantage to let legislation on producer responsibility be preceded by voluntary undertakings to gain time to learn more about how the systems work as regards competition, the economy, and practical issues. It is further concluded that this procedure may even lead to voluntary agreements working so well that legislation will not be required. Thus, voluntary agreements, such as within the IPP approach, can coexist with legislative measures such as the producer responsibility. A voluntary producer responsibility is indeed possible, and has been suggested for some materials. It can even be argued that a legislative imposing of producer responsibility when voluntary measures are not enough is consistent with the IPP approach, as legislative measures are indeed allowed within the IPP approach, as long as market forces are used to the largest possible extent.

4.2 Scenarios

The instruments above may be applied to plastic recycling in a number of ways. We have in chapter 2 defined criteria for resource efficient plastic recycling, and in chapter 3 applied these to current plastic consumption in Sweden. In this chapter we aim to develop a number of scenarios combining instruments with the plastic fractions that can be recycled more efficiently than is done at present.

Basically, a resource efficient plastic recycling according to the criteria in this study can be achieved just by fulfilling the criteria for resource efficient recycling in section 3.3. In order to substantiate these criteria, and make the analysis more pragmatic, the scenarios can be used as examples. The scenarios do not aim at fully describing all possible developments and instruments.

The scenarios have been developed through a workshop with the reference group of the project. The idea was that their expertise in practical recycling in combination with more theoretical research would result in scenarios that are both feasible and visionary.

4.2.1 Analysis of Scenarios

Many aspects are important for the feasibility of the scenarios. Not only their environmental and economic performance according to the criteria in chapter 3.3, but they also have to be socially acceptable, fit into the legislative structure of Sweden, the EU and the WTO, etc. In order to illuminate all relevant aspects, the scenarios will be evaluated with respect to the following parameters:

- Technology – is the scenario technologically feasible within a foreseeable timeperiod?
- Economy – is the scenario implementable from an economic resources perspective? Does the scenario lead to a different allocation of resources among actors, and would this new allocation be acceptable?
- Legislative – is the scenario in accordance with Swedish or international law and practice?

- Social – does the scenario induce changes in consumer contact, and if so will the public accept the system?
- Market demand – is the industry willing to accept the quality of the recycled material at a premium price?
- Applicability to plastic wastes – is the scenario applicable to relevant plastic waste fractions?

4.2.2 Homogenising the use of plastic materials

Within the recycling industry there is a wish to homogenise the use of plastic materials in order to facilitate the processing. The industry has up to date improved the recyclability of plastics, but there is still a large heterogeneity within the fractions described in chapter 3. For example, for packaging plastics it is only exceptionally that the color additives serve a packaging purpose (i.e. light barrier in bottles). However, an even more strict homogeneity within the groups would drastically increase the potential of substituting virgin plastics.

The system

This scenario implies that, within different industry sectors, a limited number of plastic materials and additives may be agreed upon in order to facilitate the collection of mono-material waste streams and subsequently recycling to a high quality regranulate. A possible development is that the packaging industry may act as a model example and voluntarily adopt a strategy that will eventually lead to this scenario. Packaging plastics are fairly clean of additives that may cause problems when reprocessed. Therefore the number of additives used and the extent to which the plastic material is defined may be homogenized. Examples of the plastic materials that may be agreed upon are the ones that are most commonly used today, namely HDPE, PP, PET, LDPE, PS and PVC. These packaging materials have the potential of being well defined as well as contain a limited number of additives.

As pointed out above, this scenario should initially be applied on products where the choice of plastic material is of minor importance to the function of the product, where there are no legal obstacles as to which plastic material is used, and where it is possible to narrow down the definition of an individual plastic material and its additives. Packaging plastics is a good example of such a product.

The scenario should thus not impede on the process of product development, but rather provide a possibility for producers to take full responsibility of their product(s) by considering the end-of-life treatments at an early stage in the product development chain. Therefore it also constitutes an important scenario in the aspect of the IPP concept.

Plastic Waste Streams of Relevance

The scenario may in the long run be relevant to consider for all plastic waste streams that are presented in table 4.2. The scenario would obviously affect the main part of todays waste streams, and may therefore have an essential impact on the resource efficiency of the plastic recycling system as a whole.

