Plastic REVolution Foundation

Mapping of available methods for plastic feedstock quality improvement for pyrolysis treatment in Accra

Report authored for and supported by the Norwegian Retailers' Environment Fund

Contents

1. Introduction

The menace of plastic pollution is one of the pressing challenges of our time. It kills wildlife, it chokes sewages and drainage systems, and not least it leaks into the oceans and threatens marine life. While plastic has revolutionized production and consumption, making what we today consider modern life possible, its mismanagement has proven detrimental. Plastic is not the problem, plastic waste is. This is the view of the Plastic REVolution Foundation, and the background for our first project in Accra, Ghana.

The Plastic REVolution Foundation (PRF) is founded on a commitment to combat plastic pollution in an economically sustainable way, by the Norwegian industrialist Kjell Inge Røkke. It is one of his many initiatives to improve ocean health. The Foundation is led by Erik Solheim, former Norwegian Minister of Environment and Head of the United Nations Environment Program.

The Foundation aims to build projects that have self-sustained project economics and thus represent long-term sustainability and replicability prospects beyond one-off charitable grants. Furthermore, PRF aims to demonstrate a visible impact, and incorporate social objectives with environmental objectives. Part of this concerns engaging local communities and local authorities and aligning with government objectives on environmental safeguarding and economic development.

PRF's first project is set in Ghana, which is believed to be in a position to take the lead in creating global solutions to plastic pollution. West Africa has over the past years been home to far fewer international initiatives targeting plastic waste than e.g. South-East Asia, despite also struggling with pollution. Ghana is nonetheless making significant progress on sustainable development, and its governments have taken great steps in tackling plastic waste, becoming the second ever partner country of the Global Plastic Action Partnership (GPAP) of the World Economic Forum.

The vision of eliminating plastic waste in nature and cities, thus improving the environment as well as sanitary conditions, is supported and promoted at all levels, including the national government, MMDAs (Metropolitan, Municipal and District Assemblies) and general society. The government has launched the ambitious National Plastics Management Policy, and President Akufo-Addo has vowed to make Accra the cleanest city in Africa, continuing to build on the work of those before him. The local authorities in Accra have also been internationally praised for their efforts to improve waste management by supporting the informal sector. Building on the valuable relationship with Ghanaian authorities built by Kjell Inge Røkke through Aker's operative presence, this was a natural starting point for PRF in exploring solutions to plastic waste.

The Foundation has identified a great opportunity to reduce plastic pollution and develop viable collection models, which can represent the first of its kind and form a model for future replication elsewhere. Pyrolysis has been identified as one of the most viable existing technological solutions for contaminated and mixed plastic waste. Nonetheless, reaching satisfactory feedstock quality for chemical recycling is necessary – it is possible, but an affordable solution is required.

PRF wishes to contribute to achieving the vision of seeing Accra free of plastic waste, and the Foundation has consulted the national and local authorities towards the realization of this first project, which enjoys broad support. There is momentum to do something about the immense problem that is plastic pollution in Accra, and PRF believes that a Plastic-to-Liquid plant would be an invaluable part of the solution. The ultimate objective is to develop a model for self-financing collection through the transformation of used plastics into a product of value. If this concept is proven, not only can the plant in Accra be realized, but it would demonstrate a solution that could subsequently be brought to other parts of the world. Enabling the valorization of currently "worthless" plastic waste would create jobs across various layers of society (including among waste pickers), improve general waste collection, and contribute to safeguarding the environment by diverting plastic waste from landfills and the environment. Further background to the potential social, economic, and environmental benefits of the project, as well as the previous work of PRF, is provided in the End-of-Phase report that was written in Q2 of 2020.[1]

As described in the End-of-Phase report, concrete challenges however persist when it comes to reaching economic viability - particularly due to the cost of acquiring feedstock, including collection, transportation and pre-treatment. This must be solved either by lowering costs or by increasing revenues. In the fall of 2020, PRF focused specifically on elements related to reaching economic viability, financially supported by the Norwegian Retailers' Environment Fund (HMF). One workstream, summarized in this report, centered around the specific topic of plastic feedstock quality for treatment through pyrolysis, and what can be done about it both in general and for the Accra project. Two other workstreams were also executed during this period, also financed by HMF and summarized in end reports. One specifically investigated Extended Producer Responsibility as a policy tool towards alternative financing mechanisms for waste management, and the status for its potential implementation in Ghana.[2] Another investigated local offtake opportunities and prospects for increasing revenues through pockets of opportunity and government support.[3]

This report on feedstock quality and pre-treatment options is divided into three parts. The first part gives further background to the importance of feedstock quality in the context of pyrolysis, and details on the work done on feedstock quality in Accra. The second part ventures into an assessment of available approaches to improving plastics quality, from a general perspective (i.e. not only specific to the Accra project). The third part presents the recommended solution for the Accra project, thus bridging parts 1 and 2.

PRF would like to thank all who have contributed to this work and report, directly and indirectly. Due to the commercially sensitive nature of some of the information presented, concrete and detailed references are not provided. PRF welcomes input around the elements presented, and we hope that this report can provide a contribution to a joint effort of solving challenges related to feedstock quality for recycling across the world.

[1] Available at https://www.revocean.org/the-plastic-revolution-foundation-summarizes-learnings-in-comprehensive-end-of-phase-report/
[2] Available at https://www.revocean.org/report-developing-extended-producer-responsibility-for-packaging-in-ghana-a-brief-introduction-and-status-report/
[3] Available at https://www.revocean.org/report-local-offtake-prospects-mapping-of-the-diesel-value-chain-and-pricing-structure-in-ghana/

2. Background to the focus on plastics quality: The pyrolysis process and problematic contaminants

Pyrolysis technology has been in use during centuries for among others conversion of coal to coke and to extract tar from wooden material. During the past few decades, pyrolysis technology has been adapted for materials containing hydrocarbons that are difficult to destroy (e.g. car tires). A reason this technology has gained traction is a combination between oil prices hiking at more than 100 USD/bbl, and growing international concern related to problems and challenges associated with plastic pollution.

The function of a pyrolysis oven, or reactor, is to convert solid state plastics to flammable gas, which depending upon the end use may be further treated and refined. The pyrolysis process is in itself relatively robust, and can accept a variety of feedstock.

The liquid output from the process is a hydrocarbon mixture with a composition not very different from crude oil, which might be used directly as feedstock to a refinery. Raw, untreated and unrefined pyrolysis oil is however a complex chemical product. It may be transported to and further treated in an oil refinery for the purpose of either selling as diesel, or feeding into olefin crackers with the aim of producing new, equal-grade plastics.

Several pyrolysis technology developers have gone to the step of including a mini-refinery as part of the tail end of the pyrolysis process. This involves upgrading the pyrolysis oil to diesel or naphtha to be blended in with virgin diesel/naphtha produced from crude oil. Such upgrade facilities will naturally increase the investment level of pyrolysis facilities. It should be noted that refinery capabilities in Ghana are limited, and there are no olefin crackers along the West African coastline. A pyrolysis facility in e.g. Ghana aiming to produce new plastics would therefore have to ship its products to Europe where customers are located. The topic of local offtake options is further described both in the End-of-Phase report as well as in a separate report on local offtake prospects financed by the Norwegian Retailers' Environment Fund.

It should also be noted that different core processing variations may be adopted, including batch vs. continuous feed, horizontal rotary kiln, fluidized bed and so forth. It has not been established whether any of these have a notable influence on tolerance for varying feedstock quality. As an industry in its infancy, process adaptations furthermore are expected to be implemented also going forward, potentially taking this challenge into account.

Regardless of process adaptations however, the quality it is possible to achieve on the end product will be correlated closely with the quality of what goes in. As put by one stakeholder: "If you put crap in, you get crap out". Thus, in the face of requirements from the off-takers of the end products, the issue of feedstock quality must be approached consciously and carefully. This section of the report goes more into detail of considerations that must be made in relation to assessing the viability of plastic feedstock to a pyrolysis plant.

In order to assess the suitability of the input material in relation to the robustness of the process and the quality of the end product, the following "categories" must be considered, as also described in the report authored by Norwaste and supported by PRF (in Norwegian)[4]:

- Polymer content, i.e. plastic types
- Content of moisture, contaminants and composite materials
- Other properties of the plastics feedstock than their polymer type only
    - Content of composite additives
    - Material shape

Each of these "categories" are described in further detail below.

Polymer content

Firstly, not all plastics types are well suited for pyrolysis. Highly wanted materials are polyolefins, i.e. polyethylene (PE) and polypropylene (PP). Some types of plastics are unwanted, but to some degree accepted, such as polystyrene (PS) and Polyethylene terephthalate (PET, polyester). PET is unwanted due to emissions of oxygen in the pyrolysis process.

Finally, some types of plastics constitute a significant problem also in very small amounts - such as Polyvinyl chloride (PVC) as the end product should contain as little chlorine as possible (which constitutes around 40% of the content of PVC). When PVC is melted down and converted to gas there will accordingly be developed chlorine gas. This is incompatible with the end product quality that a pyrolysis facility must meet, i.e. a chlorine level close to zero.

