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SUSTAINABLE PLASTIC RECYCLING IN MONGOLIA

THE PLASTIC RECYCLING TECHNOLOGY GAP ASSESSMENT REPORT

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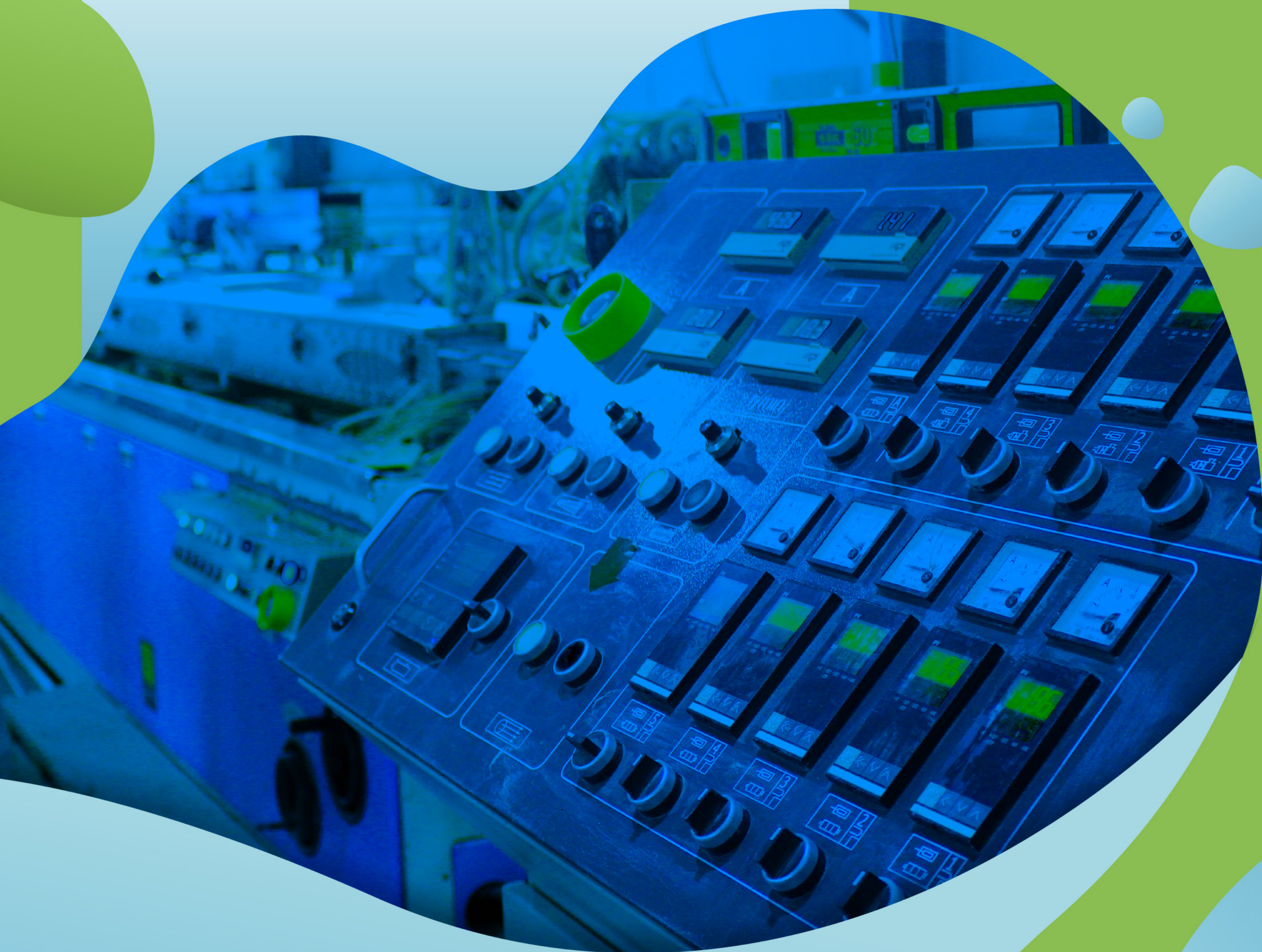

PRAGUE, JANUARY 2022

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Title of the action:

The Sustainable Plastic Recycling in Mongolia

Start and end the project:

May 2020 – April 2024

Place to save the message:

SVTI VÚV TGM, v. v. i.

