End-of-Phase Report

Contents

Report written by the Plastic REVolution Foundation during Q2 2020

For more information about the Foundation, see www.revocean.org/plastrev

Abbreviations

ACARP = Accra Compost and Recycling Plant

AMA = Accra Metropolitan Assembly

GAMA = Greater Accra Metropolitan Area

GPAP = Global Plastic Action Partnership

IRECOP = Integrated Recycling and Compost Plant

KCARP = Kumasi Compost and Recycling Plant

Kt = Kilotons

MMDAs = Metropolitan, Municipal and District Assemblies

MSW = Municipal Solid Waste

PRF = Plastic REVolution Foundation

PtL = Plastic-to-Liquid

Tons = Metric Tons

WIEGO = Women in Informal Employment: Globalizing and Organizing

1. Executive summary

The Plastic REVolution Foundation (PRF) was founded by Kjell Inge Røkke in 2019 with the objective of developing economically viable solutions to plastic waste. Led by Erik Solheim, the Foundation set out to investigate the feasibility of building a pyrolysis plant in Accra, thus supporting the development of an economy around used plastics. Large-scale collection can be motivated by assigning a value to plastics and changing the way used plastics are viewed: From waste to resource.

PRF 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. By valorizing a currently uncollected stream of plastics, the project has the potential to significantly reduce plastic pollution and create jobs along the value chain, also for vulnerable groups in the informal sector. Potential collaboration partners have been identified, a number of dialogues initiated for the project's successful implementation, and wide support received.

It has been established that sufficient volumes of plastic waste are generated in Accra to support a medium-scale plant, and concrete collection models have been identified and tested through pilot studies. To foreign direct investment within recycling, a challenge often encountered is the lack of security and predictability of feedstock supply. This has been a key focus of PRF's work thus far. Through a feasibility study and two pilots, it has been established that collecting 30 tons/d is achievable, and raising this to 60 tons/d is viewed as feasible over time.

Technological solutions that enable the processing and valorization of mixed plastics have been identified, and a decision remains to be made. Pyrolysis has been identified as one of the most viable existing technological solutions for contaminated and mixed plastic waste. This process can produce pyrolysis oil, which may be further upgraded and refined to naphtha, used for production of new, equal-grade plastics. It may also be transformed to diesel fuel or feedstock for crude oil refineries. The choice of technology and target market has varying implications for the project's economic viability.

Reaching satisfactory feedstock quality for chemical recycling is necessary, and PRF has begun investigating how to achieve this – it is possible, but an affordable solution is required. Besides security and predictability, achieving the right quality is a key aspec**t** for ensuring viability of a chemical recycling plant, as chemical recycling does not yet offer solutions for highly contaminated plastics. This is a costly addition to the cost of acquiring suitable feedstock, particularly washing that involves water. Reducing cleaning costs would constitute an important step in reaching an economically viable venture.

A key priority for PRF is to identify solutions for offtake that contribute to enhancing the economic viability of the project. Different end-markets have been identified, spanning from producing a refined product for export to a potential European premium market, to selling an unrefined product locally. Under the current assumptions, revenues beyond market prices are necessary to reach economic viability.

With the support of industry, Ghanaian authorities and global actors, this pioneering project may achieve economic viability. Extensive work has been done to establish the potential of a plastic-to-liquid plant in Accra by PRF, and while a great opportunity is identified, challenges remain in achieving economic sustainability. PRF strongly encourages stakeholders to consider how they may contribute to building a more conducive environment to establishing an economically viable venture for the large-scale collection of plastic waste in Ghana, representing a leap towards solving plastic pollution globally.

2. The Plastic REVolution Foundation and its first project

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 plastics have 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. Kjell Inge Røkke is the majority shareholder of the Aker Group of companies covering oil production-, oil service-, engineering, construction, technology and fishing companies. The Foundation is led by Erik Solheim, former Norwegian Minister of Environment and Head of the United Nations Environment Program.

> *The Plastic REVolution Foundation is founded on a commitment to combat plastic pollution in an economically sustainable way*

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.

Drainage system in Agbogbloshie, Accra

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 Aker's operative presence in Ghana, and the valuable relationship with Ghanaian authorities built by Kjell Inge Røkke, this was a natural starting point for the PRF in exploring solutions to plastic waste.

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 (PtL) 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 the concept will demonstrate a solution that can subsequently be brought to other parts of the world.

Choosing to make an investment of this size, potentially $45-50 million in total, requires strong certainty around the viability of the project. The factors affecting economic viability and overall feasibility of building a pyrolysis plant can be grouped into three main areas[1]. Firstly, the addressable volume of plastic waste – not only in terms of total volumes that exist, but volumes available through cost-effective channels. The cost of feedstock acquisition and treatment costs, i.e. everything involved in bringing the feedstock to the plant in a suitable condition for processing, are part of this initial factor. Secondly, the pyrolysis design and operating costs, including capacity and sophistication level. Thirdly, the targeted market for the end-product, taking into account availability, requirements and price.

These three areas have all been examined in-depth during the Foundation's first year of operations and are detailed in the main part of this report – section 5. First, it is however necessary to provide some background on the context in which PRF wishes to launch its first project.

3. Waste collection and plastics management in Accra

5 million

Inhabitants in Greater Accra

0.72 kg

Waste generated per person every day in Accra Metropolitan

200-270k tons

Plastic waste generated per year in Greater Accra

Accra, Ghana's capital city, has more than 2 million inhabitants. According to estimates published by the Ghana Statistical Service, there are nearly 5 million inhabitants in the Greater Accra region[2]. The estimated municipal solid waste (MSW) production in Greater Accra 1.6m t/y, and municipal waste generation is estimated at 0.72 kg/day per inhabitant[3]. There is an estimated between 200 and 270k t/year of total plastics in the MSW stream.[4] The estimates of how much is collected and recycled varies significantly, PRF having seen figures ranging from 16k t/year to min. 50k t/year (6-25% recycling rate). The actual rate is likely at the higher end of this, possibly even more.

A significant part of the recycling activity is done by the informal sector. The role of the informal sector in waste collection has been, and remains, extensive in various societies across the globe. In particular in developing countries, making a living through the collection and selling of recyclable materials is an invaluable contribution to resource recovery, and a source of livelihoods for many. High informal sector activity often complements shortcomings in ensuring full coverage in formal sector collection. Challenges in coverage accompanies the fact that in developing countries, generating

[1] As also described by reports on the topic, e.g. *A Circular Solution to Plastic Waste* (2019) by Boston Consulting Group: https://image-src.bcg.com/Images/BCG-A-Circular-Solution-to-Plastic-Waste-July-2019_tcm9-223960.pdf

[2] Ghana Statistical Service: https://statsghana.gov.gh/nationalaccount_macros.php?Stats=MTA1NTY1NjgxLjUwNg==/webstats/s679n2sn87

[3] Accra Metropolitan Assembly, Waste Management Department

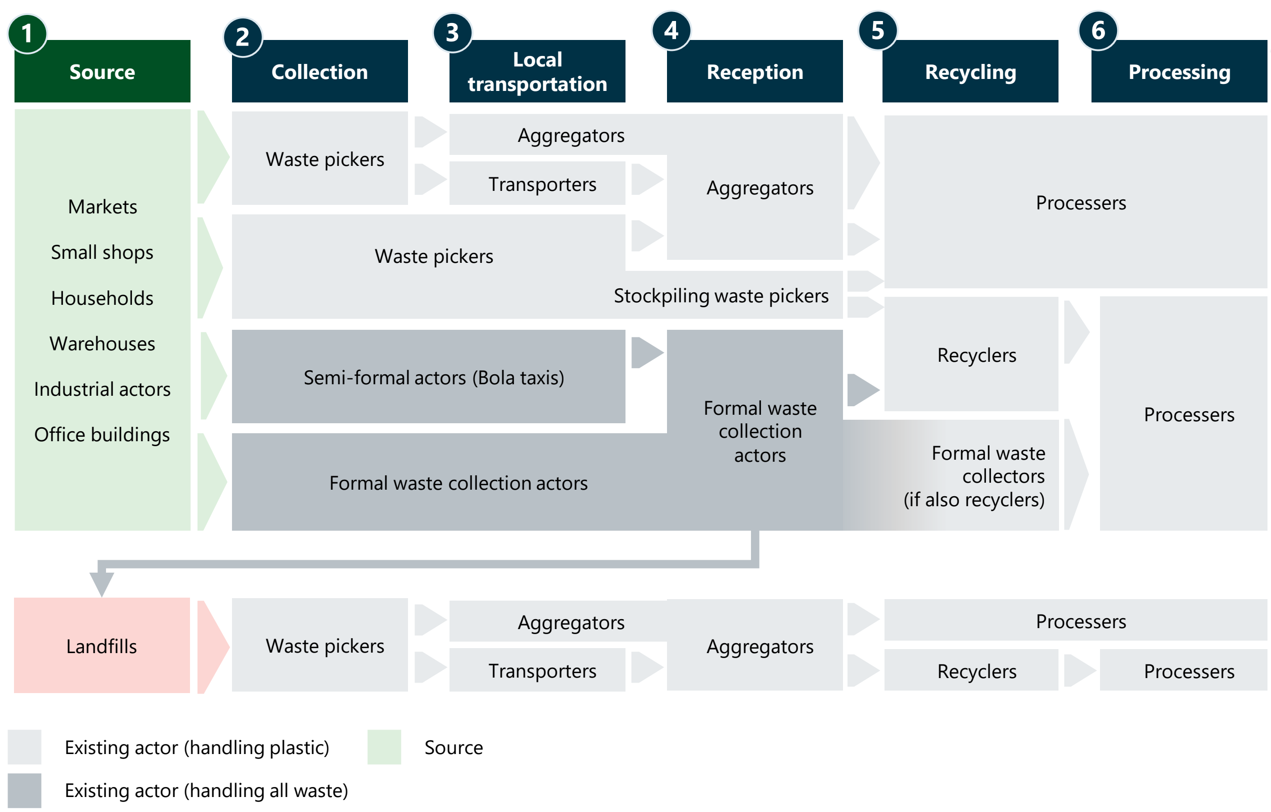
[4] Feasibility study conducted by Seureca and Systemiq

sufficient tax revenue to cover basic services such as waste collection is difficult. A greater proportion of government budgets are therefore already spent on services of this type than in industrialized countries. While the targeted collection of recyclables is largely done by the informal sector (other than a few first-moving formal actors), collection of general waste is dominated by "formal" actors.

The below figure provides a crude illustration of the existing value chain for collection and processing of used plastics in Accra. To the left, various sources are listed, such as markets, small shops, households and industrial actors. Moving from left to right, activities involved in the valorization of plastic waste are presented. Below are the types of actors involved in each stage. As illustrated, the extent of the engagement of individual actors varies, spanning a small or larger part of the value chain. Key elements to understanding opportunities within recycling in Accra includes the nature of the sources (including what types of plastics can be expected from what source), the characteristics and variation among actors within the different categories, and the variation in price for plastic waste across actors and stages of the value chain.

> *The division between formal and informal is often artificial*

Moreover, while certain terms are used to denominate sectors and groups of actors, it is important to emphasize that such terms are often fluid. For instance, the division between formal and informal is often artificial – informal workers are involved in formal collection (both directly and indirectly), and formal actors are often also involved in the informal space. Moreover, "types" of actors may be involved in various parts of the value chain depending on what their background, contacts and location allows. For instance, a picker may sell directly to a recycler if she has the means to transport and store the plastics, and happens to have the information about whom to sell it to.



About the formal collection

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, a development that has been underway since its privatization was initiated in the late 1990s.

In 2009, a new refuse collection system termed Fee and Performance Based Solid Waste Collection was developed, where waste companies were awarded waste management contracts for a specific area through a tendering process. They are subsequently held responsible for the cleanliness of these areas, including all residential, commercial and industrial waste generated in their zones.[5] The zones for which contracts are awarded originally corresponded to the districts of Accra Metropolitan, but today count 6 in total, distributed on 6 contractors (on a 5 year term). AMA prepares the waste management contracts, which do not involve any funds, but the companies are given the right 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. AMA collect from purely commercial areas such as the Central Business District, lorry parks and markets.

In return for waste collection services, residents are required to pay a token fee to the accredited waste management company. Households in low, middle, and high-income areas are expected to pay differentiated fees, set by Assemblies and thus varying between districts of the Metro. However, contractors face difficulties collecting these fees from the majority of households[6], particularly if paid monthly. Interviewed Borla taxi drivers collecting in inaccessible areas report negotiating the collection fee on a daily basis. While work is continuously done to improve coverage, especially low-income areas of the city face challenges with waste collection. Part of this is due to inadequate infrastructure, but lack of purchasing power to pay the collection fee upon service delivery may also represent an obstacle. Nonetheless, before 2009 the city collected the waste tax and paid the contracted company for its services. For several reasons, this model was abandoned in favor of the present model.