Table 4.2 Plastic waste fractions that are affected by homogeneising the use of plastic materials

Plastic flow	
Households	
PET	X
HDPE	X
PP	X
LDPE	
Businesses	
HDPE	X
PP	X
LDPE	
Agriculture	
LDPE	
Non-packaging	
LDPE, HDPE, PP, PET	(X)

Technological Aspects

Concerning technological aspects, the implemetation of this scenario should not result in any major problems. It would rather help solve the possible extisting complications that are a result of heterogeneity in input material, in the recycling process.

Some companies may have created a niche within their field of operation by developing company-specific materials, either through a specific molecular structure or through a used mixture of additives, that may not correlate well with the possible narrowed definition of the plastic materials to be used. This issue is considered to be of a competitive nature rather than product function related.

Economic Aspects

To some extent the scenario may cause increased costs due to minor switchovers in production in the standardisation of homogeneous plastic material flows. The largest increase in cost of this scenario probably comes from companies that have niched their production.

This scenario does not in itself entail any increased collection and recycling costs rather the opposite, since a high-quality output may lead to a higher demand that enables higher margins for the recycling industry. With more homogenous plastic streams, the quality of the recycled plastic will increase and hedge the margin between prices of recycled plastics and virgin plastics. The extra cost would be for research and development to achieve virgin plastic functionality.

Legal Aspects

On a national level, homogenisation of plastics does not pose any legislative problems. The homogenisation may gradually be implemented for relevant packaging sorts and in an extended timeperiod for other relevant business sectors. However, national legal constraints for packaging producers and products would probably inhibit competition as opposed to international producers and products. This may impose a problem both concerning EU competition law and WTO agreements. For this reason, the best instrument for homogenisation of plastics is probably voluntary agreements within the industry that will eventually lead to the homogenisation of plastic materials and their additives. Thus, the IPP approach may serve a crucial role in the homogenisation of plastics.

Social Aspects

A homogenisation of plastics would not change consumer contact considerably. Collection of consumer plastic waste would not differ from today's system. There is a possibility that more homogenous plastic materials will change the appearance and function of some plastic products. This estethic effect may be of greater concern for the industry than consumers. A homogeneisation of plastic materials, as a result of environmental awareness in the design process may be well understood and accepted by consumers. In its extreme, the scenario may even lead to a consumer demand driven system, as the homogeinity of plastic materials may be recognised as a small sacrifice for a proper end-of-life treatment.

Summary

The scenario has firstly been evaluated with respect to its possible implementation within the packaging industry. It is relevant for products where the choice of plastic material is of minor importance to the function of the product, and where the amount of additives may already be reduced to the minimum. The scenario may very well be applied to certain non-packaging products, as long as the same conditions hold for these fractions too.

The scenario is summarized as feasible. It would be applicable on large volumes of the current wasteflows. It is also possible to carry out at different levels of ambition, with the aim set for different levels of homogeneity or for specific fractions of plastics or business sectors. Considering the globalisation of trade it is to a large extent dependent on the development of and engagement on the issue in the rest of the world. Therefore, the future development of the IPP approach within the plastic sector is probably very important for the feasibility of this scenario.

The scenario may be regarded as a logical step in the refining of the plastic recycling system as a part of the evolution towards a more sustainable society. If we are to have a well functioning and more resource efficient plastic recycling system in the future it is of importance that the material streams are somewhat homogeneous with respect to material and additives.

4.2.3 Extending the deposit-refund system

The existing deposit-refund system in Sweden only includes beverage bottles in PET. This scenario develops the idea that the system can be extended to include other containers than beverage bottles in other polymer materials than PET. Since the polymer material is very sensitive when it comes to recycling it may be wise to establish proper collection systems for this material in particular (as opposed to other materials of more inert character). This would again, in as much as it is possible, secure homogeneous wasteflows in the end. The current deposit-refund system in Sweden has proven to be exceptionally successful in this aspect.