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This report was developed under the "Sustainable Plastic Recycling in Mongolia" project funded by the European Union. The content of this report does not reflect the views of the European Union.

TABLE OF CONTENTS

LIST OF FIGURE

LIST OF TABLES

ABBREVIATIONS

BPA	Bisphenol A
EPS	Expanded Polystyrene
EU	European Union
EVOH	Ethylene vinyl alcohol
HDPE	High-density polyethylene
LDPE	Low-density polyethylene
MNT	Mongolian Tugrik
OECD	The Organisation for Economic Co-operation and Development
PA	Polyamide
PC	Polycarbonate
PE	Polyethylene
PP	Polypropylene
PET	Polyethylene terephthalate
PVC	Polyvinyl chloride
PS	Polystyrene
PU	Polyurathene

ANALYTICAL PART

INTRODUCTION

As part of this report, a description and evaluation of plastic waste recycling facilities' network in selected areas was carried out, specifically in Ulaanbaatar, Bulgan and Khishig-Undur. Due to the fact that recycling companies only exist in Ulaanbaatar out of the 3 target locations, the report will address the evaluation of the plastic waste recycling facilities' network only in the aforementioned city.

The report does not include a detailed description of the plastic waste collection and disposal systems. These systems were described in the report "Research Report on the existing policies and process regarding the recycling sector, waste generation, production and collection in Mongolia".

Unless otherwise stated, the data used are taken from the "Baseline data collection report for plastic recycling technology gap assessment of the Sustainable Plastic Recycling in Mongolia project". The report was the output of a survey conducted for Caritas Czech Republic by Bayalag Eco LLC in the period between June 10 and July 9, 2021. The survey took place in the form of personal interviews or, due to the COVID-19 pandemic, by filling in questionnaires by phone and e-mail. A total of 24 recycling companies in Ulaanbaatar took part in the survey.

1 ANALYSIS OF PLASTIC WASTE PRODUCTION AND MANAGEMENT

In Ulaanbaatar, 258,000 tons of plastic waste are produced annually. According to the plastic composition reported in the "Ulaanbaatar Household Waste Composition Study Report 2019"[1], 116,100 tons of PET, the same amount of LDPE, PE, and PP plastics and 25,800 tons of HDPE hard plastic are produced annually (see Table 1).

Table 1 – Annual production of waste including plastic waste in Ulaanbaatar[1, 2], Bulgan

	Ulaanbaatar		Bulgan		Khishig-Undur	
	Summer (%)	Winter (%)	Summer (%)	Winter (%)	Summer (%)	Winter (%)
Food	36	23	24	19	15	30
Plastic	22	14	12	7	23	14
Paper	22	13	11	5	7	4
Metals	7	u. d.	5	5	1	1
Glass	9	u. d.	20	11	30	21
Textile	4	1	4	3	u. d.	u. d.
Ash	u. d.	49	22	27	11	54
Total annual waste	1 433 431		9 056		267*	
Annual production per person [kg/person]	978		146		86*	
Total annual plastic production [tons] **	258 000		860		51*	
Amount of PET from total plastics production [tons] **	50 175		326		10	
Amount of LDPE, PE and PP plastics from total plastics production [tons] **	23 694		154		5	
Amount of HDPE hard plastic from total plastics production [tons] **	41 813		272		8	

*Note: *including ash (own calculation according to Ecosoum data)[3, 4]; ** own calculation; u. d. - unavailable data*

2 PLASTIC RECYCLING

In 2018, plastics were managed in the EU in three main streams: 42.6% was used for energy recovery, 32.5% was recycled and 24.9% was landfilled [5].

Efficient recycling of plastic waste supports the transition of the industry into a circular economy and at the same time contributes to reducing greenhouse gas emissions by keeping discarded waste as a resource in the circular economy.

Collection and sorting processes are the first steps to ensure that segregated items end up in recycling plants.