AMA has been working on improving the city's waste management the past years. Upon the implementation of the new system, AMA supplied 5,000 free waste bins to complement the role of the private sector. AMA has also put down a lot of work in formalizing the informal sector, and was among the recipients of the 2019 C40 Cities Bloomberg Philanthropies award for "building a future that engages all citizens". This involves registering tricycles collecting waste – Borla taxis – by requiring that they receive a registration number and a free sticker as a first step towards harmonization and regulation.[7]

Borla taxis waiting to empty their load

[5] Accra Metropolitan Assembly, Climate and Clean Air Coalition (CCAC). Municipal Solid Waste Initiative for Short-Lived Climate Pollutants (SLCPs) and Greenhouse Gas Emissions: Workplan for Implementing Solid Waste Management Strategies of Accra City (February 2014). https://www.waste.ccacoalition.org/sites/default/files/files/accra_usepa_ccac_workplan_february2014_0.pdf

[6] Aweso, Davis Mawuena: An Evaluation of Zoomlion Ghana's Participation in Solid Waste Management in Ablekuma Central Sub-Metropolitan Area. https://pdfs.semanticscholar.org/4dc1/3970f061fc3647c7873f112cde94d6b1a64a.pdf

[7] Oduro-Appiah, Scheiberg, Miezah, Mensah, de Vries: *Existing realities and sustainable pathways for solid waste management in Ghana* in Sustainable Waste Management Challenges in Developing Countries

Nonetheless, challenges remain with regards to service user fee harmonization and training. Furthermore, dumping of waste outside of dedicated areas still occurs despite efforts to target this specifically.

Finally, existing final disposal sites for municipal solid waste in Ghana are not engineered and many may be described as crude dumpsites. These form the basis for extensive informal sector activity, with inadequate working conditions and health hazards such as fires, one of which occurred earlier this year at Kpone landfill. Waste pickers working on landfills have not been targeted by the project so far due to the hazardous nature of this work and the objective of collecting recyclables before they reach the landfill.

<u>About informal collection</u>

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 as described earlier. A number of different actors are involved in informal collection, and a brief elaboration of the categories used follows below.

Waste picker is a general term for informal workers in the collection part of the industry, and according to WIEGO[8] the term was adopted at the First World Conference of Waste Pickers in 2008 to facilitate global networking – and to eliminate the use of derogatory terms like "scavenger". Waste picking is a profession that is easily accessible, as it does not require any previous investment or education. Thus, it does not involve the risk of going into debt as one would from taking up a loan to e.g. purchase a vending truck. This represents an attraction to many marginalized and impoverished persons and is an important livelihood for those with few other opportunities. For others, it represents a chosen source of income – either on its own or combined with others (such as petty trading, cleaning or "sweeping" – cleaning the streets at dawn and dusk as formalized employment). It represents an opportunity to move up the value chain and capture more of the value over time, or to collect larger volumes and increase income proportionally. Some people working as waste pickers report facing discrimination because of their profession, both in general society and, claimed by some, in the health care sector. Advocacy groups such as WIEGO work to increase the recognition and dignity of waste pickers, emphasizing that this group makes a significant contribution to waste management and recovery.

Waste pickers at Kpone landfill demonstrating for their rights, at an event organized by WIEGO

Borla Taxi Drivers are operators of tricycles, either motorized or manual. According to Seureca[9], WIEGO estimates that around 2000 people in Greater Accra work as "Borla Taxi" drivers, providing door-to-door collection service in the districts that are not served by franchised service providers. Generally, these districts are difficult to access (narrow roads) and are not accessible to the collection trucks operated by large service providers. The Borla taxis generally segregate valuable materials like plastics and metals

[8] Women in Informal Employment Worldwide – Globalizing and Organizing: https://www.wiego.org/informal-economy/occupational-groups/waste-pickers

[9] Seureca Technical Note for Department for International Development (DFID): *Informal plastic sector study – a focus on pickers, aggregators and middlemen*

before or at an end-point such as a transfer station. This represents an opportunity for both additional income and reduced costs (as they pay a small fee for properly disposing of the waste).

Transporters is a category chosen to denominate people involved in the transportation of the plastic from its source of collection to a location where it is sold, stockpiled or handed over to another actor. They are generally paid ad hoc to assist in the transportation of the plastic. Aggregators or recyclers may also be engaged in transportation. Transportation takes place on many levels across the value chain although it is only highlighted once in the diagram.

Aggregators (or middle-men, here used interchangeably) are people buying recyclables to gather larger volumes to make profit out of selling these volumes. They often have the means to make a small investment, in the form of a vehicle for transportation or a storage space. This enables them to capture larger profits, but involves higher risk and requires a better starting point. Several aggregators may be involved along the value chain. Some pickers circumvent this step by taking care of transportation and stockpiling themselves, see below.

Stockpilers is a group of waste pickers that collect the plastics themselves, but have more investment capital or assets such as storage space compared to others. Thus, have the capacity to collect larger volumes for more infrequent collection. They moreover often have the necessary market knowledge and logistical access to capitalize on differences in prices across the value chain – skipping the step of initial aggregators and earning more per kg of plastics.

One of the pilot participants engaged in stockpiling

About the recyclers and processers

Recyclers and processers are actors engaged in the processing of the plastic waste one way or another. In Accra, the term *recycler* is often reserved for companies producing pellets or flakes from used plastics – but not finished products. In order to distinguish the two, the term *processers* is chosen to denominate producers of final materials either from used plastics directly or from pellets. Often, but not always, companies are engaged in both recycling (to pellets) and processing (to end products).

A multitude of companies exist locally that are engaged in the recycling and processing in Accra. Depending on the type of recyclable (PET, HDPE, etc.) and its characteristics (flexible, rigid, color etc.), different end products are produced. The most common in Accra are[10]:

Example of chair from recycled materials

Polybags for sale at Kaneshie Market

- Plastic bags, often black (locally called *polybags*) – often made from water sachets, mixed plastics;
- Cables, pipes – often made from PP and HDPE;
- Plastic chairs, tables, flower pots etc. – made from HDPE, PP and/or LDPE;
- Road pavement bricks; boards and floors (these fractions are newly initiated) – made from any combination of mixed plastics, also PS, PVC and PET.

[10] Based on Seureca Technical Note for Department for International Development: *Informal plastic sector study – a focus on pickers, aggregators and middlemen,* confirmed and adjusted somewhat by own observations and experiences

Generally, plastics are bought by type at a differentiated price by recyclers and processers. The market for HDPE, higher-quality LDPE and rigid PP is very well-developed, and at high quality these plastic types can be sold to recyclers at high prices. For instance, HDPE sees a price increase from what initial pickers receive of 1-1.2 GH¢/kg (depending on cleanliness), to 2.5 GH¢/kg when aggregators sell to recyclers/processers. If pelletized, HD sells at 4-5 GH¢/kg. This price increase along the value chain is similar to that for the other plastic types recyclers and processers buy. (High-quality) LDPE increases from 1.5 GH¢ when sold by waste pickers to aggregators, to as high as 2.5 when sold to recyclers and processers, and when pelletized it trades at 4-5 GH¢/kg.

Water Sachets collected by a waste picker

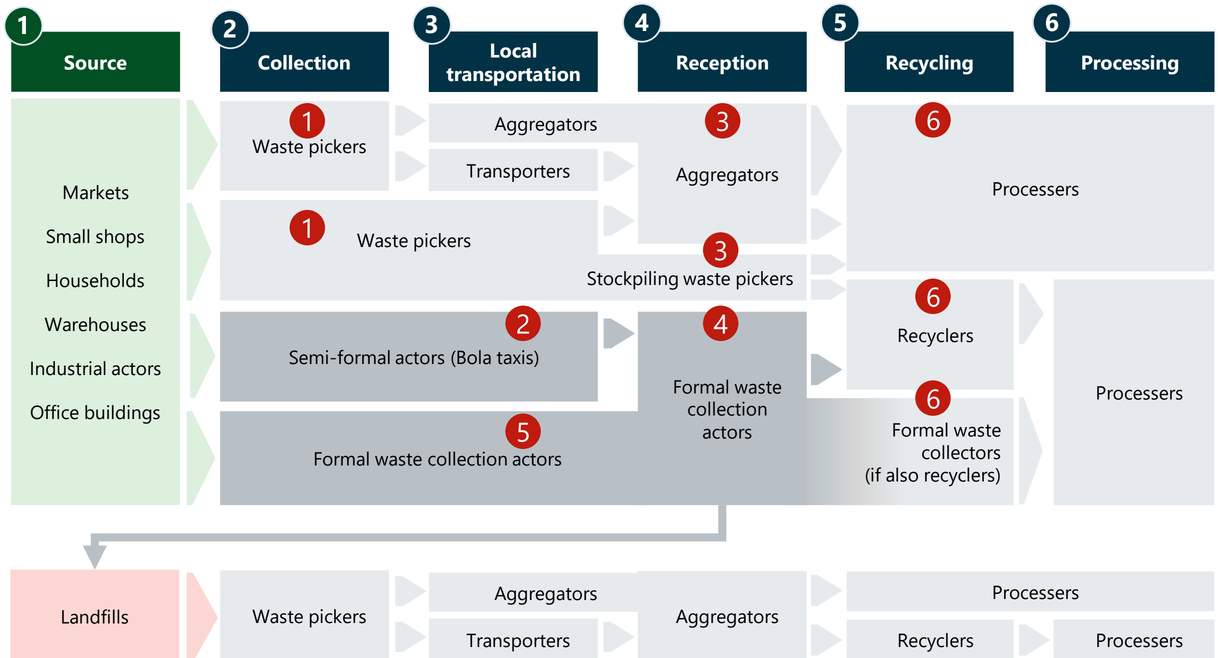
The market for low-quality LDPE is less developed – some actors trade in this, others account that nobody buys it. For PET, there are not many actors currently buying, and the collection infrastructure is underdeveloped. Thus, even though some may be interested in selling it also at lower prices (it trades from waste pickers at 0.5-6 GH¢/kg if clean, as low as 0.3 GH¢/kg if not), many pickers do not have anyone to sell it to, or lack the means to transport it to a buyer. Water sachets, an often co-extruded product from a mixture of LDPE and HDPE (or even LLDPE), is widely used for water consumption. The collection of this product is also widespread, and they are used among others for the production of polybags or other products that use a mixture of LD and HD.

The price of plastics in a transaction depends mainly on 3 things: type, cleanliness and step in the value chain. If waste pickers manage to circumvent a step in the value chain and sell directly to a recycler, this gives high returns. Furthermore, the color of plastic is normally an important quality factor in the international waste plastic market. For instance, natural LDPE is more valuable than mixed color LDPE. The Ghanaian plastic market appears to maintain local price characteristics. In general, at least during the pilot period, prices for plastics in Ghana appear to be higher than in Europe.

> *The price of plastics in a transaction depends mainly on 3 things: Type, cleanliness and step in the value chain*

The potential placement of Plastic REVolution Foundation in the value chain

The Plastic REVolution Foundation aims to intervene in the existing value chain on multiple levels, as indicated below. This will have a direct impact on several other actors in the value chain.



1. PRF aims to collect from waste pickers directly, through the initiation of stations where plastics can be delivered close to where it is collected. This allows for direct interaction with the initial collectors, involving benefits with regards to fully grasping the social impact of the project.
2. PRF aims to receive plastics directly from Borla taxis collecting from households and commercial actors, to divert the plastics from the municipal waste stream supporting door-to-door collection models and eventually encourage further sorting at source.
3. PRF aims to collect directly from aggregators and stockpilers, targeting locations that can provide large enough volumes for customized collection to pay off.
4. PRF aims to sort out plastics from the mixed municipal waste that has already reached the sorting plants, thus diverting it from landfilling and limit potential further leakage into the environment. Furthermore, by valorizing a fraction of household waste that currently has no value, it is considered possible to indirectly incentivize improvements to general waste collection.
5. PRF aims to establish collaborations with formal waste management actors to institutionalize dedicated collection of plastics from households, encourage sorting at source as well as formalize channel 2 described above.
6. Finally, PRF aims to work with other processers and recyclers, receiving plastics that they are not interested in and thus utilizing the channels of others for collection and establishing synergies.

The above channels represent various possibilities for ensuring a steady feedstock supply while also maximizing social impact and livelihoods creation. Channels 1-4 have been tested through two pilot studies, as described in the section on feedstock supply and collection. The ideal mixture between sources remains to be determined, and it is expected that any collection system should be adaptable to market reactions. Furthermore, an important question in selecting the right channels for collection concerns the trade-off between collecting plastics earlier in the chain compared to later and thus paying more but saving on logistics costs – it may be beneficial to collect at an aggregated stage. Generally, it will however be desirable to collect plastic as close to the source as possible, not least for quality reasons.

Introducing the project will potentially have a large, positive impact on employment, but there are always actors that will be negatively affected by the entry of a new actor. By entering into and changing the dynamics of an established value chain, roles of certain actors early in the value chain may be reduced thus creating unintended negative social consequences, and potentially sparking a backlash. Here, dialogue with affected groups should be initiated early on, and ideally they should be somehow integrated in the development of a new value chain.