As mentioned in the introduction to this section, some adjustments may be made to the process to remove unwanted chemical components, such as chlorides, through e.g. hydrogenation or adding of chemicals to the process for the purpose of binding unwanted compounds. For instance, the formation of chlorine gas may be reduced by introducing caustic, and grinded limestone can bind unwanted sulfur in the reactor. However, process adjustments have certain limitations and will not greatly alter the properties of the end product. Thus, it should rather be considered a control mechanism to achieve the desired end quality, in combination with a relatively high degree of control over process input.

The below table illustrates an example of requirements for polymer contents from a pyrolysis provider. While the exact acceptable percentages may vary somewhat, it is found that the general proportions apply across the board for various pyrolysis technology developers.

4 Available at https://norwaste.no/muligheter-for-pyrolyse-av-blandet-plast/

Table 1: Example of quality criteria for pyrolysis of plastic.

Symbol	Name	Abbreviation	Acceptable [weight-%]
	Wanted polymers		
02 PE-HD, 04 PE-LD	Polyethylene	PE, HDPE, LDPE	100
05 PP	Polypropylene	PP	100
	Unwanted polymer		<10 (total)
01 PET	Polyethylene terephthalate	PET, Polyester	<5
6 PS	Polystyrene	PS, EPS	<10
	Other (Polycarbonate)	PC	<1
03 PVC, 3 V	Polyvinyl chloride (contains chlorides)	PVC	<1
	Polyamide	PA	<1 (total)
09 ABS	Acrylonitrile butadiene styrene	ABS, (Lego)	

Content of moisture, contaminants, composite materials

Other than wanted vs. unwanted types of plastic materials, other materials than plastics can be described as the second challenge to solve when dealing with plastics recycling as usage will expose the material to various types of contamination.

Specifically, types of contamination that may constitute an issue include:

- Moisture. Water constitutes an issue to the process because energy requirements will go up when water is evaporated during the pyrolysis process, which takes place at a temperature of 400^0 C +. Furthermore, water contains “trapped” oxygen, which may disturb and even destroy the pyrolysis process which takes place under the absence of oxygen.
- Organic contamination. This includes food waste, soil etc. While some types of organic contamination may not constitute a challenge, there are indications that this correlates closely with prevalence of unwanted chemical components such as chlorides. It must be clarified whether elevated levels of e.g. NaCl and other sources of chlorides would cause a challenge, through the formation of chlorine gas or hydrochloric acid that may affect the equipment, the process and the end product. Furthermore, the nature of some organic contamination makes

it difficult to remove in a sorting and pre-treatment process (e.g. it is sticked to the surface of plastics, such as food oil). This challenge was encountered during the collection in Accra, as will be further described later in this report.
- Metals, inert materials (e.g. sand) and the like will not cause any reaction during the process, but merely be left in the reaction chamber as waste to be removed.
- Paper, cardboard and other types of material that do not contribute to the production of the wanted end material (and often can bring unwanted humidity into the process as these materials soak up water, as well as oxygen).
- Unwanted chemical elements. Waste plastic may contain traces of sulfur originating from plastics that are contaminated with sources of sulfur, and this will end up in the final product. Diesel specifications in Europe have an extremely low tolerance level for sulfur. Ghana has adopted similar specifications, i.e. sulfur content for diesel will have to be negligible in order to be traded and sold to the domestic market. As described in the previous section, this may be partly handled by passing the product through a hydro-treater, or by adding chemicals to the process. If however the final product is sold and taken over by a refinery or a cracker operator, there should be less of a problem with traces of sulfur in the pyrolysis product.

Some of these contaminants would be introduced from mixing with a general waste stream or being otherwise exposed to mixed waste incl. some organics, and some would enter the feedstock stream as an inherent part of the product such as labels. Post-consumer plastics is particularly difficult in this regard, as post-industrial and post-commercial is often more homogenous and relatively clean.

It must be highlighted that while some types of unwanted non-plastic materials do not constitute a problem neither to the end product nor to the chemical process, their presence lowers the yield of the process and thus contribute to worsening the economic prospects of the plant.

Furthermore, high levels of waste will require additional maintenance and more down-time due to the formation of tar and soot that must be cleaned out of the reaction chamber, than when dealing with a pure feedstock stream where most is transformed into a usable end product.

The below table illustrates an example of quality specifications regarding unwanted non-polymer materials.

Table 2: Tolerance limit for contaminants

Element	**Tolerance (weight-%)**
Inert materials (dust, ash, sand, metals)	< 5
Organic materials	< 5
Moisture	< 5
Total tolerance for non-plastic	*< 10*

Table 3: Tolerance limit for Chlorides and Sulfur

Element	Tolerance (mg/kg)
Chlorides	100
Sulfur	10

Other properties of the plastics feedstock than their polymer type only

Lastly, several factors contribute to determining whether the plastics feedstock is suitable for pyrolysis based on product properties.

Content of composite additives

The plastic products may contain composite additives, in order to alter their properties - enhancing for instance softness, durability, chemical stability or flame resistance. For instance, cable insulation polymer made of PE is blended with flame retardant substances is a typical example of a material that must be avoided as feedstock. Also bio-based plastics may create significant difficulties if introduced to a pyrolysis process, as they can contain long alkanes with heavy contents of chlorides. These additives may constitute a significant part of the polymer and contain elements not expected in polymers. Finally, rigid PP and PE often contain filler material (often light minerals like chalk) which will end up as waste material in the pyrolysis process. Such filler material represents little or no problem process wise but is reducing the yield. I.e. process capacity is utilized to manufacture waste instead of processing as much as possible of saleable product.

These are merely some examples of products that should be avoided due to their content of composite additives.

Material shape

Also the shape and related properties of materials going into the process can affect the efficiency and performance of the process. For instance:

- Flexible plastics have more surface and lower weight than rigid plastic materials, which makes them more prone to contamination.
- Both flexible plastics and expanded types of plastics (foam) have a lower density than rigid types of plastics, which creates capacity limitations.
- Furthermore, the lower density potentially increases logistical costs of transportation and storage of feedstock, as well as makes sorting procedures more difficult.
- High variation in plastic types (e.g. rigid, flexible, expanded) makes automated (e.g. cleaning) processes difficult to adapt properly to the needs of the feedstock stream.

The next section gives further background to PRF's strategy to the outcome of the pilots in Ghana, given this starting point of quality considerations that must be made in the context of considering building a pyrolysis plant.

3. Outcome of the pilots in Ghana and strategy to assess available cleaning techniques

A great deal of the work in Ghana has been centred establishing certainty in the area of feedstock supply – with regards to quantity, quality and cost.

The key to developing a viable supply chain for plastic waste is seen by PRF as utilizing both the formal and the informal waste management sector locally. This involves being prepared to be agile and adaptive to local changes and reactions once the project is initiated, but ensuring sufficient certainty that enough feedstock at a high enough quality can be obtained from the onset of the project.

Initially, the majority of plastic feedstock is expected to come from sorting plastic feedstock from general waste at existing waste management plants, and some from collection directly from the informal sector (e.g. through the use of collection points). By initiating sorting of feedstock from established waste management plants and putting value to a fraction of household waste that currently has no other final treatment solution than landfilling, it is considered the effect of successful implementation will indirectly incentivize improvements to the general waste collection in Accra. This would likely benefit areas that currently do not enjoy well-developed service infrastructure or cannot pay for collection and would contribute to building sustainable value chains based on household waste.

Over time, it is the ambition of PRF to collect the plastics closer to the source, by working with formal waste management companies and increasing the share received from the informal sector. Eventually, this should lead to improved sorting at source through a variety of channels: direct collection policy by waste management companies, economic incentives, and/or government-driven educational programs.

The feedstock availability has been investigated through initial feasibility studies commissioned during the first months of the project, and two pilot studies conducted on the topic on feedstock supply specifically - piloting both the sorting of feedstock from central sorting facilities, and incentivization of informal sector workers to deliver mixed plastics being collected from the streets and other sources.

The work around the pilots is described more in-depth in the End-of-Phase report authored by PRF during Q2 2020 and published in October '20[5]. This report also covers an extensive description of the Accra waste and plastics value chain, for further background information.

Overall, the main challenge related to the feedstock quality is to reduce the contamination level of biological and inert materials in the feedstock to an acceptable level. Relatedly, the observed levels of Chlorides and Sulfur exceed the acceptable levels for a pyrolysis process.

Below, further detail to the tested collection methods and findings on quality for each source are presented.

[5] Available at https://www.revocean.org/the-plastic-revolution-foundation-summarizes-learnings-in-comprehensive-end-of-phase-report/

3.1 Feedstock from central sorting facilities

In Accra today, a mix of private contractors and the Accra Metropolitan Assembly’s (AMA) Waste Management Department handle waste management. Solid waste management is largely privatized. Waste management companies are awarded waste management contracts for a specific area through a tendering process. AMA prepares the waste management contracts, which do not involve any funds, but the companies are given the right and regulated through the Assembly's fee fixing resolution by gazette to collect a fee from the households and other waste producers in their allocated zone.