Improvements to collection systems and sorting technologies are essential to achieve higher recycling rates.

The recycling rate of plastic waste is ten times higher for separate collection compared to mixed collection systems. Recycling waste and creating reusable materials is a key benefit of sustainability. It reduces the need for resources to produce new plastics from raw materials. Recycling also saves energy needed for refining and production processes and reduces emissions from refining [6].

Plastic materials can be recycled in a variety of ways and the ease of recycling varies according to the polymer type, packaging design, and product type.

The concept of circular economy has brought about a paradigm shift in plastic waste management and requires increased effort to reduce the dependence on primary materials by replacing primary materials with recycled (also known as secondary) materials. The process chosen for recycling plastic waste is preceded by several steps, such as separation at the source of collection and sorting at the plant. There are four plastic waste recycling processes.

2.1. PRIMARY RECYCLING

Primary recycling is the most common method of processing by melting and transforming pure or semi-pure industrial plastic waste into the production of secondary material. It does not require sorting and decontamination

This type of recycling can be effective if:

1. discarded materials are instantly sent back to the production chain;
2. the polymer is stable and sufficiently suitable for passing through high temperature processes; and
3. the recycled materials are processed in almost the same way as the original materials.

Primary recycling could potentially involve re-extrusion of plastic waste after consumer use. However, given the many challenges associated with the segregation, collection and separation processes that are part of the chain of plastic waste management processes after consumer use, this option is not considered to be technically feasible or economically viable. .

2.2. SECONDARY RECYCLING

Secondary recycling is also known as mechanical recycling. Mechanical recycling is the dominant way of recycling plastics. In this type of recycling, plastics are sorted by polymer type and color and then remelted and undergo regular conversion processes to produce plastic goods.

ДThis method of recycling is a suitable procedure, especially for thermoplastics (e.g., polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (PS)). In general, material recycling is based on the input of thermal and mechanical energy and additives to transform the waste raw material into new material with mechanical and aesthetic properties close to the virgin polymer. It includes the simplest grinding processes of used products and subsequent thermal mechanical treatment, up to compatibilization processes in the melt. The quality of the recycled material depends on the nature of the input raw material. In some cases, it is necessary to compensate for the partial loss of polymer heat stabilizers after its initial processing, i.e., to stabilize the recycled material. Material recycling is not rationally usable for all types of waste plastics. Some polymers are prone to degradation during reprocessing, which complicates the recycling process itself and significantly impairs the quality of the recycled material [7, 8]. Another factor complicating the use of material recycling is the requirement for relatively high purity of the input raw material. It is therefore important to avoid undesirable mixing of different types of polymers and undesirable contamination [9].

In some EU countries, such as the Netherlands, Germany or Italy, plastic packaging materials are collected and processed separately. Usually, these countries collect PET bottles separately and are therefore considered to be the sole source of income for this method of recycling. Plastics with a recycling triangle number 1 - 6, i.e., PET, HDPE, PVC, LDPE, PP and PS can be mechanically recycled. A significant problem is the collection and sorting by type and especially the quality guarantee of regranulated plastics for applications involving food and water contact. However, multilayer products, such as PET/PE, PET/PE/EVOH or PA/PE are often used as plastic packaging [10]. Typically, the initial sorting of such products is done by flotation in water: polyolefins (PP and PE) will float, the settled fraction will consist mainly of PET (around 50%), multilayer plastics, PP, PS, and PVC [11].

The OECD report [12] considers the following to be the main barriers to the wider use of mechanical recycling:

2.2.1 Economic - high costs of collection, sorting, and re-granulation:

I. Non-competitive price of re-granulated plastic compered to virgin plastic,,
II. Many smaller companies without experience and without laboratory background do business in recycling.

2.2.2. Technical - non-existent or imperfect plastic waste collection systems (two billion inhabitants of the Earth do not have access to waste plastic collection systems):

I. Contamination by other materials and more than 100 types of plastics;
II. Problematic additives in plastics – 21 to 33 million tons of various additives are applied (34% plasticizers, 28% fillers, 13% flame retardants, 6% antioxidants, 5% heat stabilizers and 2% colorants);
III. Older applications of plastics with now banned additives;
IV. Mixtures with biodegradable plastics;
V. Non-existent systems for collecting thermosets.