Furthermore, it is difficult to know at the current stage what the effect on actors also later in the value chain will be (recyclers and processers). As PRF would accept mixed and low-grade types of plastics, the direct competition with some actors may be limited. However, there may be increased competition over the types of plastics that multiple actors are interested in, and existing recyclers may be negatively affected by this. There is however no doubt that there remains a large and untapped potential for plastic waste collection in Accra. The optimal outcome of the initiation of this project on the collection side would be consolidation of the value chain and obtaining mutual synergies among recyclers – thus resulting in overall more collection of the plastics that is currently polluting the environment and clogging the city's drainage system.

"*The optimal outcome of this project on the collection side would be consolidation of the value chain and obtaining mutual synergies among recyclers*

4. The work of PRF and high-level learnings

I. Feedstock supply and collection

Approach and rationale

Making the decision to build a plant with a possible design capacity of 30-60 tons per day and eventually expanding (at a sizeable investment of potentially $45-50 million) requires strong certainty in the area of feedstock supply – with regards to quantity, quality and cost. In many developing countries, there is an abundance of plastic waste polluting cities and the environment. However, the question of how to ensure an effective supply chain is much more difficult, keeping many from venturing into processing.

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 a high degree of certainty that enough feedstock at a high enough quality can be obtained from the onset of the project.

Furthermore, by initiating sorting of feedstock from established waste management plants and valorizing 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 general

> *The key to developing a viable supply chain for plastic waste is utilizing both the formal and the informal waste management sector*

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.

Initially, the majority of plastic feedstock will 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). 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.

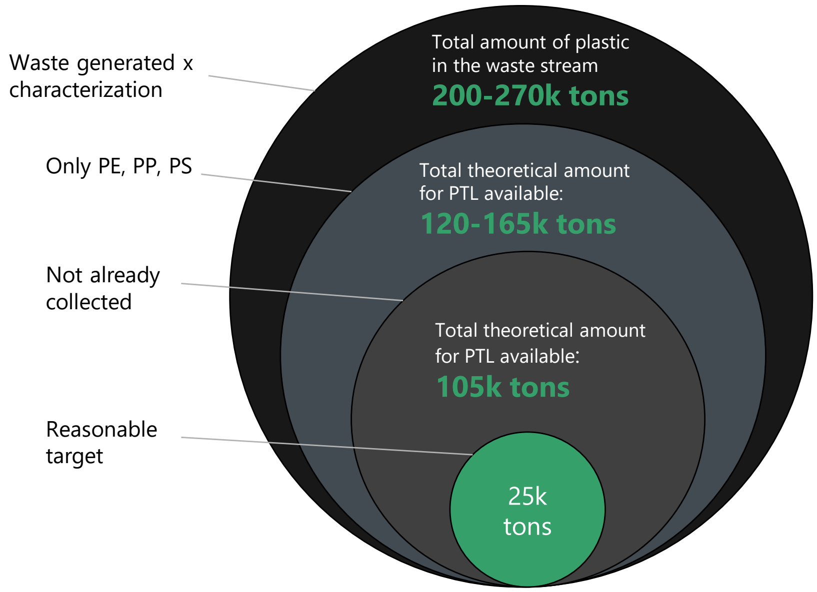
Feasibility studies

During the first months of the project, a feasibility study was commissioned to the consultancies SYSTEMIQ, Seureca and Norwaste to assess the prospects of a Plastic-to-Liquid plant in Accra. These advisors have strong backgrounds in systems change, resource management and waste management, and were highly qualified to advise PRF on the prospects for the initial project.

The conclusions from the initial phase of the feasibility studies included that Greater Accra is the only coastal city in Ghana with suitable feedstock for a sizeable investment. Moreover, enabling conditions for plastics-to-fuel recycling in Accra are stronger than in many similar locations – particularly due to the waste collection system and pre-existing waste sorting facilities. Furthermore, a preliminary analysis of a conservative business case showed how it should be possible to reach profitability, and credible technology providers were identified at an early stage. Among numerous risks identified at this stage, none were considered to be “no-go” issues. The feedstock supply model was however identified as a key challenge to be addressed in project concept and through partnerships.

The subsequent phase went more in-depth on quantity and quality of feedstock and plastic collection system design, among other things. From this study, it emerged that there is an estimated municipal solid waste (MSW) production in Greater Accra of 1.6m tons per year. Between 200 and 270 000 tons per year of total plastics in the MSW stream. PE, PP and PET represent 80% of total plastics.

The main plastic types accepted by identified pyrolysis technology providers are PE, PP and PS. Out of the 105 000 tons per year of theoretical plastics available for the PtL plant, 24 000 tons per year, or 66 tons per day on a continuous basis, seemed to be reasonable ambition based on the available plastic and the quantity already recycled. A significant amount of the plastics in Accra is already recycled – at the date of presenting (July 2019) 40 000 tons per year is recycled, mainly PE and PP. Most collection is done by the informal sector. The below figure illustrates the establishment of a reasonable target for plastics collection.



Furthermore, the feasibility studies started out with a long list of potential feedstock alternatives, which was concretized and shortened to the proposal of three main channels. It was proposed that pilot studies test them in practice. In Q4 2019 and Q1 2020, pilot studies were conducted by PRF for this purpose, as further detailed below.

Pilot studies

<u>Waste sorting plant pilot</u>

The possibility of obtaining a volume from the two existing municipal solid waste (MSW) sorting and composting facilities in the Greater Accra region (IRECOP and ACARP) was explored through a five-week pilot in Q4 2019. The pilot was planned and executed by Norwaste on behalf of PRF, a waste consultancy based in Norway with strong competencies in waste value chains. The background for these conclusions is documented and available to PRF.

This pilot set out to test the sorting of plastics out from existing waste management plants, thus diverting it away from landfills and other solutions for mixed waste. It was conducted at the two sorting and composting plants (IRECOP and ACARP) within the Jospong Group of Companies (JGC) in the Greater Accra region. Both these plants have the objective of establishing a sustainable waste management system to ensure divert waste from being landfilled and create valuable recyclables and compost. Both plants receive residual waste from households, markets and others.

Bailed PET following existing sorting procedure

The "RDF" fraction

The scope of the pilot was to optimize the throughput of both plants, the so-called RDF fraction (refuse derived fuel), after organic bio-waste and recyclables are sorted out. Today there is no other final treatment solution for the RDF stream than landfilling and there is no landfilling capacity adjacent to the IRECOP plant. The aim of the pilot was to test whether it would be possible to obtain a mixed plastic quality (PtL material) at the two plants suitable for pyrolysis. A further aim was to test what changes would be necessary at the two plants and to establish the future potential for extracting mixed plastics. Changes should primarily be made within the facilities' framework and not lead to significant costs.

> *Today there is no other final treatment solution for the residual stream than landfilling*

In normal operation both plants are optimized to divert as much organics as possible to produce compost. During the pilot the objective was to sort out as much mixed plastic suitable for a PtL production as possible. The focus was not on bringing those two objectives together, i.e. the sorting mode was different from normal operation. One of the two sorting lines at IRECOP and the entire plant at ACARP was used for the pilot. During operation of the pilot, more detailed modifications were agreed upon. Different sorting modes were tested, both positive and negative sorting, one- and two-step sorting, as well as different levels of conveyor speed and positive sorting of recyclables. Samples were taken and analyzed at the in-house laboratory of ACARP. Some samples were brought to Norway and analyzed at Norwegian laboratories. Analyses of heterogeneous plastics with high contamination is difficult, and few labs have experience in this area. Among tests conducted was an estimated percentage of plastic content, the method for which was specifically developed for sorted mixed plastics in close cooperation with Roald Aasen at the NIBIO biogas laboratory in Norway.

Sorting in action during the pilot

This pilot involved plowing unchartered territory, as manually sorting out (PtL) plastics from mixed waste from households, markets and shops has, to the knowledge of both PRF and Norwaste, never been done previously. It is moreover important to highlight that sorting out the necessary quantity and quality involved is not only a technical challenge, but to an equal extent an organizational challenge in completely changing how things were done at the plants for a limited time.

The supervisors from Norwaste were present in all parts of the operation, including the sorting cabins with the JGCs supervisors. This gave valuable information for the pilot, and knowledge was also gained by the JGCs supervisor, the plant managers and other relevant staff members of the JGC.

On the basis of the pilot, recommendations were given on how to optimize the sorting operation, both in terms of sorting modes, operational routines, management and minor equipment modifications. The results show that both plants with small but targeted modifications should be able to produce sorted mixed plastics with less than 10% non-plastic items with a capacity of approximately 9% of the treated residual municipal waste.

However, a clear challenge emerged with regards to quality. The sorted mixed plastics contained +/- 30 % moisture and contaminants (organics and inorganics) and elevated levels of chloride and sulfur above the specifications given for feedstock to a pyrolysis plant – this is further described under the section on technology selection. To meet the quality criteria, further cleaning is necessary. As the contaminants are water soluble, washing technology is likely the most appropriate way of cleaning the material to meet the quality specifications. However, as described in the dedicated section, washing that involves water involves very high costs which strongly challenges the project economics.

> *A clear challenge emerged with regards to quality – to meet the quality criteria, further cleaning is necessary*

It should be mentioned that the very heterogeneous nature of mixed municipal plastic waste makes it difficult to find sound correlations between the material sampled and the analytical results obtained – this should be kept in mind in interpreting the results. For instance, black rubber bags filled with a variety of content is very common in the local waste stream. This has the potential of skewing the results if it has not been emptied as instructed, and contains e.g. some sort of organic waste. Furthermore, these bags may be too small to be opened by the shredder and too large to be sorted out with the organics. This represents one example of the challenging nature of the task, but it is deemed manageable.

Sorting results from the pilot compared to quality criteria

	Quality criteria	Observed results (range)	Expected performance
Sorting quality		82-98%	90-95%
Plastic content			+/-70%
Water content	5%	11-35%	10-20%
Organics	5%	8-15%	>5% (with washing)
Inorganic contamination		1.1-20	1-10% (with washing)
Chlorides	100 mg/kg	1050-3400	<100 mg/kg (with washing)
Sulphur	10 mg/kg	Ca. 300	<10 mg/kg (with washing)

The estimations of quantity must also be adjusted based on the estimated volumes after sorting. With the removal of +/- 30% moisture and contaminants, the proportion of the treated residual municipal waste that can be extracted to PtL feedstock is approx. 6.3%. The overall capacity of the waste management plants today is 190 tons per shift at IRECOP and 210 tons per shift at ACARP, both currently running at one shift per weekday.

Expected volumes – 2020 and 2022 with planned upgrades

	Total processed waste per shift & weekday	Production sorted mixed plastics per weekday	Clean PtL material after washing per weekday	Clean PtL material per day, 24/7 under single weekday shifts
IRECOP	190	17,1	12,0	8,6
ACARP 2020	210	18,9	13,2	9,5
Total 2020	**400**	**36**	**25,2**	**18**
IRECOP	190	17,1	12,0	8,6
ACARP 2022	400	45	31,5	22,5
Total 2022	**690**	**62,1**	**43,5**	**31,1**

With recommended optimizations and the present waste processing rates the plants should be able to produce 25.2 tons of pure (i.e. after washing) PtL material per weekday, corresponding to 18 tons per day. With future expansions at one of the waste management plants, foreseen to be completed by the end of 2021, both plants will have the potential capacity to produce 31.1 tons per day and shift, equivalent to 22.2 tons per day of the week. If this was expanded to for instance double shifts for both lines in the medium term, allowing one shift on one line per day for second-step sorting, as well as introducing Saturday shifts, the existing capacity would allow for producing 32.8 tons per day. With the planned expansion, the corresponding shift expansion would allow the potential extraction of 40.0 tons per day.

In addition, the pilot partner has recently built a new plant in Kumasi which may supply further plastic feedstock. The Kumasi Compost and Recycling Plant (KCARP) has a full operating capacity of 1,200 tons of waste per day, but is expected to commence operations with the processing of 5-600 tons of waste daily. PRF visited this plant and extracting PtL quality plastics from this source is considered as, if not more, achievable. While this would add some transportation costs, it allows further certainty around achieving the goal of 60 tons/d capacity if it proves time demanding to build a large-scale collection system from other sources.

This pilot provided reassurance of PRF's quantity ambitions, but presented new challenges to reaching economic viability. This source of plastics is relatively inexpensive to extract, but due to its contaminated nature the costs of pre-treatment are expected to multiply the overall cost of plastics feedstock from this source.