The system

The system implies that plastic packaging waste of rigid character should be returned in one single automat at the place of purchase, which thus would serve a number of plastic reuse (possibly also recycle) containers rather than just PET bottles. In an extended time period an automatic sorting system may be connected to the recycling automat. The sorting system may sort from the material information that is stored in the product-specific EAN-code. In an extended time perspective more detailed information may be stored in the EAN-code, e.g. information of when the packaging product was produced (this gives an indirect idea of whether the packaging has been reused e.g. for a private purposes in the household as well as the probability of the level of degradation of the material). This system would allow for the possibility to sort out products for the waste treatment alternative (reuse, mechanical recycling or energy recovery) they are best suited for. In this way the plastic recycling system as a whole may be made more resource efficient by both increasing the wasteflows for reuse and for mechanical recycling. The scenario does however presume a detailed sorting system and a rather extensive logistical system for collection of plastic fractions from the place of purchase/refund.

Plastic Wastestreams of Relevance

The scenario may be relevant to consider for the household plastic waste flows (see table 4.2). It would include plastic waste to the amount of approximately double the size of todays volumes, some 8-30 000 tons extra (depending on how large the hard plastic fraction from the households actually is). It would thus not cover the majority of plastic waste fractions for which a more resource efficient recycling may be relevant to achieve.

Table 4.2 Plastic waste fractions that are affected by an extension of the deposit-refund system

Plastic flow	
Households	
PET	X
HDPE	X
PP	X
LDPE	
Businesses	
HDPE	
PP	
LDPE	
Agriculture	
LDPE	
Non-packaging	
LDPE, HDPE, PP, PET	

Technological Aspects

The technology needed for the implementation of this scenario basically already exists. The recycling automats function for several different types of PET bottles. EAN code readers exist in practically every store in Sweden. It is the combination of the two that needs some development in the extended version of the scenario. Therefore, technology is not considered a problem for this scenario.

Economic Aspects

The increased deposit-refund system will probably lead to increased administration. In order to get the system to work without increasing the demand for transportation and storage, the logistics need to be made more advanced. The same is true for the system of recycling a large amount of different container types from a vast amount of producers. The costs are likely to trickle down to the consumer. A possible benefit from the system is that it may lead to a better use of the normally empty return transports from deliveries.

Legal Aspects

In the aspect of legal issues there does not exist any major problems in the implementation of the scenario. The system may be based either on a voluntary system or a legislative system similar to the law on certain beverage packaging that regulates the PET refund system. However, according to the Department of Law, the PET system was created under a strong public opinion at the time of introducing PET bottles as a substitute for glass bottles. There was a strong demand for a recycling system similar to the one that already existed for glass bottles. In order to implement a similar system for other plastic containers, the same public opinion would probably be needed. This renders the voluntary system as a more probable solution for this scenario.

Social Aspects

An increased deposit-refund system according to the specifications made above would lead to an increased effort for consumers in returning plastic containers to the place of purchase, and theoretically the consumer would have to have more money lended to the recycling system in form of deposits. This lending is however considered to be of marginal importance. The increased bulk of containers would also be of marginalimportance – the consumer manages to carry the same containers the other way, and the weight of plastic containers is negligible.

The existing deposit-refund system for PET bottles has been fully accepted. Consumers consider it a functioning system, and it has reached very high levels of recycling. The deposit works as bait for the customer to return the used packaging.

An issue that could create problems in the implementation is the lack of space in the individual stores that handle the returned bottles today. The storage capacity is however directly related to the pick-up frequency: if the recycled volume triples, a tripled pick-up frequency would result in the same storage capacity demand and the same amount of transports per container. The assumption that the same machine may be used for all plastics rather than just PET plastics leads to the fact that no change needs to be done in the stores other than changing machines.

Summary

In summary the scenario may lead to an increased opportunity to reuse (and recycle) high-quality materials and goods. Through coding, it becomes fairly easy to assure a high level of quality for the recycled product. The scenario does imply certain positive changes in the market structure: returned containers are to a larger extent handled as a product or resource, rather than as waste. It also implies a greater potential to "close the loop" in the recycling chain of plastic material. Used products may to a greater extent be reused or recycled to substitute the same or a similar product/ material once more. It is probable that the system would lead to very high levels of reuse/recycling because of the refund incentive.

The negative aspects of the scenario are that it is heavy in administration, expensive, and is only relevant for a rather small part of the plastic consumption.

4.2.4 Applying Automated Sorting Technologies

In Europe, and to some extent in Sweden, there are many new sorting technologies being tested. Examples are near infrared technology, flotation techniques and electrostatic sorting. No specific technique will be considered in this scenario, but the general possibilities of implementing automated sorting systems will be developed.