The formal collection of waste from households, markets etc. is carried out primarily by three-wheel motor vehicles Borla Taxis/tricycles. Some are also collected by ordinary collection vehicles with a compacting chamber.

Much of the waste still goes to landfills, but increasingly it goes to further sorting. There are two major waste sorting plants in Accra. The oldest facility, ACARP, is located on the border of the Eastern region, while the newest, IRECOP, is located centrally, by the Korle Lagoon. The opening of IRECOP in the first half of 2019 has led to increased central sorting. Both sorting facilities are owned and operated by Jospong Group of Companies. The waste initially received at the sorting plants is mixed, and the plastic is highly contaminated. The estimated composition of this waste includes 55-60% organic waste, approximately 15-17% plastic, as well as textiles, metals, diapers and mixed residual waste.

The main purpose of the ACARP and IRECOP sorting plants is currently to extract as much organic waste as possible for composting. The organic waste is separated through holes in a drum screen, followed by a two-stage screening. What passes the drum goes to manual sorting. The manual sorting primarily takes out some PP, PE and PET, but the volume is relatively low, partly due to early picking from the informal sector. The sorting operators also sort out some bulky, large items, textiles and more. A magnet removes magnetic ferrous, and while it should be noted that this method does not remove non-magnetic metals (such as aluminium), very little of these materials were observed during the pilot. At the end of the process line comes a fraction, called “RDF”, with high plastic content.

During the pilot at the two sorting plants in Accra, IRECOP and ACARP, the project sought to test whether it was possible to sort additional plastics out of the RDF. Various changes to sorting layouts were tested with improved preparation for sorting, testing negative and positive sorting, and providing new sorting instructions. Further, the premise of the pilot was that no further investments should be made, i.e. to achieve the best possible outcome with the existing equipment.

For this reason, the pilot did not succeed in extracting *all* the plastics, and simultaneously certain unwanted fractions remained in the sorted material. One of the key challenges to quality concerned unopened “black bags” containing anything between heaven and earth. Based on the sorting results and the visual supervision of the pilot, it is obvious that these bags can represent a challenge for the sorting quality, as they may be too small to be opened by the shredder and too large to be sorted out with the organics.

During the pilot, it also became clear that with relatively reasonable investments, a higher proportion of the plastics suitable for pyrolysis can be sorted out, with a lower proportion of unwanted materials. Determining what measures should be done at a sorting level to improve output quality in an economically reasonable manner has been part of the task described in this report.

The below table summarizes the plastic quality perspective from the sorting plant pilot.

Table 4: Sorting results from the pilot compared to quality criteria

	Quality criteria	Observed results (range)
Sorting quality		82-98%
Plastic content		
Water content	5%	11-35%
Organics	5%	8-15%
Inorganic contamination		1.1-20
Chlorides	100 mg/kg	1050-3400
Sulphur	10 mg/kg	Ca. 300

The manual sorting analyses indicate that a result of +/- 90 % plastic items may be achieved, when unopened plastic bags can be avoided. This is backed by observations of high sorting quality under optimal sorting modes. For instance, the importance of spreading the waste evenly on the conveyor belt, adjusting shredders and screens carefully in relation to the purpose of sorting, and providing good instructions, thorough training of sorting operators and hands on management were all proven to be of crucial importance for satisfactory results. Furthermore, sorting results depended on the sorting strategies tested during the pilot, yielding varying results. Finally, numerous more general observations were made from the sorting pilots in terms of external factors affecting the quality. For instance, waste that was up to several weeks old gave a significantly drier output than fresh waste.

However, the analytical results on material distribution showed that organic contamination, inorganic particles and moisture remained a key challenge for the sorted plastics. The fact that the plastic waste is sorted out from mixed waste means it has already become thoroughly mixed with organic contamination, and the level of contamination possibly has been aggravated by the handling of the waste itself (collection, mixing, shredding, sorting, often passing through a transfer station where the waste has become hard packed). This effect typically increases with higher moisture content, and especially concerns flexible types of plastic due to their high surface proportion, as described in the previous section. Furthermore, the analysis results showed elevated levels of chlorine and sulfur, likely closely related to the high organic contamination.

Thus, although it may be possible to sort out the right types of plastic and nearly only plastic items (i.e. no banana peels, diapers, or wigs), challenges remain with contamination from organic and inert material, as well as moisture. Manual sorting of the mixed plastic waste likely is not sufficient to achieve the specified low levels for contamination for a PtL plant (see section 2). The same goes for the levels of chloride and sulfur, which were found to be significantly above the given specifications.

Further cleaning of the fraction of feedstock recovered from the mixed waste stream is therefore necessary, and depending on the quality deemed achievable from sorting, different cleaning solutions may be suitable based on the trade-off between quality improvements and costs.

3.2 Feedstock from the informal sector

Millions of people worldwide make a living collecting, sorting, recycling, and selling materials that someone else has thrown away, and in Accra the informal sector plays a large role in waste management. For further detail on the actors operating in the informal sector locally, please see the End-of-Phase report. As further described in this report, the key determinants of plastic price in the informal sector are at what stage in the value chain it is collected, plastic type, and plastic quality. The level of collection is highly sensitive to changes in prices.

It should be highlighted that so far, PRF has chosen to work with waste pickers who collect from the plastics source – markets, households etc. Many also collect at final disposal sites (landfills, dumpsites), but due to the hazardous nature of this work and the desire to collect plastics closer to the source, the potential for this source of plastics has not been assessed and tested by PRF.

During the pilot, a low price was tested, but it was simultaneously established that numerous aggregators and recyclers currently pay multiples of the price paid during the pilot for clean and sorted plastics. Thus, it is possible to buy cleaner plastic in the market that requires less cleaning measures. In that case it would however mean significantly higher price and competition with existing mechanical recycling solutions, and thus enabling a solution where also contaminated plastics is accepted is preferred.

Further, non-price mechanisms were also central to incentivizing collection - easy access and short transportation to collection points (thus lowering implicit costs), acceptance of all plastic types and a variety of mixed plastics, made people more likely to deliver plastics. Thus, accepting different types and qualities of plastics in the same place, whether for chemical or mechanical recycling, would likely increase overall collection rates as well as lower per-ton logistical cost.

Quality analysis from the pilot study with the informal sector shows that the quality was better than was found at sorting plants, even at a low price. This applies primarily to the contamination from other types of waste, especially organic and inert. These differences can be explained by the fact that the informal sector sources separate plastics while the formal sector does post-sorting of mixed waste. However, both sources need improvement in order to live up to the quality requirements described in section 2.

The below table summarizes the expected quality from a collection point scale up, based on data collected on each individual plastic type collected during the pilot and expected composition from a scaled-up scenario.

Table 5: Expected quality from collection point scale-up

(1) Plastic fraction	(2) Sorting quality	(3) Liquid proportion	(4) Ash content	Non-plastic from washing	Minimum non-plastic	Measurable maximum non-plastic	Chlorides (mg/kg)	Sulphur (mg/kg)
Scale-up quality (before cleaning)	5 %	5 %	8 %	5.8 %	18.1 %	23.9 %	766	55

While the table above illustrates an aggregated scenario, some analysis was carried out on the different fractions received. It could, through these, be established that certain fractions collected involved clear challenges, such as fast- food containers made from Expanded Polystyrene (EPS) soaked in cooking oil. Furthermore, some of the same issues encountered in the plastics from the central sorting plants persisted, such as film being more dirty due to its large surface compared to weight of plastic material. Finally, it was found that large PP bags (of the type usually used for agriculture and industry) had a high content of inerts, measured through ash remaining after heating up the material over an extended period. The reason for this is either the material of the bags themselves (sometimes they are produced with composite materials such as glass fibres), or the fact that they have been used multiple times (for e.g. agricultural or industrial purposes) which has led to dust and sand sinking deep into the fabric of the bags.

It is anticipated that some of these challenges may be solved by setting higher requirements in exchange for a slightly higher price for the plastics. During the pilot, no differentiation in price was made to accommodate for plastics quality - rather, deliveries were only rejected if they were found to contain a high amount of non-plastic items (cardboard, metals, rocks etc.). The people delivering showed a high degree of responsiveness, and it is expected that specifications on quality could easily be incorporated as part of the collection.