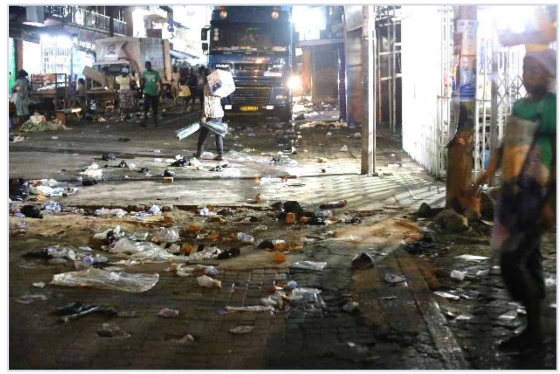
> *This pilot provided reassurance of the quantity ambitions of PRF, but presented new challenges with regards to reaching economic viability*

<u>Collection point pilot</u>

The possibility of obtaining plastics from the informal sector was explored through a dedicated pilot in Q1 2020, with the objectives of testing informal sector collection channels, gain more knowledge about the sector, map EHS and human-/labor right risks, and collect information on quantities, qualities and price.

The pilot was planned and executed by PRF and the Accra Metropolitan Assembly Waste Management Department, and operationally supported by Norwaste.

The informal sector collection pilot spanned a period of 39 days, out of which 34 were operational days. Two separate prices for plastics purchase were tested during the pilot, starting at an initial 0.3 GH¢ per kg which was increased to 0.5 GH¢ per kilo after two weeks. This provided valuable information on the current price of plastic waste in existing markets, price responsiveness and potential for incentivizing individuals to deliver a new fraction of mixed and flexible plastics.



Plastics flooding the streets of Makola market at night

Two collection channels were initially planned, but another two were initiated because it was observed that non-price incentives played a large role in determining whether people chose to deliver plastics. Initially planned was one collection point for waste pickers in the Central Business District (CBD) close to the markets Makola, Okaishie, Tudu and Kantamanto. The second involved setting up a collection point for Borla taxi drivers, located at the Waste Management Department. Additionally, weekly collection from stock pilers in Zongo Lane, Jamestown, was introduced the first week on request from people who collect in large quantities during the week and stockpile in their houses. Secondly, it became clear that a large part of the collection from markets takes place at night, after the stalls close around 4/5pm. For this reason, an improvised collection location was set up for the relevant 2-3 hours until 9pm. This was complemented by a reduction in opening hours at the nearby collection point.

Among waste pickers, there were initial challenges in understanding the "new" arrangement, as people generally do not sell unsorted plastics at a flat kilo price. The initial price received a lot of complaints. However, as people observed how others maximized their revenue by collecting large volumes and sometimes sorting out the more valuable plastics for sale elsewhere, deliveries to the pilot increased. Once the price was increased, volumes increased somewhat and the number of complaints decreased, as 0.5 GH¢/kg is within the current market price range for plastics. It is deemed possible to collect at this price if a general mix of plastics is accepted, allowing increased revenues for waste pickers through collection of larger volumes.

Transaction during the pilot: The plastics was first weighted, verified by both parties, the calculation done transparently and finally the payment made

What became clear early on is the importance of non-price incentives, such as proximity of delivery options (as transportation involves extra costs), other aspects of convenience (opening hours, predictability) as well as immediate payment. Many people described how they initially would bring only some plastics in order to check whether they would receive money for it.

With regards to payment system, the intention was to use Mobile Money, a payment service which enables transactions between phones and withdrawals in cash. There were delays and challenges in setting this up during the pilot, and thus the majority of transfers were made using cash. However, for a scale-up of a collection system utilizing the informal sector, Mobile Money transfers is a viable solution as it can be done to any phone and easily allows for tracing transfers back to deliveries. With a merchant account, transfers can be made without sizeable fees. However, a small fee applies to the withdrawal of cash which must be added on a regular basis.

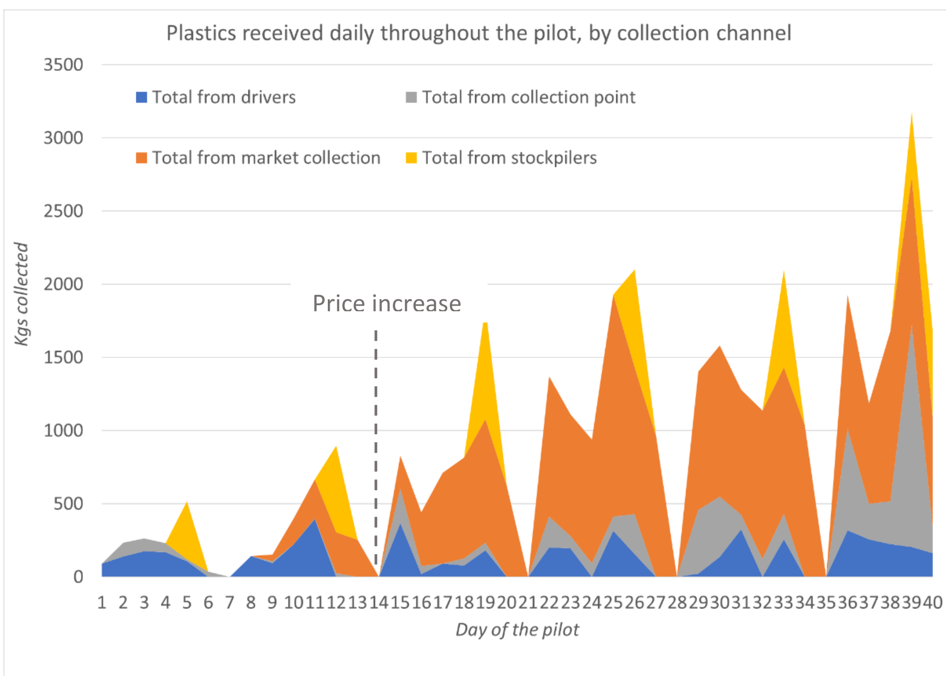
> *Mobile Money transfers is a viable payment solution as it can be done to any phone and easily allows for tracing transfers*

34 tons

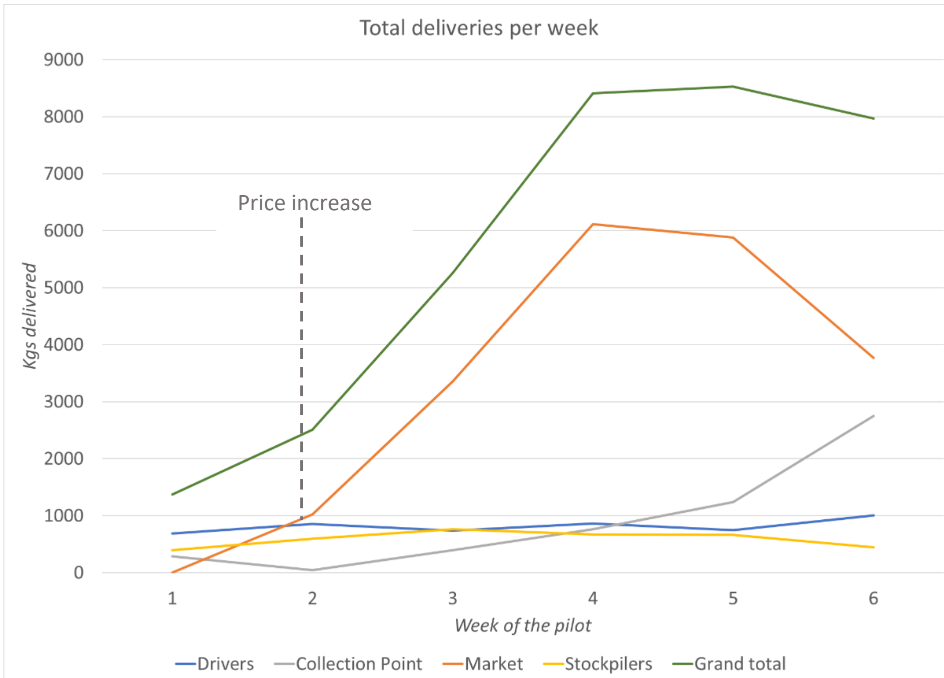
Plastics collected during the collection point pilot

Across the collection channels, a total of 34 050 kgs of plastics were collected – averaging nearly exactly one ton per operational day.[11] There was however a large variation in volume across days, with a steady growth in the total plastics delivered across the period. Every Friday represents a peak as this was the day that involved collection from stockpilers.

As can be seen from the graph below, market collection was by far the largest source of plastics, with an average of 746 kgs delivered on the days collection from there was done. Furthermore, a significant increase was seen during the pilot in total plastics delivered to the market as well as towards the end to the collection point.



[11] Including PET. A decision was made to also accept PET despite this not being suitable feedstock for a pyrolysis process, due to the ambition of cleaning all plastics and to investigate the potential of developing joint collection infrastructure with initiatives that recycle PET.



It can furthermore be observed that from the market collection, volumes increased at a higher rate after the price was increased. Market collection and the collection point complemented one another well for those picking at the markets in the evening, as this gave people the option to either deliver on the spot, or to bring it to the collection point the next day. It should also be noted that collection from stock pilers was only done once a week from a single location, meaning that if this were expanded to daily collection (from multiple locations), it may involve volumes more comparable to what was received directly at the market. There was a decrease in plastics collected the last week of the pilot, partly due to the fact that collection was terminated on Thursday this week due to a public holiday Friday and other logistical considerations (usually market collection was done both Friday and Saturday as well).

During the pilot, samples were taken in the beginning and the end and brought to the same Norwegian laboratory as the samples from the first pilot. During the last week, sorting analyses of a larger selection (120-160 kg each) from three days were also done to learn more about the types of plastics received. The results from the sorting analyses are summarized in the below table.

Two of the pilot participants in Zongo Lane, Jamestown

	Average across days excl. waste[12]
LD film	18,9 %
PP film	19,6 %
PP strips/bags	27,6 %
Water sachets	4,7 %
PS	3,2 %
PET	26,1 %

The sorting also involved the removal of waste. This constituted 8.7-10.9%, on average 9.67%, of the received plastics. With more institutionalized random controls to prevent cheating and better instructions to pickers, this fraction is expected to decrease to around 5%. The composition above is specific to the source utilized during the pilot (central market areas). Naturally, any scalability considerations must be adjusted to expectations from other sources.

Sorting of plastics during the pilot

Overall, it is observed that a high proportion of PP was received (much higher than the proportion of this fraction in the plastic waste of Accra[13]), assumed to be due to the fact that the markets were the main source for the pilot collection channels and represent a key site for the production of PP waste. Furthermore, there appears to be a large, untapped potential of lower-grade LDPE despite the high prices of primarily transparent and high-quality LDPE observed on the market. On the other hand, nearly no HDPE was received, likely partly due to high existing recycling rates for this fraction in Accra. Finally, PET constitutes a large proportion of received plastics, which is taken into account when considering scalability prospects of collection. The tested collection model and price had a large incentivization effect for PET, and thus collaboration models with actors interested in collecting PET should be explored.

The plastics quality from the samples derived during this pilot was measured both aggregated and by type. It is however a better option to consider the types separately, as this provides a good foundation for scalability considerations, as mentioned above. A method described in the Annex 1 was used to determine a range for expected proportion of non-plastics received for each fraction. The results are summarized below.

> *The tested collection model and price had a large incentivization effect for PET, and thus collaboration models with actors interested in collection PET should be explored*

[12] Insignificant amounts of rigid plastics were received

[13] Based on previous information received from Seureca and Systemiq

Quality of plastics from collection point pilot

Plastic fraction (1)	Sorting quality (2)	Liquid proportion (3)	Ash content (4)	Non-plastic from washing	Minimum non-plastic	Measurable maximum non-plastic	Chlorides* (mg/kg)	Sulphur* (mg/kg)
Film (LDPE & PP)	10 %	4,4 %	6,1 %	4,6 %	20,5 %	25,1 %	554	
PP Bags & strips	10 %	5,3 %	19,5 %	10,2 %	34,8 %	45,0 %	512	
EPS	10 %	1,3 %	3,6 %	3,7 %	14,9 %	18,6 %	3831	
Water Sachets	10 %	19,1 %	5,6 %	8,5 %	34,6 %	43,1 %	282	
(PET)	10 %	2,2 %	0,8 %	1,1 %	13,0 %	14,1 %	45	
Total (PtL suitable only)	10 %	5,5 %	11 %	6,9 %	26,5 %	33,4 %	843	47

*Acceptable levels of Chlorides and Sulfur are 100 mg/kg and 10 mg/kg respectively, i.e. observed values are 5-8.5x higher than accepted

As can be seen, the received plastic quality is challenging, in particular with regards to the levels of ash and non-plastics from washing in significant types of plastics received. Not unexpectedly, water sachets have a high level of moisture, but during the pilot these represented a relatively small proportion of the overall volumes.

Based on an analysis of the data collected from the pilot, several collection channels are proposed as a starting point for future scale-up of the collection point model

Based on an analysis of the data collected from the pilot, several collection channels are proposed for a future scale-up. The proposal is based on an important lesson from the pilot, namely the importance of readily accessible collection points, both in terms of geographical location and in terms of opening hours. Most proposed collection channels were tested during the pilot, but we also recommend collection from commercial and industrial actors, office building and institutions, as this is expected to have significant potential.