The system

This scenario implies the implementation of automatic sorting systems for plastic on a central or decentralized level, depending on what solution is more economically and practically feasible. The sorting may be placed after collection in the facilities where the plastic is sorted manually today or in connection with the recycling facilities. The purpose is to increase the purity and homogeinity in material of the sorted plastic waste fractions.

Plastic Wastestreams of Relevance

This scenario is firstly relevant for the hard plastic fractions (HDPE and PP) from households as the industry usually manages to deliver well-sorted fractions already. The scenario is therefore relevant for around 10 000 tons of plastic waste which is a minor part of the total plastic consumption.

Table 4.3 Plastic waste fractions that are affected by the implementation of automated sorting technologies

Plastic flow	
Households	
PET	
HDPE	X
PP	X
LDPE	
Businesses	
HDPE	
PP	
LDPE	

Agriculture
LDPE
Non-packaging
LDPE, HDPE, PP, PET

Technological Aspects

As noted in the introduction several sorting techniques are used for commercial purposes today and are constantly being refined, and technology is therefore an issue that concerns this scenario. The actual technical performance and competitiveness of the different methods is difficult to evaluate, as no studies have been found on this issue. The choice of sorting system is dependent on the waste fractions to be sorted. Some techniques may sort out one sort of plastic material at a time or may be more relevant for waste fractions that also consist of materials other than plastic. An evalutation of different techniques relevant for the plastic waste fractions in Sweden needs to be made in order to assess the possible improvement of the resource efficiency of plastic recycling that may result from the implementation of a feasible, automated sorting system.

Economic Aspects

The economic aspect is probably of minor relevance for this scenario. The implementation of a new sorting technology would entail a single investment. This would in turn enable more elaborate recycling and products of higher quality. The manual sorting carried out in Sweden today has relatively high running costs, which would probably be cut with an automated sorting technology and thereby maybe even reduce the overall cost of recycling.

Legal Aspects

As there are no legal obstacles in the way of implementing new sorting techologies, the aspect is not of relevance for this scenario.

Social Aspects

In the social aspect the scenario does not imply any obstacles. The scenario affects the system further down the recycling chain, away from customer contact.

Summary

In summary the scenario would probably lead to positive effects on the market, since it implies a recycled material of higher quality, with a greater potential to compete with virgin material in certain applications, than today. It would entail higher investment costs, but in the long run also lower running cost and therefore total costs compared to the present system. The scenario is, however, at present only relevant for a relatively small part of the total plastic consumption.

4.2.5 Implementing new recycling technologies

The System

This scenario implies a complementary addition of recycling methods under development, or methods that due to other priorities in Swedish waste management (energy recovery) have not been interesting before, to the current recycling system. The method that is closest at hand in Sweden is the use of pretreated plastic packaging as a reducing agent in blast furnaces of steelworks. This method has been well implemented in Germany. Another method that has been well implemented in Germany is the gasification process of the Sekundärrohstoff Verwertungs Zentrum (SVZ) “Schwarze Pumpe”. This method can however not be implemented in any existing processes, but rather implies the construction of a new recycling plant. Other chemical recycling methods of interest may be hydrolysis, glycolysis and methanolysis of PET.

In order to simplify the evaluation of this scenario and with respect taken to the fact that no relevant information was found on the chemical recycling of PET, it will be restricted to considering the first to chemical recycling methods presented above. The blastfurnace and the gasification process of the SVZ “Schwarze Pumpe” will therefore be evaluated. The blastfurnace requires a separate collection and pretreatment of the plastic fractions and therefore it is assumed that the first activities in the recycling chain are similar to the ones of mechanical recycling. The gasification process also requires some kind of separation, although not as thourough as the one preceding the blastfurnace.

Plastic Wastestreams of Relevance

This scenario is, as defined and delimited above, relevant for all plastic waste fractions, including non-packaging plastic. It may thus affect the larger parts of the plastic consumption, see table 4.4.

Table 4.4 Plastic waste fractions affected by the implementation of new recycling technologies

Plastic flow	
Households	
PET	X
HDPE	X

PP	X
LDPE	X
Businesses	
HDPE	X
PP	X
LDPE	X
Agriculture	
LDPE	X
Non-packaging	
LDPE, HDPE, PP, PET	X

Technological Aspects

In the aspect of technology this scenario may not have to imply any major obstacles. Both the blastfurnace and the gasification process of the SVZ "Schwarze Pumpe" are in successful operation in Germany. The use of plastic waste in blastfurnaces requires some modifications of the current process, where coal is used.