It should be highlighted that the pilot specifically involved working with waste pickers in the central market area, and that the scale-up concerns expectations from expanding collection to other areas of the city, as well as involving also other sources of plastics delivered to collection points - for instance Bola taxis choosing to deliver plastics directly from households, and small commercial actors and institutions who are looking for easily accessible solutions for their plastic waste. Especially when working with these sources of plastic materials, it is important to take into consideration the effect on other solutions for plastics recycling. In Accra, there is a high demand for rigid plastics (nearly no rigids were received during the pilot) as well as transparent, high-quality LDPE. The focus should not be on cannibalizing on plastic streams that are already directed towards mechanical recycling, but rather to develop solutions to capture plastics that are not currently being recycled. This should be done both by increasing collection rates and by having a broader specification for accepted types and quality (such as already-recycled film and plastic bags in circulation that will eventually have exhausted their further potential for mechanical recycling).

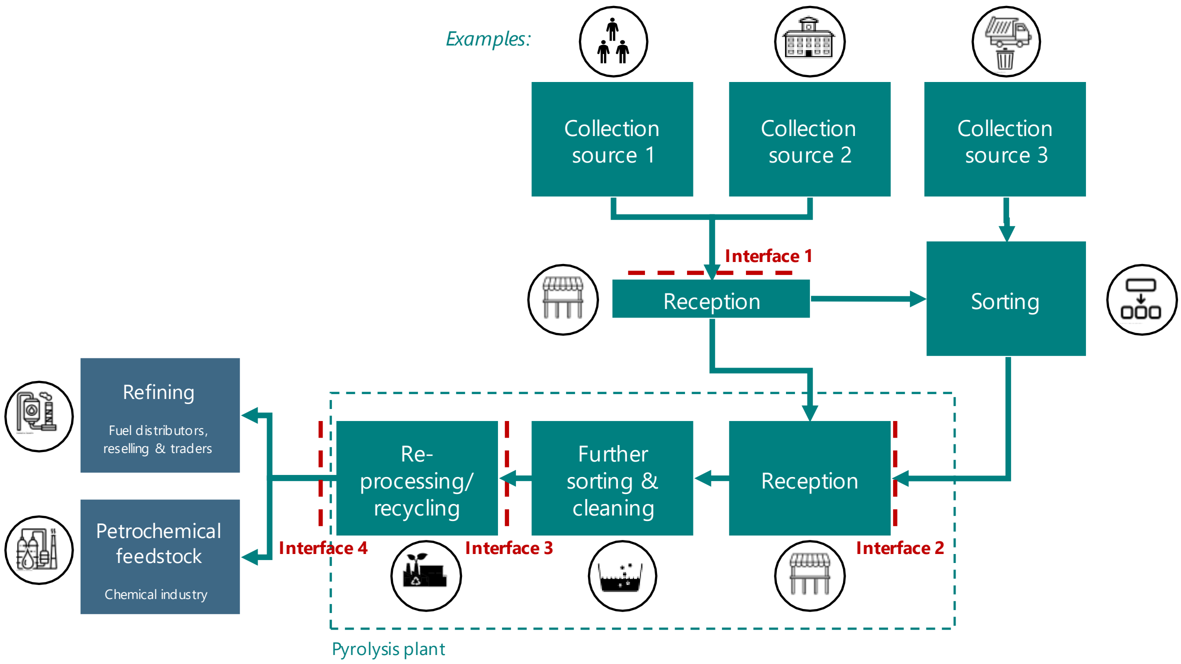
Having set the stage for the background of the challenges faced in Accra, the next part of the report goes into detail around what may be done to bridge the gap of plastics quality, considering three separate components of a potential solution: 1) setting clear expectations throughout the value chain, 2) improving the sorting procedures to extract the plastic material, and 3) introducing a post-sorting cleaning procedure.

4. Setting clear expectations throughout the value chain

Controlling the quality of the plastic feedstock into the pyrolysis plant is key to achieving the required quality of the offtake from the plant. Ensuring a satisfactory plastic quality furthermore requires thinking holistically about how to obtain the required plastic quality, including evaluation of requirements to the plastic sorting process which produces the plastic feedstock. Spreading out the responsibility of achieving a viable feedstock quality will be done by setting clear expectations throughout the value chain. Introducing the interfaces with corresponding acceptable plastics quality requirements will make the value chain predictable and enable the different actors to be incentivised in their deliveries.

The below figure exemplifies how interfaces may be identified along the value chain of feedstock coming into a pyrolysis plant in Accra - but transferable to other contexts of developing a value chain for feedstock to pyrolysis in other locations.

Figure 1: Example of interface identification and expectations along the value chain



Here, four key interfaces are identified:

Interface 1

The initial interface would receive plastics from other sources than waste sorting plants, and be based in strategic locations to receive plastics from first and foremost the informal sector, but also other sources that may have an interest in delivering directly in small quantities such as commercial actors.

Here, quality can be ensured through uniform operation routines across reception/collection points, as a way to merit “authorization” and ensure predictability for people delivering at any one of them.

This should include among others trained staff, weighing and control of received plastics (including opening bags), light sorting and payment. Furthermore, the control will be able to redirect unwanted waste to a central sorting plant for further sorting.

This interface functions as the first point of quality requirements for plastics that is not sorted out from central sorting plants for mixed waste, and quality requirements set here must correspond to anticipated improvements to the quality in further steps of the value chain.

Interface 2 At a reception point located at the pyrolysis factory, plastic is received from a previous sorting facility (central sorting plants). If the plastics received at Interface 1 is deemed below the required quality, it may be passed through the sorting facilities as a way to improve it (and will encounter Interface 2 for further inspection).

By the time the plastics reach this point, most of the contaminants that require manual sorting should have been removed. As will be described further in section 5.2, most post-sorting cleaning procedures involve a fully mechanical process (beginning with shredding), and thus hand picking of unwanted items will not be possible past this point.

Depending on the chosen cleaning method, the requirements at Interface 2 (both accepted *level* of contamination and accepted *type* of contamination) must be designed so that any remaining pre-treatment can bring the plastics to the quality accepted going into the pyrolysis reactor.

Interface 3

This interface represents the specifications required by the developers of a pyrolysis reactor and associated downstream treatment and its potential effect on end-product quality. While this represents the final interface of the plastic waste as feedstock, the requirements at this point will be determined by the final interface - quality requirements on what comes out of the plant.

Interface 4

This interface represents the quality requirements of an end-product being produced from the pyrolysis plant, and must be achieved from a combination of the process itself and the quality of what goes into the plant (feedstock). As described in Section 2, the ability of the process to enhance the quality of the end product may for instance the inclusion of a hydrotreatment facility or inserting chemicals (such as lye) into the process. Nonetheless, there are limits to what such measures can achieve, so any ambition of a clean end product must necessarily involve a tightening at all the interfaces described above.

In Section 6, the proposed requirements at each interface are described, taking into account the recommended solutions for additional sorting and cleaning of the feedstock (and what these measures can be expected to achieve).

But first, section 5 described the technology and methods suitable for sorting, cleaning and drying the plastic waste - relevant to specifying what is possible and realistic to achieve by interfaces 2 and 3, respectively.

5. Technology and methods suitable for sorting, cleaning and drying

To recap, the quality challenges that largely has to be solved in the value chain up to the pyrolysis reactor are the following:

1. **Remove anything that is not plastic (organics, inert, textiles, metals etc)**
   The composition of mixed waste from households is different in Africa than in many European countries. It may be said that the composition of municipal waste is to a certain extent linked to GDP level. The percentage of wet organic waste is significantly higher than in e.g. Norway. In Accra, up to 50-60 percent of the waste consists of food residues and other wet organic waste. On the other hand, there is significantly less hazardous and electronic waste in Ghana. The large proportion of wet organic waste in Ghana means that waste with potential for recycling is polluted by inert (sand and soil) and organic residues.

2. **Remove unwanted types of plastic (PVC, PET, ABS, PC, PA)**
   Assessments of plastic types in Accra have been made based on visual observations. Unwanted plastics were sorted out during the pilot at the sorting plants, such as PET bottles, pipes, tarpaulins and multilayer plastics. It remains to be investigated whether any common types of plastic products may contain anything other than what is known from Europe. When it comes to plastic types and sources of plastics where it is received already sorted, this is specified directly to the sources. This opens up for the potential of also collecting other types of plastics than what is desired for the pyrolysis plant (e.g. PET), in order to coordinate collection for both chemical and mechanical recycling.

3. **Remove moisture (tolerance < 5%)**
   There are two main reasons for the high moisture content of plastic in Accra. The high content of wet organic waste makes plastic moist. The second is the climate. During hot and wet seasons there are often heavy rainfalls.

To solve these three main challenges, different methods and technology are needed. Below, the potential manual and mechanical solutions that may contribute to improving plastics quality are described - both at the sorting and at the post-sorting level.

5.1 Methods available to improve the sorting procedure

Firstly, it is necessary to consider how sorting procedures may be improved, both through the means of manual sorting and technological sorting equipment. In this report, "sorting" is considered as any process that aims to extract (or remove) specific items, but ideally also with an additional effect on contamination levels (e.g. organic contamination stuck to the "right" items). Furthermore, it should be noted that PRF views anything related to *sorting* to be the primary responsibility of feedstock suppliers, while cleaning/pre-treatment may be an integrated step prior to the pyrolysis plant.