2.2.3. Environmental - hazardous additives: unclear origin of plastics for recycling.

2.3. TERTIARY RECYCLING

Tertiary recycling is also known as chemical recycling. It is the method by which plastic waste is chemically converted into basic chemicals (i.e., monomers / complete reversion or oligomers / incomplete reversion). It changes the chemical structure of the material so that the resulting chemicals can be used in the production of the original material. This process includes methods, such as solvolysis and/or thermolysis (also known as depolymerization), pyrolysis, thermal cracking, gasification, photodegradation, glycolysis, methanolysis, hydrolysis and chemosis. Successful depolymerization of PET and PC (made from BPA) to their monomers and oligomers was achieved by microwave irradiation. Hydrolysis or glycolysis of PU to polyols has also been achieved; glycolysis proved to be much more practical, while hydrolysis was too expensive mainly due to the high temperatures (> 280 oC) associated with it. Other polymers, such as PE and PP, cannot be successfully depolymerized down to their monomers. However, they can be degraded at high temperatures to a number of products used in the petrochemical industry and/or as flammable gases due to the accidental decomposition of the CC bonds. This process, in which the resulting chemicals are used for a purpose other than the production of the original material, is called raw material recycling. Both chemical and raw material recycling are not widely used due to several environmental impacts and/or high energy consumption, and very high financial costs.

Chemical recycling – there is currently no legally binding definition of chemical recycling of plastics. Chemical recycling can be defined as a process in which the used material is replaced with new material, while its structure must be preserved. Due to the fact that chemical recycling is based on a change in the structure of the polymer chain, according to some opinions, its outputs cannot be included in the plastic recycling rate. Chemical recycling can be considered as a complement to mechanical recycling, making it easier to meet the EU's recycling targets [9]. However, the EU does not include chemical recycling in circular economy technologies [10].

Chemical recycling allows for wider use of blended, difficult-to-recycle thermoplastics, rubber, thermosets, textiles, and plastics with additives limited by EU legislation. By depolymerization or pyrolysis processes, monomers can be obtained to produce virgin polymers.
The association Chemical Recycling Europe [11] includes the following processes as chemical recycling of plastics:

I. Dissolving of the target polymer from the polymer or additive mixture by a special solvent, subsequent polymer isolation, drying and re-granulation, such as the EPS recycling with hexabromocyclodecane to standard polystyrene – the PolyStyrene Loop;

II. Depolymerization is the decomposition of a polymer into the source monomers – an example of PET to ethylene glycol and terephthalic acid, PS to styrene;

III. Thermal pyrolysis and cracking of mixed plastics to pyrolysis oil and subsequently in petrochemistry to ethylene and propylene.

2.4. QUATERNARY RECYCLING

Quaternary recycling is a method by which the energy content of plastic waste is acquired. The most effective and popular way of reducing waste volume is incineration with energy recovery, especially for very low quality, mixed, and highly contaminated plastic waste streams. Depending on the geographical area and context, plastics can also be incinerated by open incineration. This option can have a number of negative effects on the environment and human health. The incineration of plastics, especially those containing chlorinated and brominated additives, may represent a significant source of air pollution, including soot and particulate matter, which can harm human health and pose serious threats to ecosystems. Open burning is not to be considered in the context of CE and will therefore not be discussed here. This type of recycling is especially suitable for thermosets. However, in order to preserve the material and to close the loop of the circular economy, plastic waste will become increasingly valuable in the EU and the energy use of plastics will be properly taxed. The number of products standardized for recycling will increase [13].