Economical Aspects

In the aspect of economy the scenario may imply some difficulties for both methods. The blastfurnace requires a secured input of plastic waste material that is relatively large in size. This may be next to impossible to achieve in Sweden without some kind of subventional regulation. The gasification process may require the building of a whole new plant, which of course requires high investment costs.

Legal Aspects

In the aspect of legal issues the scenario does not imply any major difficulties. The aspect is therefore of minor relevance for this scenario.

Social Aspects

In the social aspect the scenario does not imply any difficulties. The scenario affects the system further down the recycling chain, away from customer contact.

Summary

In summary this scenario would impose a major change to the plastic recycling system as a whole. Under the condition that the findings made in chapter 2.2.1 are true the scenario would imply great environmental improvements as well. However this scenario needs further evaluation under Swedish conditions before any major decisions can be made.

4.2.6 Other approaches

IPP and insurance financing

A possible solution within the voluntary IPP approach (or, for that matter, also for a legislative instrument) is that producers "buy themselves out" of their responsibility through an insurance, where the insurance company ensures proper end-of-life treatment of their products. By differentiating the insurance fee for the recyclability of the products, the producers get a direct economic incentive to produce more recyclable products. The purpose of the insurance solution is that the administration of the system is market based rather than institutionalised, which will improve its efficiency. The voluntary system would have to be backed up with a threat of direct economic or legislative instruments in order to produce incentives for participation. The system has not been developed in detail, and has at present no solution for the free rider problem – companies that choose not to participate in the insurance system and therefore avoids the recycling costs altogether.

Legislation on environmental information

Information is a necessary part of all systems, and is rarely seen as a separate instrument. An example of an information instrument in combination with other instruments is a legislative demand for information on the recycling of producing companies' products in their annual or environmental reports. This would produce a direct feedback to a specific company's compliance with the recycling goals for its products.

Public procurement

Sweden already has a law that says that environmental consideration should be taken in public procurement. This law could create a demand for more environmentally friendly products and open up new markets that would otherwise open up by themselves.

4.3 Overall summary of instruments and scenarios

This chapter has shown a number of possible ways of increasing resource efficiency in plastic recycling. Instruments at hand have been described and then applied to some scenarios. Basically, there seems to be several ways of increasing resource efficiency in packaging plastic recycling, but in order to include non-packaging plastics, which probably has the largest potential of improving in resource efficiency, either an IPP based approach (a voluntary system) or an extension of the producer responsibility seem to be the most viable way. It is very difficult to say what effect these instruments would have as relatively little is known about the composition and possibilities of non-packaging plastics.

The scenarios presented are in no way exhaustive or exclusive – they may induce a more resource efficient system as they are, or a combination of the alternatives may result in an even more efficient system, and there are most certainly other options available that have not been analysed here.

5 Discussion

Resource efficiency cannot be unambiguously defined. This has implications as to what conclusions may be drawn from the study. However, under relatively liberal constraints, the most important resources that have to be considered may be defined. The process of a step-by-step definition of the most important issues and more resource efficient treatments does not avoid the weighting of disparate resources, but it does give a structured and yet pragmatic approach in defining resource efficiency of plastic recycling. This methodology permits comparison of any plastic waste fraction to the hierarchy. The hierarchy may be used as a checklist in order to pinpoint what treatment is the most resource efficient for a specific waste fraction, dependent on the characteristics of the fraction. The method does include elements of implicit valuations, such as the checklists for resource efficiency and the ranking of treatment options. It cannot provide a definite answer to resource efficiency, as can no other method. It is our hope that it may provide some structure to the problem analysis.

There is an inherent problem with reuse or mechanical plastic recycling, namely the degrading of the plastic material. In order to maintain durability, one of the most important aspects of the plastic material, continuous inflow of virgin plastic is needed. This inhibits the level of reuse and mechanical recycling that we should aim for – a too high percentage of reuse and recycling may result in deficient products. The case in which the function of the plastic product cannot be maintained may not be regarded as resource efficient.