It should also be noted that any task at the sorting and post-sorting stage may be facilitated by implementing better procedures at the *pre-sorting,* or collection, stage. This could for instance include partial sorting at source, separation upon collection, or separation of difficult fractions during the transfer stage.

5.1.1. Manual sorting

In order to achieve the best possible sorting result for plastic, there is a need for various methods and technology that work together holistically and are well adapted to local conditions. From a European perspective, a fully or partially automated sorting process will be prioritized due to high labor cost. The waste is then often heavily shredded (size minimized) early in the process. More homogeneous sizes give a better effect of sorting equipment based on weight and density. Fully automated sorting also requires advanced and expensive equipment, such as near infrared technology (NIR). Furthermore, fully automated sorting normally takes place in a continuous (rather than batch) process.

In countries with relatively low labor costs, such as in Ghana, a combination of manual methods and technology will be more relevant. In the case of significant manual sorting, the first phase in the sorting process will be to remove as much unwanted material as possible and facilitate the manual sorting. Manual sorting is more efficient when the size of the waste has a larger size, and thus shredding prior to a manual sorting procedure will reduce productivity. When the waste arrives at the manual sorting, some unwanted materials should already have be removed. The waste should be relatively dry, containing small amounts of fines. In addition, the waste must be evenly distributed throughout the conveyor belt. When the setup for manual sorting is done right, and the operators have been trained, a high capacity and quality can be achieved.

Manual sorting has as its main purpose to either remove unwanted materials (negative sorting) or desired materials (positive sorting), or both. It will not solve challenges with moisture.

When considering the design of a sorting line, there are several factors that to be considered, including the composition of the waste and what fractions to be sorted out (both for pyrolysis but also for other uses). The composition of the mixed waste and which fractions are to be sorted out will determine the design for the plant. Quality requirements for materials and level of ambitions for the sorting must be clarified. This includes deciding whether the purpose of sorting is to produce a pre-sorted product with a need for further processing, or whether a final plastic feedstock quality is to be produced. It may be shown that reaching a satisfactory quality through sorting only can be difficult, as was the case in Accra.

5.1.2. Technological equipment for sorting

Various technological methods and equipment that can either improve existing sorting plants or be part of completely new plants have been considered. Common principles that contribute to the development and function of sorting equipment include (and sometimes in combination):

- Gravity
- Centrifugal force
- Air currents
- Heat
- Demolition
- Cutting
- Press force
- Magnetism

Several types of equipment utilizing these principles can be applied and will directly and indirectly affect quality. The most important that have been considered and further investigated in the context of the Accra project are described below.

Equipment for spreading waste on conveyor belts

Applying equipment for spreading the waste evenly over the entire width of the conveyor belt and being loaded at an even and predictable rate is a crucial prerequisite for manual sorting being effective. As sorting operators can see the waste better getting an even and predictable amount of waste to sort through, this will lead to more correct sorting. Moreover, it will generally lead to higher capacity and efficiency in production.

There are various pieces of equipment to facilitate this. At the ACARP plant there is an impeller between the mare and the conveyor belt. Another alternative is to allow the waste to fall onto a cone device above the conveyor belt.

Bag opener

As described in section 3, black bags filled a variety of contents constitute a big challenge in the mixed waste received at the Accra sorting plants. There are different types of equipment for bag opening, but in general the bag opening works by squeezing the waste between rotating objects that tear. Some types of bag openers may have the same effect as pre-shredding units.

It should be investigated whether there is an advantage to include equipment for opening bags, also due to the large number of black bags with different contents. This means that the content is spread out and becomes more difficult to get out later in the process - it may be better to simply sort out the bags themselves.

Screening units

Screening units' main purpose is to separate waste by size. Different types of screens exist, as described below.

Trommel Screen (also called drum screen, rotary screen)
A drum screen is a cylindrical rotating drum where the walls are perforated with holes. The waste enters one end of the drum and is thrown around several times before exiting at the other end. Materials with size smaller than the mesh holes will be filtered out, while the balance materials exit at the other end of the drum.

In order to adapt screening to the relevant waste and purpose, several factors are important. This includes drum speed, drum length, slope on drum and mesh diameter. Utilizing a drum screening is the main method for sorting by size.

Flip-flop screen
A flip-flop screen is a vibrating screen with mesh size adapted to the purpose. The flip-flop screen requires a steep slope. Waste is fed on top of the screen and shaken vigorously on its way down the unit. As with the drum screen, undersized materials fall through the mesh holes while oversized materials will continue to the end of the unit. Some screens are made of elastic material so that the mesh holes can be expanded slightly. This system is widely used in mineral processing, but also in waste handling.

Star screen
Star screens consist of several axles, each of which has many impellers. The name comes from the star-shaped impellers. The waste passes over the high-speed impellers. Again, the principle resembles that of other screens - undersized items will fall between the blades while larger objects pass across the line, while oversized materials will be flowing over the impellers. A star screen can be equipped with one or two decks to sort different sizes of what goes into the impellers. Star screens are gaining popularity in the waste industry.

Wind shifter (also called air separator)
In a wind shifter, air currents are used to separate light from heavy fractions, based on both difference in density and in size. When waste comes to the separation chamber on the conveyor belt an airflow blows light, large surface particles in one direction. Heavy and massive fractions will fall down. Airflow volume and direction can be adjusted.

Wind shifters are often applied at the end of other screening systems, such as star screens.

Ballistic separators
The basic principles for ballistic separators are based upon rotating paddles being situated parallel to each other. The paddles operate independently of each other and rotate horizontally and vertically. The unit is inclined by an angle which can be adjusted. Input material is through this process separated into two main fractions: 1) Rolling, heavy fraction (such as stones, wood, tins, massive plastic parts) and 2) Flat light fraction (such as plastic film, paper, cardboard, textile). Based on the perforation in paddles, a third fraction can be separated, namely fines (inert and organic). Based on ballistic

principles, heavier parts will roll down and the light fractions will move upwards. The waste is fed to the bottom of the unit and moves upwards.

Ballistic separators can be effective in preparing for further sorting of plastics.

Shredders (grinders)

There exists a large selection of shredder/grinders for almost any purpose. In general, the role of grinders/shredders in the waste industry are used to divide the waste and make the size more homogenous for further processing, or for reducing transport costs.

Industrial shredders (heavy-duty and high volume) can be used for “end of life” vehicles (ELV), wooden pallets or mixed waste. Industrial shredders are equipped with different kinds of cutting systems such as vertical shaft design, horizontal shaft design, single shaft, two-shaft, three-shaft, and four-shaft. In fact, large shredders will tear the waste rather than cutting it. Screen mesh adjusts the size for the purpose.

Balers

Balers are used primarily to optimize further transport and efficient storage. This involves making the waste more compact by the use of physical pressure, before binding it to keep it in place. The baler will in addition contribute in driving moisture out of the plastic feedstock.

There exist many different balers for waste purposes, the most common of which are horizontal channel baler primarily used for old corrugated cardboard (OCC), paper and plastic film. They are also available as vertical balers that require less space. These balers will have a high capacity.

More powerful industrial balers that handle difficult materials in difficult applications are twin ram balers or multi fraction balers. They press against a solid steel plate and allow very high pressure. They can use several hundred tons of power and handle most types of materials, have slightly lower capacity than channel balers and are more expensive. If the purpose is to squeeze out as much moisture as possible , then a baler with a large pressing force will work best.

The balls coming out of the baler after pressing needs binding. Iron wire has traditionally been used, but plastic material, such as PET, is also capable of withstanding the extensive pressure and is increasingly used. When compressing plastic bottles and cans, great force is required to suppress their expansion. To a certain extent it can be compensated by being able to choose the number of threads that will bind the balls, or by utilizing cross-wiring. Some balers can be adapted to the number of threads to the material to be tied.

5.2 Systems available to improve the plastics quality post-sorting

The plastic pre-treatment system is designed to, post-sorting, reduce contamination to a level that is uniform across feedstock sources and acceptable to the pyrolysis technology. To reiterate, PRF views anything related to *sorting* to be the primary responsibility of feedstock suppliers, while *cleaning/pre-treatment* may be an integrated step prior to the pyrolysis plant.

There are some key distinctions that may be highlighted when it comes to pre-treatment options. The perhaps most important one is whether cleaning is done by use of water, or not. The pyrolysis process has limited tolerance for moisture, which is a strong motivation for avoiding the use of water for cleaning the plastic at any stage in the plastic sorting or pre-treatment process - any moisture added must later be removed. Solutions involving water for cleaning also require a water treatment plant to treat the waste water coming out of the process, ideally with a high degree of recycling/re-usage. This management of contaminated water is by itself a complex process adding cost to the process of cleaning the plastic. When cleaning is done with the use of water, several other factors influence the cleanliness that can be achieved - including the temperature of the water and whether chemicals are introduced to the process. Dry cleaning systems will, as the name indicates, not introduce water to the process but rather rely more heavily on the effect of friction and air, as well as the density of materials introduced.