The following is proposed as a starting point. Estimated volumes are based on observations from the pilot, and quality adjustments made on the basis of expected composition of each source. A differentiation is made between operational day (generally 6 per week) and expected feedstock per day.

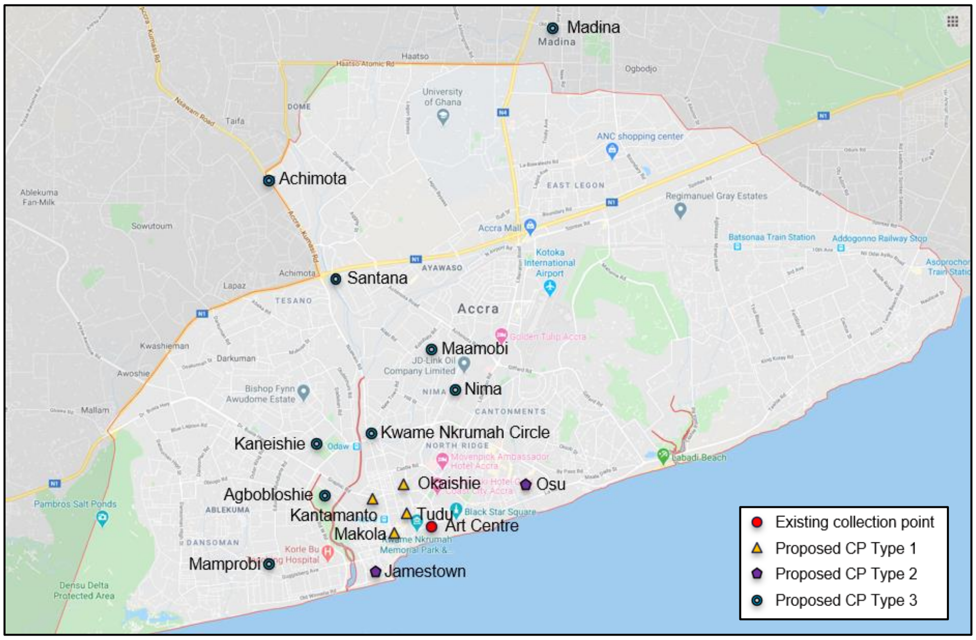
(a) Collection points type 1 (in CBD markets): 4 such collection points are estimated to collect a total volume of 3 200 kg per operational day, when adjusted for composition and quality resulting in a daily supply of 1343 kg per day, every day, to the plant.

(b) Collection from stockpilers: Activating a network of 6 clusters of stockpilers and organizing collection directly from their households is expected to result in 500 kg of plastics collected per operational day, 210 kg of feedstock per day, every day, when adjusted for composition and quality.

(c) Collection points type 2 (in the central business areas of Osu and Jamestown): Establishing collection points in these critical urban areas is expected to enable the collection of 800 kg of plastics per operational day, 347 kg of feedstock per day, every day, when adjusted for composition and quality.

(d) Collection points type 3 (in high-activity areas outside of the CBD): Establishing 9 such collection points is expected to result in the collection of 3 600 kg of plastics per operational day, 1580 kg of feedstock per day, every day, when adjusted for composition and quality.

Map of potential initial collection points



(e) Households and Borla taxis: Inserting the project in the existing collection patterns of Borla taxis already collecting household waste, a 10-20% engagement rate is estimated to result in the collection of 10 000 kg per operational day, with 3693 kg per day, every day, of feedstock to the plant when adjusted for composition and quality.

(f) Collection from institutions: Establishing collection agreements with larger institutions, it is expected that 1 500 kg of plastics can be collected per operational day, entailing 642 kg of plant feedstock per day, every day, when adjusted for composition and quality.

We emphasize that this is a proposition of how to set out with collection – there will certainly be market reactions once collection is initiated, and better ways to structure collection may emerge. A lesson learned from the pilot is the need to be flexible and adapt collection to changing market conditions.

The below table illustrates the expected quality from a scaled-up model, taking into account the expected composition of feedstock from each channel and the quality of each type observed during the pilot.

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

These channels and their expected volumes (taking into account quality[14]) are summarized below.

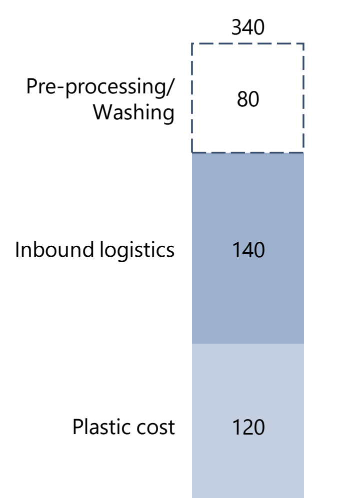
Expected volumes from scaling up collection

Source	Channel	Volume per operational day	Volume per day, 24/7	Clean PtL material per day, 24/7
Central Business District markets, small shops	Deliveries from waste pickers to collection point type 1	3 200 kg	2 743 kg	1 343 kg
Central Business District markets, small shops	Collection from stockpilers	500 kg	429 kg	210 kg
Central business areas	Deliveries from waste pickers to collection point type 2	800 kg	686 kg	345 kg
High-activity areas, e.g. food markets	Deliveries from waste pickers to collection point type 3	3 600 kg	3 086 kg	1 580 kg
Households, some commercial actors	Deliveries from bola taxis to aggregation/ collection points	10 000 kg	7 143 kg	3 693 kg
Commercial actors, institutions, other sorting at source	Collection from location	1 500 kg	1 286 kg	642 kg
Total				**7 811 kg**

The suggested scale-up model is expected to deliver a total of 7.8 tons per day in plant feedstock in the short-medium term. In addition to working with the local authorities, partnerships with waste management companies should be established for collection from households and institutions, as well as with other recyclers to build a more consolidated value chain for plastics collection in Accra (through which the 4 tons of PET collected daily can be sold/exchanged).

The assumed cost of plastics bought from the informal sector is USD 90-110 per ton unwashed plastics, i.e. the same price as tested during the pilot and allowing for a potential small increase. Also labor-, transportation-, operational- and other social costs associated with the running of the proposed collection system, must be factored in, making the cost per ton of collected unwashed plastics exceed $200 per ton (given that a sales option for collected PET plastics is found). Depending on washing costs, the total cost of plastic from the informal sector may be in the proximity of $350 per ton, accounting in that the expenses previously mentioned must be dimensioned up to correspond to one ton of *cleaned* plastics. If a solution is not found for covering the cost of PET collection, the price would be nearly 70 USD higher per ton using the proposed collection model.

Feedstock cost for informal sector plastics estimated at around $340/t plastic processed



[14] And deducting PET which cannot be used as feedstock for pyrolysis

EHS and Human Rights considerations

As part of the collection point pilot, EHS and human rights risks in the informal and semi-formal waste management sector were mapped, giving the conclusions below. A similar mapping was not done in the waste sorting plant pilot, though careful observations from the waste sorting facilities indicated a good EHS culture and low risk of injury to staff. For a future scale-up, a more comprehensive mapping of EHS and human-/labor rights risks will need to be completed for the formal sector institutions and their supply chains as well.

Pilot participants at the kick-off session while receiving training, wearing distributed PPE

The key risks that emerged from the informal sector risk mapping are detailed below.

(1) EHS risks and mitigating measures

The largest risk factor observed during the pilot relates to the physical strain and risks of injuries participants are exposed to when engaged in informal waste collection and transportation. PPE use in the sector is minimal and, in many cases, superficial (providing little actual physical protection). Few have health insurance. Borla taxi drivers are exposed to the highest risk when navigating busy and dangerous roads on unsafe vehicles.

> *The largest risk factor observed during the pilot relates to the physical strain and risks of injuries participants are exposed to when engaged in informal waste collection and transportation*

The project cost estimate includes the purchase of medical insurance and PPE for participants, which will be important to reducing these risks. The use of PPE provided during the pilot was high, indicating that it will be easy to change the culture on PPE, as participants themselves are aware of the risks and wish to reduce them.

(2) Labor rights and child labor risks and mitigating measures

In the markets at night, child labor is not uncommon within e.g. cardboard collection

During the pilot, children were observed involved in the collection of cardboard for recycling and minors supporting stockpilers with the handling of their plastics. In the collection points operated close to collection activities it was easier to control that those who came to sell the plastic were of an appropriate age and that the money went straight to those doing the work. In the scaling-up of a larger collection system, where more plastics may be collected from actors at a later stage in the value chain, this will be more difficult to control. Additional audit routines should be introduced to increase supply chain management on this area. This also applies to ensuring those working at the primary stages of the supply chain receive the PPE and wages they are due according to the project model.

Having clear expectations on labor conditions, wages and child labor set out in the project's Charter and communicating this throughout the project's supply chains is furthermore central to reducing this risk.

(3) Wage analysis

During the pilot, interviews included questions on how long it took the waste picker to gather the collected plastics. The results show a great discrepancy in how quickly individuals collect plastic waste, pending on physical health, time of the day, etc. The analysis regardless shows that individuals participating in the project very rarely reported collecting at a rate which did not allow a minimum payment of 2 GH¢/hour (at a price of 0.5 GH¢/kg). When it did occur, it was often elderly participants who collected slowly and reported having taken many breaks. An hourly wage of 2 GH¢ amounts to a daily wage of 16 GH¢ if assuming an 8-hour workday, which is above Ghana's minimum wage requirement of 11.82 GH¢/day (1 January 2020). Especially if waste collection for PRF serves as an additional income stream, the economic rights of participants appear to be well safeguarded. This issue must be followed up during a scale-up, in order to gain a full picture of how the project influences existing actors and their livelihoods – both positively and negatively.

Pre-processing of feedstock

The focus area of pre-treatment was one that emerged following the two pilots, and where further work remains. The results from the pilot studies show that certain contaminants need to be removed to meet the PtL feedstock quality requirements – most notably organics, chlorides and sulfur. Quality requirements for the feedstock will depend on the specific technology selected, but for advanced pyrolysis treatment elevated concentrations of chloride and sulfur remain unacceptable. Further evaluations are however needed to determine the source of contaminants. This is because the chloride is expected to come largely from food waste, and chlorides in the form of NaCl will not go through to the end product and thus not affect its quality, as it does not decompose when exposed to higher temperatures. Rather, it would end up in the ashes subsequently removed from the oven. The NaCl appearance is a subject to be further clarified with the pyrolysis technology providers.


Plastics sorted out from mixed municipal waste contains high levels of organic contamination

Nonetheless, the plastics need to be cleaned by way of improved sorting, dry or wet washing due to the elevated levels of organics. The cleaning technology applied will have consequences to the cost of acquiring suitable feedstock.

Initially, the prospects of washing with water were investigated, and to understand more about the cleaning process, a visit was made to a Norwegian waste management service provider as well as their washing technology providers in Italy. These visits gave the opportunity of learning about cleaning of plastic by washing with water and detergents. The water introduced to wash the plastics is by itself a challenge as it needs cleaning to be reused. The principle is that 90% of the water used in the washing plant is cleaned and recirculated water. This recirculation reduces the need for new water in the system.

However, handling the washing water is a process which requires a facility and creates costs. The waste water treatment plant has not been investigated by PRF.

Contaminants need to be removed in order to meet the PtL feedstock quality requirements

The plastic that has been washed with water would furthermore need to be dried to meet the pyrolysis moisture requirements. This would be the last part of the washing line and introduces heat to evaporate water from the plastic. The heat required could possibly be sourced from the pyrolysis plant excess heat, but this possibility remains to be investigated.

The complexity around the washing water system gave the incentive to identify a “dry washing” alternative. This was introduced by another potential washing technology provider as a possible solution, as chemical recycling has less stringent quality requirements compared to mechanical recycling (to which washing systems with water are primarily adapted). As a dry washing system is based on purely mechanical handling it is important to reduce the amount of inerts in the sorting process ahead of the process. Solid components coming in with the plastic will create a high degree of wear and tear, resulting in high maintenance costs on the washing facility.

On the basis of conclusions from the pilot at the waste management sorting plants, the tested sorting process needs further improvement in order to reduce contaminants on the plastic if a dry washing process is adopted. PRF has been in dialogue with a German actor who specializes in sorting systems for municipal waste. They received information on the current set up at the waste management plants together with the sorting result obtained from the pilot done on the formal sector, on the basis of which recommendations on equipment as well as manual improvements were provided.

Finally, the exact feedstock requirements will depend on the pyrolysis technology selected. This information is of importance in the ongoing dialog with the local waste management partner on the prospects of providing plastic feedstock of an adequate quality to the PtL plant.

The area of cleaning is one where further work is required before concluding the concept. It has been shown that washing with water involves extra costs, with consequences for the project economics due to the significant power usage, a cleaning facility for the water itself, and additional drying of the plastic to meet moisture specifications of the pyrolysis plant. The focus for the coming work would need to find solutions for improving sorting quality (relatively inexpensively) sufficiently to utilize dry washing, which is a more affordable option. If this is not achieved, it is very difficult to achieve viable project economics.