Other problematic issues are the data gaps that exist. For the end-of-life treatments, there is mainly a lack of data for and studies on feedstock recycling, where blast furnace and gasification seem to be the most interesting alternatives. This means that innovative, and potentially resource efficient, treatments cannot be properly evaluated. For the actual plastic waste streams and the composition (and amounts) of non-packaging plastics are relatively unknown. Therefore, some two thirds of the total plastic waste that also has the largest potential to increase in resource efficiency cannot be properly evaluated. However, as long as these plastics can be defined by the characteristics in the hierarchy, they may be evaluated to give an indication of direction.

Eventhough this study mainly deals with recycling i.e. end-of-life treatments, waste minimisation requires some attention as well. As long as the waste arises, all end-of-life treatments lead to environmental impacts, often on the same level of magnitude. If no waste arises, no environmental impact occurs, and if less waste arises, less environmental impact occurs. Thus, waste minimisation is the only "option" that can lead to dramatic improvements in resource efficiency (apart from the reduction of landfilling). Instruments that have the possibility of increasing incentives not only for end-of-life treatment but also for upstream performance and product design are thus potentially very powerful. IPP does, in contrast to the producer responsibility, have the possibility of directly including upstream performance and product design, and is therefore potentially a much more powerful instrument. When looking at product design and upstream performance it is important to consider the product functionality – changing the former may also cause a change in the product functionality, which in turn may lead to environmental impacts that can be more difficult to predict. An example of this is if reducing the amount of material in a beverage container also leads to an increase in the amount of broken containers.

In order to place the contribution of plastic recycling in a context, it may be helpful to benchmark it to some other areas. This is done below through two examples.

How much fossil fuels are saved through plastic recycling?

In Carlsson (2000) it is calculated that in the most favourable case for plastic mechanical recycling compared to energy recovery, the emission of some 27 kilos of CO_2 equivalents are avoided per capita and year. This roughly equals 160 kilometers car driving per capita and year (if the car driven is small, economical on petrol, and of a recent year model, with no passengers in the car).

The relative environmental impact of plastic waste

The plastic waste constitutes some 2-12% of the weight of the household waste(municipal solid waste) (Sundqvist et al, 1999). Thus, plastic waste is relevant, but not dominant, in waste mangement decisions.

The municipal solid waste contributes to some 0,1-1% of the per capita environmental impact (concerning global warming, acidification, eutrophication, and photo-oxidant formation) in Sweden (Sundqvist, 2001). Thus, waste management has minor importance for the per capita environmental impact.

These two examples give a notion as to how much effort should be put into resource efficient plastic recycling compared to other environmental issues (this, of course, as long as there is a trade-off between the effort spent on different efficiency issues). It can be argued that it is much more important to spend time and effort on reducing transports in society (which account for to some 20-25% of the carbon dioxide emissions in Sweden) rather than increasing resource efficiency in plastic recycling. It can also be argued that the one does not inhibit the other.

5.1 Further research

Relatively little is known about feedstock recycling, which makes analysis of this option difficult. The other treatment options undergo constant technological development aswell and this development may change the relative ranking with respect to resource efficiency. Therefore, there is a constant need for updated LCA studies in the area in order to make informed decisions.

For non-packaging plastics, there is a large need for a mapping and compilation of waste streams, waste composition, etc. The composition of plastics may probably be relatively homogenous within specific ranges of application (such as automotive parts, electronic casings), which then would suggest a division of this large, heterogeneous plastic fraction into subgroups that may be easier to analyse and recycle.

6 Conclusions

Resource efficiency cannot be unambiguously defined if more than one resource is involved. To define resource efficiency for several resources, valuations need to be made. A strict definition of the relative importance of resources for resource efficiency is highly dependent on the studied conditions. Therefore, the method used in this study to define resource efficiency aims to improve transparency and pragmatism, although the valuating steps cannot be avoided altogether. The method ranks treatment options for plastic waste and conditionalises their applicability.

Plastic recycling in Sweden can become more resource efficient, using the definition of resource efficiency from this study. This improvement can be done by decreasing the amount of plastic waste to landfill, and by pushing the waste fractions up the hierarchy of resource efficiency. There is possibly a large potential improvement in resource efficiency for non-packaging plastics, but as there are large data gaps for this fraction, there are large uncertainties as to the possibilities of recycling these waste streams.

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