It is important to highlight that any pre-treatment process will normally be fully mechanized and rely on a supply of material uniform in size (by means of shredding) coming into the process. This is a commonality for both dry and wet washing systems. The shredding brings the sorted plastic into a homogeneous feedstock and will make contaminants accessible for removal from the plastic. Furthermore, the shredding process which tears the plastic apart will often by itself contribute to detaching some heavy contaminants from the plastic feedstock.

For the pre-treatment system, the goal is to:

- Further reduce inert
- Further reduce organic contamination
- Further reduce moisture content
- Shred and granulate the plastic ahead of pyrolysis process

The purpose of the pre-treatment system is thus not to sort out unwanted plastic types or distinct non-plastic items, and any manual sorting will be finalized before this point. Removing unwanted items should be the responsibility of the plastic feedstock provider and done at the sorting stage, as described above.

In order to ensure predictability of the plastic feedstock coming into the pre-treatment system (both to ensure that it functions optimally and to respect any relevant limits to the system), a verification system needs to be set up to check the incoming plastic quality. Here, it must be possible to reject feedstock shipments if the quality is not met and provide feedback to the plastic provider with the aim of investigating the cause of the quality deviation. This ties into the section on setting clear expectations throughout the value chain at predetermined interfaces.

Potential end-to-end cleaning systems are described more in detail below.

5.2.1. Water based cleaning systems

End-to-end cleaning systems involving water were initially investigated, as these constitute a large share of the market for pre-treatment systems for plastics. There are a number of providers of these systems, and operating units are found globally.

The washing line starting point will be where the operator manually (by means of a loader), feeds the bale on the loading belt and removes the cleats. The plastic film is then fed into the shredder. The shredder is operating under dry conditions and reduces the plastic film into flakes of 60-80mm.

After shredding the material is fed into a buffer bunker to provide the required dosing flow rate through a belt conveyor with load cells. The amount fed into the system is monitored by using the load cells. The conveyor belt provides material into a decanter. This first decantation separates out heavy objects, such as stones, sand, mud, glass and metal. The pollutants decanted are periodically and automatically unloaded by an extractor belt.

The first high friction action is carried out in a wet grinding unit with a 20 to 30mm grid. Water circulating into the grinder is continuously filtrated after it has been used and will then be transferred to the waste water treatment plant (WWTP). All the water used in the washing process units is going through the water treatment facility/WWTP. The WWTP should be designed so that it enables 90% of the water used in the washing process to be recycled water. The WWTP filtrates and purifies the water before it is re-entering the different units in the washing line.

The plastic flakes are subject to intensive washing by means of a series of “Turbo Washing” machines in a continuous process. Through an intense water flow, the flakes are subject to strong friction and centrifugal force, which enables the extraction of dirty particles and the rinsing of their surface.

The next step is the Friction Washer, whereby the plastic flakes are cleaned with hot water and chemicals. This unit allows an intensive washing with a suitable residence time depending on the contamination of the material being treated. The Friction Washer is included when a high cleanliness quality of flakes is required.

Final rinsing is done in a Turbo Washer, where the plastic flakes are separated from those pollutants that were washed from the action of the Turbo Washer and Friction Washer. There is a continuous water circulation in this unit to bring the debris away from the plastic flakes. It’s extremely important that the quality of the recirculated water from the WWTP meets the necessary requirements, i.e. it must be well purified and filtrated, in order to secure the cleanliness of the plastic flakes exiting the turbo washer.

A drying process needs to be in place at the end of the washing line to make the plastic flakes suitable as feedstock to mechanical or chemical recycling. The drying of the product is one of the process steps that has a high energy demand. Typically, the plastic film entering the drying process has a moisture content exceeding 60%. A screw press is typically applied to reduce the energy demand by bringing the moisture content down to 15%. This enables the plastic flakes to be transferred to a dryer whereby warm air in a cyclone type vessel will reduce the moisture further. A moisture level of 2 to 3% in the plastic flakes should be expected after the dryer and the plastic flakes are then transferred to a silo for storage until used as feedstock into the pyrolysis plant.

A key consideration in judging the suitability of pre-treatment systems ties back to the quality requirements described in section 2. Most plastics pre-treatment systems involving water are developed for the requirements of the mechanical recycling sector, with very low tolerance for impurities. Here, the use of water (cold or hot) together with detergents in the cleaning process, followed by drying, is the norm. While this is a process that is highly effective in removing contaminants, it involves high investment costs and is costly on an operational basis (mainly due to high power consumption). The priority for this investigation done by PRF has been to map the available opportunities, while considering the economic aspect of the solutions. For this reason, a key focus has been on trying to establish whether a satisfactory quality can be achieved *without* the use of water, and what such a solution entails for the quality requirements to the plastic feedstock further up in the value chain.

5.2.2. Dry cleaning systems

There was found to be a much lower prevalence of providers of dry cleaning systems for plastics, but two end-to-end system providers have been successfully approached to investigate the application of dry cleaning technology as pre-treatment for a pyrolysis plant.

The two providers have niche technologies and neither of them focus their sales efforts towards cleaning of plastics as pre-treatment to pyrolysis plants. Through conversations and virtual demonstrations, PRF has sought to understand the specificities of their technology.

Similar to the cleaning systems involving water, the size of the pieces must be reduced before entering the system. The plastic feedstock needs to be grinded to a flake size of 60 to 80mm ahead of the dry-cleaning system. This grinder should be sized with an overcapacity of at least 20% to cater for interruption of the grinding due to foreign objects in the plastic feedstock causing downtime of the grinder.

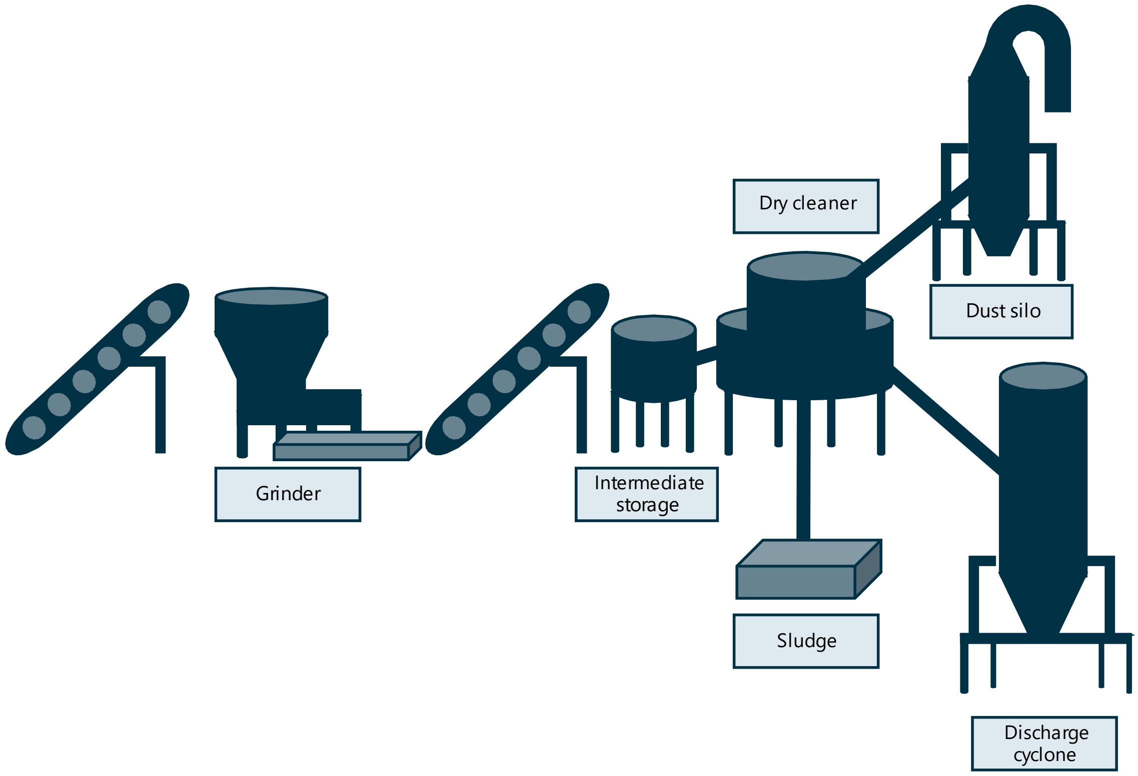
The operating principle for dry-cleaning systems is a combination of friction generated by movement and gravity forces induced by means of rotating impellers or drums. Heated air is added in the process to drive moisture out of the plastic feedstock. Inert contaminants and moisture will be removed to a high degree, however organic contaminants sticking to the plastic will be removed to a limited degree. Thus, this should be avoided to the extent possible in advance.

The dry cleaning process will produce a side stream of sludge as a result of the reduction of moisture in the plastic feedstock. This sludge will contain water, organic material, inert and small size plastic flakes. The amount of sludge in the side stream is depending highly on the amount of contaminant being part of the plastic feedstock entering the system. This must be dealt with in an appropriate manner.