II. Technology selection

The second main component of the project concerns processing the plastic waste, including a choice of technology and technology provider. The main objectives in this regard is identifying a technology that 1) is capable of removing end-of-life plastics from the environment (and preventing other forms of environmental degradation to the extent possible), and 2) provides the best possible economy for the project, thus representing sustainability and replicability to a larger scale and new locations.

A key priority in choosing a technology has from the onset been to utilize one that is capable of handling contaminated, mixed plastics – also that which is currently not captured by existing actors (mechanical recyclers and others). Furthermore, it must offer a sufficient valorization of the end product to finance the operations of the plant. Chemical recycling offers the prospect of dealing with plastics which mechanical recycling, due to its stringent quality and single-stream plastics requirements, often cannot treat.

> *Chemical recycling offers the prospects of dealing with plastics which mechanical recycling often cannot treat*

Chemical recycling

Chemical recycling involves the decomposition of plastic waste through a chemical or heat-induced reaction, to its monomer (or in the case of solvent-based purification, polymer) stage. It can subsequently be recombined to create the same grade as the original plastic using naphtha as feedstock. It may also be transformed to diesel fuel or to straight feedstock for crude oil refineries. Moreover, while mechanically recycled plastics generally cannot be used for food packaging, it is possible to reach equal-grade quality through chemical recycling. In short, chemical recycling represents the possibility of processing plastics that is currently not captured by existing recycling activity. Secondly, it may represent a future opportunity to improving recycling practices to avoid down-cycling, which unfortunately remains the nature of much modern-day recycling.

Pyrolysis

PRF was from the outset focused on pyrolysis technology (but also considered other options along the way, see note at the end of this section). Pyrolysis technology involves depolymerization through heating in an oxygen-starved environment, thus "reversing" the plastics to hydrocarbons in gaseous form that is subsequently transformed into hydrocarbon liquids. The process itself emits little carbon dioxide.

Pyrolysis can handle primarily Polyethylene (High-Density and Low-Density, i.e. HDPE and LDPE) and Polypropylene (PP) types of plastics, but also low levels of Polystyrene (PS). It is capable of handling mixed polymer streams of varying quality (including previously recycled products), and may, in the given circumstances, therefore function as a supplementary process to that of mechanical recycling. This is important in the context of Accra – while there is a high demand for transparent, high-quality LDPE, and there are large amounts of already-recycled film and plastic bags in circulation that will eventually have exhausted their potential for further mechanical recycling.

Rather large volumes of PET water and soda bottles are littering the environment in Accra. Such plastics unfortunately cannot be used as feedstock in a pyrolysis plant. PRF strives to establish a collaboration with one or more mechanical recyclers of PET to ensure a high recovery rate and optimization of collection infrastructure.

> *Raw, untreated, and unrefined pyrolysis oil is a complex product, but pyrolysis enables the possibility of cleaning out some additives and contaminants as part of the process by applying catalyzers*

Potential end-products from the process

The output from a pyrolysis process involves three different fractions: gas (8 w%), liquids (73 w%) and solid residues (19 w%) (carbon char). Gas will be used internally for heating while char is considered waste and will be handled accordingly. The liquid output would be 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 product. To illustrate, PRF was, during a visit to a Norwegian plastics research institute, shown a mass spectrograph picture of pyrolysis oil indicating more than 50 different molecules – some of these will be carcinogenic and other highly volatile. Oil refinery producers have furthermore objected to contaminate their sophisticated and expensive refineries with a product of varying chemical characteristics.

However, pyrolysis enables the possibility of cleaning out some additives and contaminants as part of the process by applying catalyzers. One article by Zero Waste Europe describes this well: "The output can be processed in the same way as oil, using conventional refining technologies to produce value-added chemicals, including new monomers, indistinguishable from virgin-grade ones. Hence, the additional processing infrastructure needed already exists in a mature and efficient value chain."[15]

By changing the catalyst to one that is promoting output of lighter products, i.e. converting the larger part of the diesel to naphtha, it is soon within reach to approach the market with naphtha feedstock generated from waste plastic as an alternative to naphtha generated from crude oil. Development of this catalyst is however in its early stages. The process of turning plastics into diesel, on the other hand, has been piloted in the past decades by a handful of companies as a for-profit way of turning plastics into fuel[16].

Pyrolysis technologies themselves have been around for many years, and small units are available in the market. This would however involve a less industrial, more crude process producing an end-product that may serve as fuel for the power production sector, or in homes for cooking. One small actor exists in Ghana, producing pyrolysis oil from car tires. However, if contaminants have not been cleaned out of the end product, this approach may represent a health and/or environmental risk.

Quality requirements for feedstock

While a pyrolysis process is capable of handling mixed plastics, it has however emerged during the timeline of the project that the market for end products has very low and stringent quality criteria for sulfur (S) and chloride (CI). Technology providers therefore have low acceptable levels for the feedstock plastic (<10 mg/kg and <100 mg/kg, respectively) in order to comply with off-takers requirements. The main challenge related to the feedstock quality is to get down to a contamination level of biological and inert materials in the feedstock

> *The market for end products has very low and stringent quality criteria for sulfur (S) and chloride (CI)*

[15] Zero Waste Europe, El Dorado of Chemical Recycling: State of play and policy challenges (August 2019): https://circulareconomy.europa.eu/platform/sites/default/files/2019_08_29_zwe_study_chemical_recycling.pdf
[16] *A Circular Solution to Plastic Waste* (2019) by Boston Consulting Group: https://image-src.bcg.com/Images/BCG-A-Circular-Solution-to-Plastic-Waste-July-2019_tcm9-223960.pdf

in the order of 5 w% (technology providers' requirements). Moreover, low levels (<5%) are required of all of the following: moisture, inert materials (dust, ash, metals) and biological material (incl. paper).

The acceptable level of contamination for feedstock will naturally also relate to the quality requirements of the relevant output. If the product is to be used in the transport sector it is expected that products should comply with normal standards for such products where chlorides and sulphates level will be negligible. Any other foreign element (apart from pure plastic) is moreover decreasing the yield of the process, thus constituting an adverse impact on the project economics.

In evaluating technologies and their end market potential, the tolerance for somewhat contaminated plastic feedstock is viewed as a strong criterion.

The approach of PRF thus far and key challenges

The main focus thus far has been on the viability of producing a higher-quality end product, for three reasons. Firstly, there are no local refineries present in Accra capable of refining a pyrolysis oil product into e.g. transportation fuel for local use. Secondly, prospects of eventually producing naphtha for use as feedstock in olefins crackers, thus developing a closed loop for the plastic material is preferred (or relying on a technology that could eventually be transformed into naphtha production). Thirdly, the economics of the project are more likely to be sustainable either through a higher price on the local market or if a "recycled carbon fuel/naphtha" premium is realized in a mature market. The next section goes more into depth on the topic of offtake.

Based on the experience over the past year, the following key design criteria have been developed by PRF.

Key design criteria for the selection of a technology provider

1. Meeting customers quality and volume requirements for pyrolysis oil.
2. Meeting customers' strategic intent regarding engagement in the plastic to fuel recycling business.
3. Flexibility regarding quality of feedstock. I.e. capable of processing different types of contaminated plastics without sacrificing the uptime of the process plant.
4. That the final product does not represent any hazards for humans when being stored and used.
5. That environmental impact from the use of the product does not add to existing levels of greenhouse gases or other not wanted emissions.
6. Ability to remove unacceptable high levels of chlorine and sulfur.
7. A design that is modularized where the initial plant can be expanded at a later stage.
8. High uptime figures, involving a design that is not prone to heavy and frequent maintenance stoppages.
9. Adaption of well-known unit processes.
10. Proven technology in an environment such as that of PRF (i.e. capable of handling the feedstock quality in Accra from the targeted sources).
11. Producing a pyrolysis oil that is reasonable stable, i.e. product can be stored and transported after production within a reasonable timeframe.

PRF has been in dialogue with a number of potential technology providers. Europe-based Plastic Energy and Quantafuel early emerged as viable options. The team visited Quantafuel's plant (not yet in operation) in Denmark, and Plastic Energy's plant (in operation) in Seville in Spain. Both visits took place in Spring 2019. PRF has received relevant feasibility study information material from both companies, i.e. process description, feedstock quality requirements, yield and output, operating costs, investment details and certain assumptions about these two companies role in a potential Ghana project venture.

No decision has yet been made on the selection of technology as this is closely related to various other considerations. Furthermore, in particular three key challenges remain in this area as described throughout this section and summarized below.

The first challenge concerns the quality requirements of feedstock, which may either limit the sources of plastic waste that can be utilized (and not allow targeting the most contaminated plastics for which a solution is most urgent) or require costly cleaning processes of the plastics.

Secondly, a more sophisticated pyrolysis process capable of producing naphtha for the petrochemical industry is not yet mature, and while significant progress is currently being made in this area, there exists no copy-paste solution that can be implemented in Ghana.

Thirdly, a technology turning out blend-in quality, i.e. diesel or naphtha, had at the time of writing not been fully demonstrated by either of the two companies. This would thus involve higher costs – both investment and operating – than a simple and proven technology producing a more crude output. In other words, a more complex process requires prospects for elevated revenues in order to maintain economic viability. On the other hand, producing a blend-in product represents the potential for a PtL plant to reach true circularity. There are pros and cons to both pathways, but the main determinant of the economic viability of any technological solution relates to the potential value of the end product. A key priority for PRF in Ghana is to strike the right balance between investments and price for the product, i.e. to enhance solutions that will contribute to improvement of the project overall economy.

> *Any technological solution should aim to fill the function of "bridging the gap" between the feedstock and the most viable offtake requirements, as defined by reaching an economically viable concept*

Any technological solution should aim to fill the function of "bridging the gap" between the feedstock and the most viable offtake requirements, as defined by reaching an economically viable concept. Finally, PRF notes that many petrochemical companies are working on developing capabilities within pyrolysis, some going as far as establishing their own, large-scale processing facilities. These may be capable of tying together the needs of off-takers to the quality of feedstock, and are likely to play a large role in the further development and commercialization of this technology.

Other investigated processing possibilities

While the project earl on began focusing its efforts on pyrolysis technology, some other options were briefly considered, including feeding plastic as feedstock into cement kilns, incineration and mechanical recycling. It does not appear that any of these options would offer the prospect of economic viability.

Mechanical recycling is already well established locally, and involves the challenges listed above with regards to only handling single-type plastics of high quality, or else involving significant down-cycling (as is the case for many recyclers in Accra). The main exception to this concerns PET, which has good prospects for food grade recycling and for which the local recycling market is underdeveloped. Due to the mutual exclusivity of feedstock needs for rPET recycling and pyrolysis, the possibility of developing joint infrastructure for the collection of plastic waste should be considered.

Using plastic waste as feedstock into cement kilns to replace coal, lowering the carbon emissions of a highly polluting industry, is another alternative. Ghana has a sizeable cement industry, but due to the low prevalence of limestone in the country, the industry largely relies on clinker imports. One interviewee informed us that there are no cement kilns locally, which would require export of the plastic waste, and consequently large transportation costs.

Finally, incineration was considered, but due to the challenging nature of the power market in Ghana, as well as the sizeable investment costs, this did not appear an economically viable option for PRF. Moreover, while pyrolysis production of fuel may be argued to be "postponed incineration", it offers prospects of eventually moving on to the production of feedstock to new plastic as technology evolves.

III. Off-take of end product

The third main component of the project concerns offtake. This involves establishing the value of the end product, identifying customers and selling the product from the pyrolysis process. The key objectives of this workstream include to: 1) Sell liquid petroleum products, serve and be active in the emerging market for fuel products derived from plastic waste, 2) Identify potential customers' quality requirements, 3) Target a price level for the products that has the potential to create an economically viable project, 4) Secure stable, reliable and long-term off-take from the pyrolysis process plant, and 5) Prioritize customers that may have a strategic interest to jointly with PRF develop the venture over time by providing market outlet as PRF expands its activities. The main priority at the current stage is to identify an end market for the product produced by the pyrolysis plant and where the price allows for viable project economics (i.e. covering the costs of collection, pre-treatment and operations).

> *A reasonably good pyrolysis product may receive a price equivalent to crude oil and possibilities exist for obtaining a price equivalent to commercial diesel or naphtha, provided that the product meets the quality criteria*

Relationship between pyrolysis oil and price

As mentioned in the previous section, untreated pyrolysis oil is a complex and potentially problematic product with volatile components. Potential off-takers of an end product are well aware of this, and have stringent quality standards that will have to be complied with if they should allow pyrolysis oil into their refineries and crackers.

A reasonably good and refined pyrolysis product may receive a price equivalent to crude oil, and possibilities exist for obtaining a price equivalent to the Platt listing for commercial diesel or naphtha, provided that the product meets quality criteria for such products. However, as further discussed in the section on technology, this requires a more advanced – and costly – process compared to one that does not include refining and cleaning the end product.