Dust containing plastic fragments will be generated in the process and will be carried by the air flow. The air flow will go into a cyclone where the plastic fragments are separated out ending in a hopper or big bags while the cleaned air is released through a vent.

A rough and generic illustration of the process is provided below.

Figure 2: Generic illustration of dry cleaning process



The dry-cleaning process is highly automated and based on continuous operation. The manual interface will be feeding sorted and baled plastic into the shredder, changing of big bags and maintenance. The operator monitoring the control of the pyrolysis plant could also monitor the pre-treatment system. The feedback provided indicates that one operator per shift will be required for the manual part of keeping the pre-treatment operating.

The basis of the discussion with system providers was the anticipated specification of plastics feedstock coming out of the sorting plant with some potential improvements. Based on the description of the performance of the systems it is considered that the two systems *can meet the cleaning requirements at hand if the sorting can contribute to some further quality improvement*. This observation is the backdrop to the final section of this report - discussing options and recommending a solution for the Accra project.

6. Discussion & recommended solution in Accra

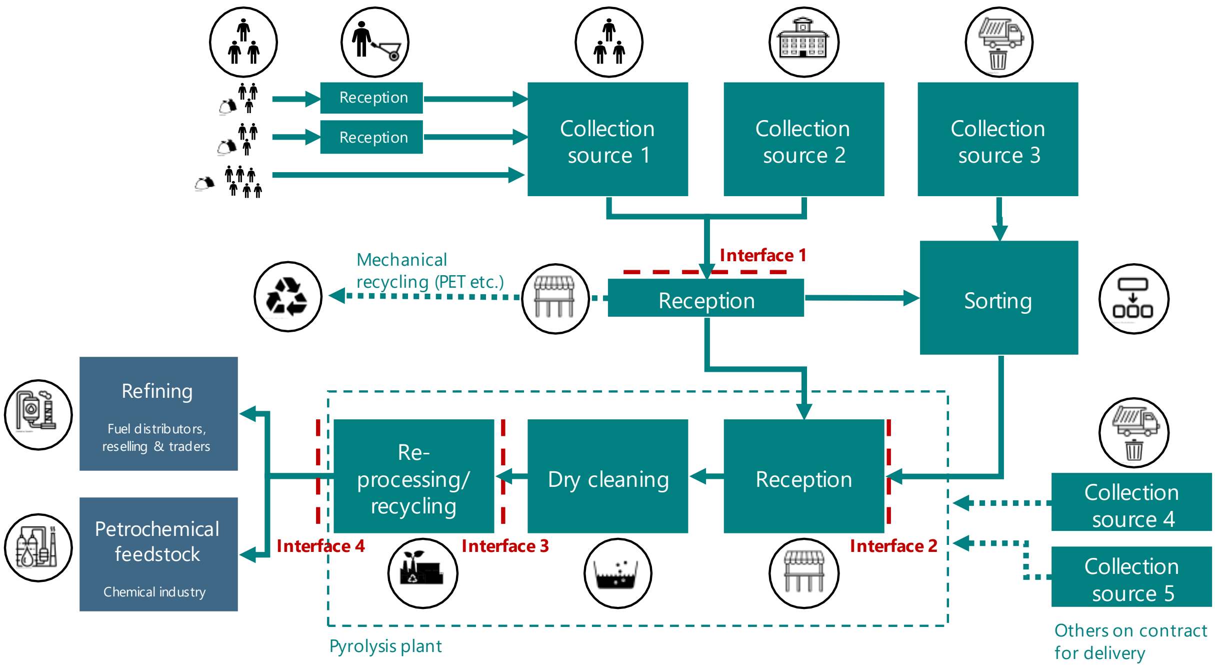
This section is dedicated to bridging the identified challenges described in section 3 with the theoretical description of components that may contribute to improving plastics quality in sections 4-5.

It is recommended that a combination of clear expectations set throughout the value chain, and improved sorting procedures (including pre-sorting) and dry cleaning is adopted to reach the required quality. Below, an elaboration of what exactly this may entail is detailed. It should be noted that due to the travel restrictions imposed during most of 2020, the proposed solutions have not been tested in practice. Rather, this section represents a recommended solution to be tested as a natural next step in achieving satisfactory feedstock quality in an economical manner.

Setting clear expectations throughout the value chain

As described in section 4, setting clear expectations throughout the value chain is instrumental in achieving a predictable and satisfactory plastic quality. These expectations must be adapted to the recommended solutions within sorting and cleaning, and their capacity to remove contamination.

Figure 3: Concretization of interface identification and expectations along the Accra value chain



Analyses from the pilot projects in both the formal and informal sector show that the quality is better in the plastics from the informal sector than what was found at sorting plants. This applies primarily to the contamination from other types of waste, especially organic and inert. These differences can be explained by the fact that the informal sector sources separate plastics while the formal sector does post-sorting of mixed waste. However, both sources need improvement.

Briefly summarized, the recommended division of tasks in achieving a satisfactory quality for the input material for the pyrolysis plant can be described as the following:

- The informal sector's task (or any source delivering at smaller quantities to collection points) is to collect the right plastic materials, as well as to avoid unnecessary pollution and moisture. They will be expected to adhere to low levels of organic contamination since the plastics are collected closer to the source and have not been mixed with organics. If the plastics delivered do not fulfill the quality criteria for delivery directly to the pyrolysis plant, it is proposed that a price differentiation mechanism allows to still deliver plastics that will be redirected towards further sorting before being subject to screening at Interface 2. This can be achieved mainly through changes in delivery conditions and good control mechanisms. In addition to differentiation of price for varying quality, it may also be possible to decide to not include certain very difficult fractions altogether (such as fast-food containers soaked with oil) at least until it is secured that the other fractions are clean enough to compensate for elevated contamination. Some minor sorting may be conducted at the reception points in order to ensure satisfactory quality, but it should not be considered an integral part of achieving the interface requirements. The plastics accepted at Interface 1 should be baled for transportation to the pre-treatment facility.
- The sorting plants have a difficult starting point as they receive mixed waste, but must take considerable responsibility for obtaining the right plastic material at the same time as they remove significant amounts of contaminants and moisture. This means that there is a need for improvements in knowledge, methods and technology. An overview of the potential improvements that can be made in equipment and procedure at the sorting plants, in order to achieve a satisfactory quality (measured at Interface 2) was provided in section 5.1.
- In the dry cleaning process - described under section 5.2 - the main task will be to remove moisture, but also to remove any remaining organic and inert waste. Here, the aim is to bring the plastics to a uniform and predictable quality regardless of its origin. However, this step will to a small extent affect the presence of unwanted *items* (non-wanted plastics, non-plastic items), which must be removed prior to the mechanical dry cleaning process. The composition of plastic is in line with the requirements shown in section 2. By the end of the dry cleaning process, the feedstock must adhere to the quality requirements of the pyrolysis process.
- Measures applied as an integral part of the processing should allow any final contaminants to be removed and the specifications met for the final product to be achieved. This will not be elaborated further in this report, as the key issue to be solved concerns achieving a satisfactory plastic feedstock quality.

The following table illustrates how expectations are recommended set at each of these interfaces in order to reach the required quality based on stepwise improvements at each interface in the value chain, based on quality improvements deemed achievable at the various steps on the way:

Table 6: Tolerated impurities at each interface of the value chain - summary

Impurity	**Interface 1** **Reception from collection points - informal sector & smaller volume suppliers - to dry washing facility**	**Interface 2** **Reception from sorting plants to dry washing facility**	**Interface 3** **Feed into pyrolysis reactor**	**Interface 4** **Output of pyrolysis plant**
Inert materials (dust, sand, ashes, metals)	< 8%	< 8%	<5%	
Organic material	<8%	<8%	<5%	
Moisture	<15%	<15%	<5%	
Overall tolerance for non-plastic	*<20%*	*<20%*	*<5%*	
Comment	Defined by what is deemed manageable for the dry cleaning process.	Defined by what is deemed manageable for the dry cleaning process (and achievable through improved sorting).	Defined by pyrolysis technology developers based on requirements at Interface 4.	Defined by off-takers.

Improvements to sorting procedures

As described in section 5, prospects for quality improvement prior to a mechanical post-sorting dry cleaning process may be done both at the collection stage (pre-sorting/ preparing for manual sorting) and at the sorting plants (manual and partially automated sorting.

Below, the recommended steps to be taken in order to improve the plastics quality are described. It is important to note that the sorting procedures adopted in Accra should allow simultaneously sorting out compost - which is the targeted fraction today - and plastics for PtL purposes. The equipment proposed must be assessed on the basis of their ability to produce both these fractions.