Markets for a PtL end product

There exist a number of potential markets for the end product of a PtL pyrolysis process. Which is the most suitable market depends on what product is produced – a crude type of pyrolysis oil, or a refined product where additives and contaminants are cleaned out as part of the process, potentially resulting in commercial-grade diesel or petrochemical feedstock for new plastic production. As mentioned in the section on technology, the latter – especially plastic-to-naphtha – is in its early stages, while plastic-to-diesel has been piloted profitably by some companies.[17]

In light of the above, several offtake possibilities exist for the PtL project in Ghana, involving different processing technology implications, end market geographical locations, and prospects for (and uncertainty around) revenue. These prospects are summarized in the table below.

	Unrefined	**Refined**
Local	Pyrolysis oil sold locally, possibly to the power sector	Diesel sold locally
Premium	N.A.	Diesel or naphtha exported to Europe

Aiming for a premium: Producing a higher-grade product and exporting to Europe

Starting in the bottom right corner of the above table, one possibility is aiming to produce a higher-value product in the form of naphtha or commercial grade diesel. This involves targeting large commercial actors willing to take the product into their refineries or petrochemical crackers, i.e. plastics producers, oil companies, or companies with activities in both sectors. This might be attractive to such petrochemical and/or oil companies that have as a strategic ambition to convert part of their feedstock supply from crude oil to plastic waste.

Generally, processes geared towards producing either diesel of naphtha will also produce a proportion of the other, and shifting towards producing a larger share of naphtha is a priority for the chemical recycling industry. This appears to be a priority in Europe, where Extended Producer Responsibility schemes are widespread (contributing to financing the feedstock collection), off-takers exist, and further legislation may contribute to pushing this development further. If PRF is to produce naphtha , the end product would

[17] *A Circular Solution to Plastic Waste* (2019) by Boston Consulting Group: https://image-src.bcg.com/Images/BCG-A-Circular-Solution-to-Plastic-Waste-July-2019_tcm9-223960.pdf

have to be transported to a market where off-takers exist, as there are no industrial actors in the region that would be potential off-takers of naphtha for use in petrochemical crackers.

Producing naphtha for a European market would, under current assumptions, require a premium on the end price

For PRF, exporting to Europe would, under current assumptions, with high likelihood require a premium on the end price, as it is otherwise difficult to achieve economic viability due to an initial gap between higher costs than revenues, further increased by transportation costs. Indications of the possibility of a premium on the end product were received in early dialogues with potential technology providers and potential off-takers, but any certainty around this has at the current stage not yet been established.

In the case of diesel, there is a possibility for the creation of a secondary market for "recycled carbon fuels"[18] in the EU as a result of the revised Renewable Energy Directive (RED II), similar to what has been observed in the market for biofuels. Member States may choose to include "recycled carbon fuels" as part of their transportation sector targets – but may also choose the option not to consider those fuels in meeting their obligations. Furthermore, "since those fuels are not renewable, they *should not be counted towards the overall Union target* for energy from renewable sources"[19] (RED II § 89, italics added). This means they could be promoted through transport targets and support schemes, but not considered under the overall renewable energy target. Finally, the EU sustainability rules for such a category have not been finalized, but are left to delegated acts due by the end of 2021. To summarize, the choice of Member States to not include such a fuel category in their transportation targets, and the sustainability requirements for said category, may hinder the establishment of a premium on the EU market. Moreover, even with the emergence of a secondary market, the size of any premium is not determined.

In the case of naphtha, there are, to the knowledge of PRF at the time of writing, no concrete plans of introducing legislation at an EU level to encourage the use of recycled naphtha in petrochemical industries. Thus, any hopes for a premium would rely either on industry commitments to move in this direction themselves – and a corresponding willingness to pay a premium for products that enable them to – or on the future introduction of legislation in this area. In early dialogue with petrochemical and oil companies, several have mentioned the prospects of a premium price on end products. Their internal commitments to reach a certain proportion of recycled feedstock has also been brought up, which indicates that even in the absence of legislation, there may be industry incentives to pay some premium for a product recycled from used plastics. At the current stage, no concrete dialogues on off-take have yet substantiated these initial signals.

There is reason for optimism around the potential for a premium for either diesel or naphtha on the EU market, but certainty must be established before selecting a technology

[18] Recycled Carbon Fuels means "liquid and gaseous fuels that are produced from liquid or solid waste streams of non-renewable origin which are not suitable for material recovery in accordance with Article 4 of Directive 2008/98/EC, or from waste processing gas and exhaust gas of non-renewable origin which are produced as an unavoidable and unintentional consequence of the production process in industrial installations" – Bellona & Zero Carbon Europe, *Joint briefing: Recycled Carbon Fuels in the Renewable Energy Directive*

[19] DIRECTIVE (EU) 2018/2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 December 2018 on the promotion of the use of energy from renewable sources, article 89 – https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=EN

In short, there is reason for optimism around the potential for a premium for either diesel or naphtha on the EU market, but certainty around this must be established before selecting a technology and initiating a Front-End Engineering Design phase.

Aiming for the market price: Producing diesel for direct sale on the local market

Another possibility for producing a refined product involves selling a refined product on the local market – this is the top right corner of the table above. Ghana is a net importer of refined petroleum products, in 2019 amounting to 3462 kt.[20] The two fractions of petroleum products that are imported are gasoline and gasoil (diesel). Import mix is about 50/50 gasoline and diesel. The transport sector consumes close to 80% of imported gasoline/gasoil. There do not exist off-takers for naphtha in the region, and thus producing naphtha for a local market is not considered an option.

Producing diesel for the local market is expected to require the same quality on the end-product as producing for a European market. In 2017, Ghana made the switch to low sulfur diesel (maximum of 50 parts per million), and according to local actors the quality requirements for imports correspond to those on the EU market. Thus, the operational cost of such a scenario is expected to be more or less the same as for producing diesel or naphtha for a premium market.

> *Local offtake of diesel is likely the most viable option if it proves difficult to achieve a premium price on the end product, but its economic viability likely depends on supporting policies*

Import prices for such petroleum products is a mirror of Platts fob price Rotterdam plus transport cost, and Platts petroleum prices are reflecting current crude oil prices with some time delays. However, higher taxes apply on local sales, unless exceptions are made for fuels made from plastic waste.

How a local offtake scenario may become economically viable, possibly in the presence of supporting policies, should be explored more in-depth. This is likely the most viable option if it proves difficult to achieve a premium price on the end product. Some dialogue has been initiated with relevant actors locally, but this is one of the areas that requires further investigation.

Aiming for a simpler process: Producing a lower-grade product for local sale

Another alternative is to produce a lower-grade product for the local market, at no premium. This could target e.g. the power production sector in Ghana. A significant part of the thermal power production sector in Ghana is fueled with fuel oil. As mentioned in the section on technology, one existing local actor produces pyrolysis oil for use in industrial boilers. It could be investigated whether this sector might take off the pyrolysis oil. However, there is a strategic ambition in Ghana

> *Local refining capacity is not well-developed and selling a lower-grade product involves environmental and health concerns*

[20] http://www.energycom.gov.gh/files/ENERGY%20STATISTICS-2020.pdf

to transfer feedstock from liquid petroleum products to natural gas derived from domestic production in Ghana, and thus long-term sustainability from such off-takers would be doubtful. It should further be noted that local refining capacity is not well-developed and PRF is concerned about existing refineries' capability to refine and remove contaminants from the pyrolysis oil. Consequently, there are environmental and health concerns related to the use of such a product.

Another option for unrefined pyrolysis oil may involve exporting it to other African countries with stronger refining capabilities than Ghana. Nigeria has got significant refinery activity and is geographically close enough to Accra that it can be reached by a tank car. South Africa also has strong capabilities in this area, with several multinational companies having a large presence there. However, shipping to South Africa would be nearly as demanding as shipping to Europe. Moreover, with regards to price expectations, it is difficult to imagine receiving more than a crude oil price, which creates a challenging picture for project economics – but the overall picture depends on how much operational costs would be reduced by taking this direction. It is expected that a technology producing a crude type of pyrolysis oil has got significantly lower investments, as well as operational, costs.

The approach of PRF thus far and key challenges

Thus far, the focus of PRF has been on the potential for exporting the end-product to Europe and targeting a premium market, due to the early indications that this may be a possibility. Furthermore, this involves the possibility of producing a higher-grade end-product, ideally naphtha, thus enabling true circularity. There is a growing sense of responsibility among international corporations on this topic, and technological development is happening fast. Current mechanical recycling has limitations in tackling mixed, contaminated and flexible plastic waste. Thus, prospects of monomer recycling into equal-grade plastics has the potential of revolutionizing the recycling industry in the future.

> *The objective is demonstrating the viability of valorization of plastic waste, and encourage economically viable, large-scale collection*

A number of dialogues have been initiated with key potential off-takers, but most came to a partial halt due to the coronavirus situation. The possibility for achieving a premium price (and a concrete long-term off-take agreement) must be established before deciding to pursue the more costly technology direction.

If it proves unlikely to achieve a premium on the end-product, local offtake should be further investigated. Landing on the production of diesel involves environmental degradation in the form of greenhouse gas emissions. Nonetheless, it is the position of PRF that this would also be worth pursuing. Uncertainty around feedstock supply is one of the main obstacles to foreign investment in recycling in developing countries. The objective is to demonstrate viability of valorization of plastic waste, and encourage economically viable, large-scale collection. This would still be realized if building a naphtha-producing plant proves unfeasible due to the immaturity of the technology and a challenging business case in a developing country setting.

> *The key challenge with offtake concerns identifying an approach that allows for sufficient valorization of the plastic waste to finance the costs of collection*

Furthermore, this may encourage others to build an environment in which going even further within environmental sustainability may become possible in the future. Finally, if the selected trajectory is to produce diesel, the opportunity exists to change the catalyst and thus direct the plant towards producing naphtha in the future if, market conditions become more favorable.

Overall, the key challenge with offtake concerns identifying an approach that allows for sufficient valorization of the plastic waste to finance the costs of collection and operation. Three different trajectories are identified, and any decision on offtake will be closely linked to a subsequent decision on the pyrolysis technology. The most important consideration with offtake and technology concerns developing a concept that allows for not only environmental, but also economic sustainability.

IV. Overall conclusions and learnings

Thus far in the project, a number of conclusions can be drawn on the basis of the above focus areas.

PRF has thus far identified a great opportunity for reducing plastic pollution and has developed viable collection models. The project will have a large impact on removing plastic waste from nature and the streets and encourage further collection through the valorization of a currently uncollected stream of plastics.

Moreover, it has the potential of creating a large amount of jobs along the value chain, including livelihoods for the most vulnerable populations in the informal sector. Potential collaboration partners have been identified, and a number of dialogues initiated for the project's successful implementation.

A key challenge prevails pertaining to achieving economic viability and thus fulfilling the mission of the Foundation. The cost of feedstock (as a combination of plastic cost, collection cost and pre-treatment cost), operational costs together with the price obtainable for the end-product need to be managed to make the project economically sustainable.

Before venturing into this section of detailing what PRF has done and learnt, it was described how the factors affecting economic viability and overall feasibility can be grouped in three main areas: feedstock, pyrolysis design/technology and offtake. Below, the key conclusions within each of these factors based on the experience so far are highlighted.

> *PRF has identified a great opportunity with large potential impact, but a key challenge prevails pertaining to achieving economic viability*

Feedstock supply and collection

Within foreign direct investment in recycling, a challenge often encountered concerns a lack of security and predictability around feedstock supply – for this reason, this has been a key focus of PRF's work during its first year of existence. The approach aimed to leverage both the formal waste management sector and the informal sector to maximize social and environmental impact while ensuring feedstock security. Initial feasibility studies provided early indications about the availability of plastics and the potential project design in various areas, and identified potential collection models that should be tested and verified. This was addressed in-depth through two targeted pilot studies with local partners. The pilots focused on testing collection models in practice, including establishing the expected quantity, quality and cost of plastic feedstock.

It was established that collecting 30 t/d is considered achievable, and raising this to 60 t/d is viewed as feasible over time

It was established that collecting 30t/d is considered achievable, and raising this to 60t/d and beyond is viewed as feasible over time through introduction of double shifts at the waste management plants and further utilization of collection sources. This involves a combination of sourcing plastics from the tested collection models, as well as exploring supplanting channels – such as formalized partnerships with existing waste management companies.

The sorting of plastics from existing waste management plants would constitute the great majority of plastic feedstock in the short-medium term. With recommended optimizations and the present waste processing rates, the plants should be able to produce 25.2 tons of clean PtL material per weekday, corresponding to 18 tons per day. With future expansions at one of the waste management plants, foreseen to be completed by the end of 2021, both plants will have a capacity to produce 31.1 tons per day and shift, equivalent to 22.2 tons per day of the week. If double shifts were introduced for both lines in the medium term, allowing one shift on one line per day for second-step sorting, and Saturday shifts introduced, the existing capacity allows for producing 32.8 tons per day. With the planned expansion, the capacity would correspondingly represent 40.0 tons per day. In addition, the pilot partner has recently built a new plant in Kumasi which may supply further plastic feedstock.

From a collection point model, several key channels have been identified for the potential up-scaling of informal and semi-formal sector collection in the short to medium term. It is estimated that these channels can collect a total of 7.8 tons of cleaned plastic for the PtL plant in the short-medium term. In addition, these channels can collect are deemed capable of collecting 4 tons of PET per day – as this is not suitable feedstock for a PtL plant, this represents an opportunity to collaborate with actors who wish to expand PET recycling. With the expansion of a collection networks (both from the informal sector as well as from institutions, office buildings and commercial actors) this volume is expected to increase over time. Furthermore, working with the informal sector represents a significant opportunity to realize social and economic objectives through a strong local impact. This comes with a responsibility, and through full-scale implementation identified risks within particularly EHS and child labor must be managed.

Besides security and predictability, achieving the right feedstock quality is a key aspect for ensuring viability of the concept of a chemical recycling plant. Existing technological solutions are not capable of producing a high-quality end product from very contaminated feedstock. It emerged from the pilot studies that the plastics collected contain elevated levels of organic contamination, chlorides and sulfur, prompting the need for pre-treatment. It early on became clear that this is a costly addition to the cost of acquiring suitable feedstock, particularly washing that involves water. This requires significant power usage, a cleaning facility for the water itself, and additional drying of the plastic to meet the moisture specifications of the pyrolysis plant. Dry washing may constitute a much more affordable option. Investigations into this have been

Existing technological solutions are not capable of producing a high-quality end product from very contaminated feedstock, and cleaning is a costly addition to the feedstock cost launched but not yet concluded – if a way can be found to implement a more affordable pre-treatment option, it would significantly strengthen the economic viability of the project.

Technology selection

PRF's main priority in choosing a technology has been identifying a process that is capable of "bridging the gap" between the feedstock (plastic waste) and offtake, and allows sufficient revenue prospects also relative to the operating costs the process involves. Pyrolysis – a form of chemical recycling through heat-induced depolymerization without the supply of oxygen – has been identified as one of the most viable technological solutions to contaminated and mixed plastic waste. It has the potential of supplementing mechanical recycling initiatives, by capturing the plastics it cannot use or whose potential has been exhausted through previous recycling.

> *Processing of plastic waste through pyrolysis may lead to sufficient valorization of the end-product to finance collection and operations*

Furthermore, processing of plastic waste through pyrolysis may lead to sufficient valorization of the end-product to finance collection and operations. Pyrolysis offers the prospects of producing pyrolysis oil, diesel or naphtha – a crucial component in the production of new (equal-grade) plastics. A technology turning out blend-in quality, i.e. diesel or naphtha, has not yet been fully commercialized and would thus involve higher costs and more uncertainty than a simple and well-proven technology producing a more crude output. On the other hand, producing a blend-in product represents the potential for a PtL plant to reach true circularity. There are pros and cons to both pathways, but the main determinant of the economic viability of any technological solution relates to the potential value of the end-product.

Off-take of end-product

In identifying a market for the end-product, the key priority is enhancing solutions that will contribute to improving the project's overall economy. In the face of challenging project economics, combined with an ambition of eventually producing naphtha and thus encouraging full circularity for plastic waste, PRF has focused on exploring the possibility for exporting a refined end-product to Europe and achieving a premium price. This originates in early indications from both technology providers and potential off-takers that such a premium may arise. A number of dialogues have been initiated with potential off-takers, but the certainty of such a premium has so far not been substantiated.

> *In identifying a market for the end-product, the key priority is enhancing solutions that will contribute to improving the project's overall economy*

While the production of naphtha is preferred to producing fuel, the question remains whether the plastic-to-naphtha route is mature enough to be deployed in a developing country setting and capable of generating enough revenue to cover the additional costs this involves. Alternatively, it is possible to sell the product locally – either as a refined product (diesel, as there do not exist off-takers for naphtha in the region) or as an unrefined product (at a price lower than crude oil price). This would also eliminate the cost of exporting to Europe, but would under the current assumptions still not generate sufficient revenue to fully cover the costs of operations and feedstock acquisition.

Removing processing steps such as refining and purification would lower costs, but revenue prospects would be reduced to crude oil price. Furthermore, if contaminants have not been cleaned out of the end-product, this may represent a health and/or environmental risk. Identifying the best trajectory for offtake is key to a successful project, and a willingness on the end of off-takers as well as public authorities to establish favorable conditions would contribute to nudging the revenue side of the project in the right direction.

Concluding remarks

While extensive work has been done to establish the feasibility of a PtL plant in Accra, further work is needed to identify a way of overcoming the identified obstacles to achieving sustainable project economics, through both internal and external efforts. Under the right conditions, a PtL plant can contribute to safeguarding the environment in Accra, generate local employment and set an example for replication elsewhere, while being economically sustainable. The Foundation strongly encourages external actors to consider how they may contribute to building a more conducive environment to an economically sustainable venture for the large-scale collection of plastic waste in Ghana.

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5. Recommendations for key stakeholders

As described throughout the last section, there exist numerous obstacles to realizing an economically sustainable venture in Accra. While mitigating actions can be pursued by PRF, the project is also dependent on other actors wishing to support its realization. Specifically with regards to strengthening the economic viability, PRF wishes to propose some recommendations to actors who wish to see the implementation of the project become a reality, and to contribute towards this end.

<u>Ghanaian authorities: local and national</u>

First and foremost, the local and national authorities can contribute to building a more conducive environment to establishing an economically viable venture for the large-scale collection of plastic waste in Ghana. This can be done in a number of ways – some of which are specific to a chemical recycling scenario targeting local offtake, but others are generally applicable to any actors aiming to collect and recycle plastic waste.

PRF wishes to propose some recommendations to actors who wish to see the implementation of the project become a reality and contribute towards this end

Firstly, the government has the opportunity to strengthen the economic case significantly by considering the introduction of tax exemptions for local sale of diesel/pyrolysis oil produced from recycled plastics. This would furthermore allow local authorities to maintain full control over the value chain, building a sustainable system for plastic collection and valorization *within* Ghana.

Secondly, the government would take a great leap towards the creation of a conducive environment to all recycling by imposing an Extended Producer Responsibility (EPR) scheme and earmarking funds for plastic collection and recycling. Alternatively, by rechanneling the existing plastic tax towards this purpose. The implementation of an EPR system has already been proposed through the Ghana National Plastics Policy, and industry actors have displayed a willingness and interest in shaping such a system. By utilizing a platform such as the Ghana Plastic Action Partnership to bring relevant actors together, a well-functioning EPR system may be developed and secure stable support for solutions to plastic pollution.

Such a collection infrastructure should be jointly developed by various actors (and financed, fully or in part, under an EPR scheme) to reach a level of consolidation of the value chain that allows for synergies and economies of scale at all levels

Thirdly, the local authorities may indirectly support the stable supply of feedstock through playing an active role in facilitating the collection model, by enabling collection from governmental institutions, and by functioning as a mediator between actors that hold waste management contracts under supervision of the city.

Finally, the authorities may contribute to providing necessary equipment, staff or land for the implementation of a collection system, which would directly lower the costs of operating collection infrastructure. Ideally, such a collection infrastructure should be jointly developed by various actors (and financed, fully or in part, under an EPR scheme) to reach a level of consolidation of the value chain that allows for synergies and economies of scale at all levels.

<u>The plastics and packaging industry in Ghana</u>

Related to the above, PRF strongly recommends that industry contributing to the use of plastics in daily life, see themselves as part of the solution and support the implementation of an EPR system. Numerous individual initiatives have made a large difference, yet at a small scale. By joining forces and institutionalizing funding for collection and recycling of plastics, the overall impact is expected to be greater.

PRF strongly recognizes and values the work done by existing recyclers and processers in Ghana and wishes to extend a hand to collaborate in the future

<u>Recyclers and processers in Ghana</u>

PRF strongly recognizes and values the work done by existing recyclers and processers in Ghana and wishes to extend a hand to collaborate in the future. If actors are open to collaborations and partnerships, it is possible to imagine the development of a more consolidated value chain for plastic waste in Accra, especially from the informal sector. Bringing this idea even further, a joint collection infrastructure would as mentioned above potentially bring synergies and economies of scale that do not exist in informal collection in Accra today. With a common goal of eliminating plastic pollution, it is clear that the problem is currently far from solved – there is enough plastics in Accra for everybody if it all could be collected.

Other international actors in Accra

International organizations and NGOs in Accra may also provide crucial support to the development of a consolidated value chain for the collection of plastic waste, particularly targeting the informal sector. Livelihoods creation and environmental safeguarding is a priority for numerous actors, and transcending typical divisions between private initiatives, civil society and international organizations would benefit everybody's efforts. Numerous initiatives have already been initiated or are underway. Communication and coordination would lead to synergies and benefit the affected actors. For instance, one actor may focus on transport and disposal, another on building collection infrastructure, a third on training and empowerment of informal sector workers, and a fourth on the industrial processing of the plastic waste. Such coordination would be of great value to the consolidation of the plastics value chain in Accra.

Other actors globally

Finally, PRF encourages global actors to support the development of secondary (premium) markets on products produced from plastic waste, as stronger revenue prospects will fast-track the development of solutions to plastic waste globally. This may be through the introduction of legislation, or through industry-driven schemes. Particularly for sourcing plastics from developing countries, where the challenge of plastic waste is the greatest, somewhat elevated revenues would make a great difference to the economic viability of initiatives. This would in turn have a great impact on the volumes of plastic waste collected, and diverted, from nature.

> *Global actors are encouraged to support the development of secondary (premium) markets on products produced from plastic waste, as stronger revenue prospects will fast-track the development of solutions to plastic waste globally*

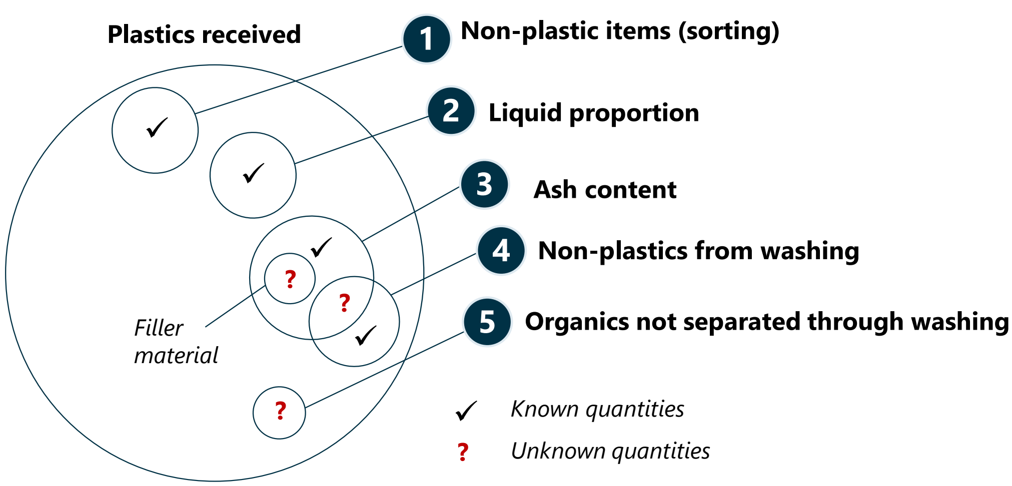
Annex 1 – description of method to determine plastics proportion from the collection point pilot

The objective of measuring plastics quality is to determine the contamination level, to determine the plastic content, and to establish the levels of moisture, chlorides and sulfur. The below illustrations show all the potential components that may be non-plastic. This approach was necessary, as it emerged that there was a large proportion of ash (i.e. non-volatile solids) in certain plastic types, namely PP sacs (also called raffia bags, a large woven bag often used for agriculture and industry).

Figures on wet weight of sample

1 Sorting quality	2 Liquid proportion	3 Ash content	4 Non-plastic from washing	5 Organics not separated through washing
Amounts to the combined % non-plastic items sorted out at sampling stage and of received samples	% of sample that is water/liquid	% of sample that is ash – i.e. non-volatile solids (contamination or filler material)	% of sample that is contamination separated through a washing process	% of sample that is organics/volatile solids but *not* captured in either the ash content nor the washing water

The relationship between components 1-5 are illustrated below. 1-3 are known and combined they constitute the minimum amount of non-plastics received, assuming there is no organic contamination. The total amount of organic contamination is captured by 4 + 5, where 4 contains the organic contamination that could be washed out, and 5 a theoretical amount that was not removed by water (likely small). There is likely to be some overlap between component 3 and 4, as some non-volatile solids may also be removed through washing (for instance sand).



In order to determine a range of likely non-plastics, (1+2+3) is considered the minimum and (1+2+3+4) is considered the maximum amount of non-plastics, as 5 is unknown and likely very small.