During the collection: Pre-sorting/preparing for manual sorting including collection at the waste owner (source), transport and reception at sorting facilities

Source sorting is not part of the current formal collection system. A small amount of recyclables is taken out by the waste pickers or the renovator who do the collection. Given this point of departure, there are not many realistic measures to take to improve quality. It is the view of PRF that while source separation may be a long-term target, this is likely to take time. Furthermore, large-scale impact may be easier to achieve and better suited to local waste management infrastructure through improvements to the central sorting facilities.

Among low-hanging fruits for collection and source separation it may be possible to test a "two-chamber" borla taxi (collection vehicle) setup. This could be done for instance tby setting up a simple partition (of for instance veneer) in the loading chamber. This would provide the opportunity to separate wet (organic) from dry waste. Although this may not immediately yield an optimal result, it would likely strongly improve the achievable quality through further sorting because the recyclables can to a large extent avoid becoming mixed with organic contamination, thus preventing moisture and contamination of the plastic.

To some extent, waste from borla taxis is transhipped at transfer stations, and emptied into larger containers. This is done to reduce transport, but also causes the recyclables to become further contaminated if it is already mixed with other types of waste.

At the sorting plants: Manual and partially automated sorting, proposed improvements to the current layout

The sorting plants, IRECOP and ACARP, use essentially the same principles in sorting. The waste is weighed on receipt, emptied and placed in piles of great height, partly under a roof._Currently, there is a wheel loader that feeds a hopper. At IRECOP, the waste goes up one conveyor belt before falling down to the next conveyor belt. This means that the waste proceeds unevenly through further process, becomes more mixed and makes sorting difficult. At ACARP, there is equipment that helps to disperse the waste on the sorting belt. The waste then goes to a sorting cabin (primary sorting). Bulky items and other unwanted items are taken out by negative sorting. The waste then goes on to a shredder for size reduction, and then into a drum screen. The mesh diameter of the drum is important. At IRECOP the mesh width measures 60mm and at ACARP it is 40mm. At IRECOP, far more compostables are screened out than at ACARP, which gives better quality of compost (higher organic content as smaller mesh holes leads to mostly inerts/sand being sorted out) and also makes later sorting more efficient. Some unwanted materials also escape through larger holes (such as plastics), but a later two-step post-screening of the compost removes most of the unwanted items and provides a good compost quality. The waste that is not screened out as potential compost material continues to a new manual sorting cabin (secondary sorting). The principle is somewhat negative sorting (sorting out what you *do not* want), but primarily positive (sorting out what you *do* want). At the end of both sorting processes, the output is a fraction called RDF (“refuse derived fuel”) for which there is no other final treatment solution than landfilling.

At IRECOP, there are 8 operators who manually sort out PE/PP hard plastic and PET. At ACARP, there are more than 30 operators, and some LDPE and corrugated cardboard are also taken out here in addition to the other fractions.

A number of improvements are proposed for the purpose of providing better plastics quality at the sorting stage (aiming to remove non-plastics, unwanted plastics and moisture):

a. *Reception and storage*

The waste is very moist when received due to the high content of wet organic waste. In order to reduce the humidity and at the same time improve later sorting/process, it is proposed that the waste at reception is placed in vines of a maximum of 2 meters in height. The vines should be turned daily for a week. The purpose is to remove moisture, and thus also improve sorting. Storage without a roof must be avoided during the wet season. Items that should not enter the process should be removed mechanically or manually as early as possible.

b. *Feeding*

The hopper should be fed with a sorting grab, and good spread on the conveyor belt should be ensured through suitable equipment (see section 5.1 for further description). Especially at IRECOP, there is a problem today that the waste does not enter production evenly, which lowers further efficiency and quality. Better dispersion of waste on the conveyor belt in the hot Accra climate is also likely to have a drying effect (thus lowering moisture content as desired).

c. *Shredding*

Today's grinding is a pre-shredding of mixed waste before screening out organics and manual sorting, and works well. Dividing to a smaller size at this stage in the production process will make further manual sorting difficult, but possibly improve the extraction of compost - thus the objectives of the sorting procedure must be balanced. The selected shredding size is closely related to the size of the mesh holes in the screening process, as described below.

After manual sorting, but before the pyrolysis reactor, sorted plastic must be divided down to 20-40 mm size. Ideally, the last grinding should take place immediately after manual sorting, but at the latest before dry cleaning.

d. *Screening*

A drum screen mesh size of 60-70 mm is optimal both in relation to the quality of compost and to streamline later sorting of plastic. It is difficult to achieve the desired quality of plastic with the current mesh size (40mm) at ACARP, and thus a key recommendation in this regard is to ensure that the mesh size corresponds better to the desired sorting outcome.

In addition to a drum screen, it is recommended that a star screen and air separator (wind screen) are installed.

e. *Manual sorting*

Manual sorting today is partly negative in the beginning and positive later in the process. In secondary sorting, it is primarily positive sorting. During the pilot at the sorting plants, it immediately became clear that a satisfactory volume of potential pyrolysis plastic would not be reached through positive sorting. Thus, the emphasis was put on negative sorting relatively early in the process. At IRECOP, there is a need for extending the sorting line for the purpose of improving quality of the output. This includes the introduction of extended conveyor belts, a new sorting cabin under roof, and additional (e.g. 6) sorting operators.

There is also a need for education, training and good management of the manual sorting line at both plants.

f. Baling

There are balers at both sorting facilities in ACARP, including a small paper baler unsuitable for the needs of sorting out plastics for pyrolysis. At IRECOP there is a round baler which is better suited for the desired purpose. This baler gives sufficient weight to the balls as long as it is primarily plastic film that is baled. At IRECOP there is also equipment for wrapping the balls. Baling the plastic is also expected to have an effect on moisture levels, if the pressure is strong. Moreover, baling the plastics will have a desired effect on costs and emissions for transportation and other logistics when transporting the plastics from the sorting facility to the pyrolysis plant, especially if they are located far from one another.

If there is a need to bale other plastic fractions, such as PET bottles (for mechanical recycling), it should be noted that other types of balers are better suited.

With all these recommended improvements at sorting stage, it is deemed feasible to improve the plastics quality sufficiently to rely on a dry cleaning process for final improvement. This involves reaching the quality specifications set at Interface 2 as described above.

Introduction of a dry cleaning procedure

The final step for improving feedstock quality before feeling the plastics into the pyrolysis process, is to introduce a dry cleaning procedure. This process is described at depth in section 5.2, so not much further detail is given here other than the recommendation of this method and the view of this as viable and sufficient to close the final gap of feedstock quality.

As also described in section 5.2, it will be necessary to include a shredder prior to the dry cleaning unit, in order to ensure a uniform feedstock stream entering the system. Depending also on other factors, it may be possible to reduce the amount of shredding to a single round. This would be highly desirable from an economic perspective, as the costs of further pre-treatment is mainly driven by power costs, and shredders have a high power consumption.

It may also be relevant to pelletize/agglomerate the feedstock after dry cleaning and before pyrolysis, to make feeding more efficient and create a more homogeneous mixture. This will also increase compactness, which is useful for storage and further transportation, and may lower the EHS risks associated with handling flakes of plastic.

While some few viable dry cleaning systems exist to remove contamination of plastic feedstock for pyrolysis, it is expected that this will become an increasing focus of the waste management and recycling industry as chemical recycling grows as a complementary solution to conventional types of recycling.

Final comments and next steps

The presented recommendation is based on extensive work on feedstock acquisition in Accra, Ghana, but may be relevant for difficult fractions of plastic waste in other locations. Moreover, this report highlights the importance of approaching feedstock acquisition for chemical recycling consciously and carefully, because it may make or break a project (either because the plastic feedstock does not fulfill the required quality specifications for pyrolysis, or because a too costly cleaning solution is chosen which makes economic viability difficult to achieve). It should also be highlighted that from an economic perspective, the earlier the contamination can be removed the better. Implementing costly processes on a feedstock stream where a high proportion will be removed later on (low yield) means that the cost per ton of clean plastic will be proportionally higher.

As mentioned in the introduction to this final section, the circumstances have not allowed practical testing of this recommended solution. Next steps should involve testing in practice the recommended improvements to the sorting procedures, and the recommended dry cleaning solution with a representative sample of sorted plastics. This would serve to further refining the approach to reaching a satisfactory feedstock quality. Such a test may also include a more refined approach to analyses of plastic quality now that a better picture of potential issues has been formed, including a device that may help to identify plastic types that are not easily identified through visual and manual inspection. Furthermore, in order to increase robustness of further testing, it may be a good idea to accommodate for trials both during the rainy (April-July) and dry (July-April) seasons, to consider whether any adaptations to the process will be necessary.

Some pyrolysis technology providers have testing plants able to receive samples of potential feedstock. This feedstock will be checked at receival to see how it meets the quality requirements provided. The output from the pyrolysis process will then be further analyzed to understand the value of the offtake.

Providers of plastic cleaning system has the same approach and have confirmed willingness to receive sorted plastic feedstock from Ghana. They would run the material through a test plant to determine how efficient the cleaning solution is for the collected plastic feedstock. It is considered that both options should be further investigated for the next phase of the project.