In addition to incineration using energy, also known as energy from waste, there are now a number of waste treatment options that can be used as part of a sustainable waste management strategy, where plastics are managed with other types of waste. These include advanced heat treatment processes (i.e., gasification and pyrolysis), advanced biological treatment (i.e., anaerobic digestion processes), mechanical heat treatment and mechanical-biological treatment. From these options, the most established is anaerobic digestion process. In this process, the organic waste fraction is stabilized through anaerobic digestion, composting or bio-drying processes and then physically treated (i.e., by crushing, grinding and milling). It produces fuel known as fuel generated from waste or solid recovered fuel, depending on the waste stabilization process used. The production of solid recovered fuels in Europe is regulated and must comply with the European standard CEN/TC 343 and the provisions of EN 15359-Solid recovered fuels-Specifications and classes.

However, for biodegradable plastics, their management in the circular economy is a key process.

2.5. ORGANIC RECYCLING/RECOVERY

Organic recycling/recovery is a method by which biodegradable plastics can be broken down by the action of microorganisms (bacteria or fungi) into water, carbon dioxide (CO_2), methane (CH_4) and biomass (e.g., growth of microbial populations). This includes the use of composting or anaerobic digestion processes. Successful implementation of the process requires separate collection of biodegradable plastics. The European standard EN 13432 sets strict criteria for the suitability of compostable, biodegradable plastic waste for organic recycling, because not all biodegradable plastics can be composted.

SUMMARY

In summary, rigid containers consisting of a single polymer are simpler and more economical to recycle than multi-layer and multi-component packaging. Thermoplastics, including PET, PE and PP, have a high potential for mechanical recycling. Thermoset polymers, such as unsaturated polyester or epoxy resin, cannot be mechanically recycled, except that they can potentially be reused as filler materials once they have been reduced or comminuted into fine particles or powders. This is because thermoset plastics are permanently cross-linked during production and therefore cannot be remelted and reshaped [14]

A major challenge for the production of recycled resins from plastic waste is that most different types of plastics are not compatible with each other due to their natural immiscibility at the molecular level and differences in processing requirements on the macro-scale level. For example, a small amount of PVC contaminant contained in a recycled PET stream will degrade the recycled PET resin due to the development of hydrochloric acid gas from the PVC at higher temperature required to melt and reprocess PET. Contrarywise, PET in the recycled PVC stream forms solid lumps of non-dispersed crystalline PET, which significantly reduces the value of the recycled material. Therefore, it is often not technically feasible to add regenerated plastic to the original polymer without reducing at least some of the qualitative attributes of the original plastic, such as color, clarity, mechanical properties, or impact strength. In most recycled resin applications, the recycled resin is either mixed with the original resin – this is often done with polyolefin sheets for non-critical applications such as garbage bags and non-pressure irrigation or drainage pipes or used in multilayer applications where the recycled resin is enclosed between the surface layers of primary resin [15].

The ability to replace the original polymer with recycled plastic generally depends on the purity of the recycled plastic waste and the performance requirements of the plastic product to be produced. This has led to current global municipal waste recycling schemes focusing on the most easily sorted packaging, such as PET soft drink and water bottles and HDPE packaging, which can be easily identified and sorted from mixed waste. On the contrary, there is limited recycling of multilayer/multi component products, because these lead to contamination between the polymer types. Post-consumer recycling therefore involves several key steps: collection, sorting, purification, downsizing and separation and/or compatibilization to reduce contamination by incompatible polymers [16].

The viability of thermoplastic recycling is affected by two key economic factors. These are the price of the recycled polymer compared to the original polymer and the cost of recycling compared to alternative forms of acceptable disposal. There are other problems associated with differences in the quantity and quality of supplies compared to the original plastics. Lack of information on the availability of recycled plastics, their quality and suitability for specific applications may also discourage the use of recycled material [17].

3 PLASTICS RECYCLING IN THE EU

Plastics production has grown exponentially in just a few decades – from 1.5 million tons in 1950 to 359 million tons in 2018 worldwide – and with it the quantity of plastic waste. After a sharp drop in production in the first half of 2020 due to the Covid-19 pandemic, production recovered in the second half of the year.

In Europe, the most widely used method of disposing of plastic waste is energy recovery (41%), followed by recycling (31%). Approximately 27% of all plastic waste is landfilled [18].

Half of the plastics collected for recycling are exported to countries outside the EU. The reasons for export include lack of capacity, technology, or financial resources for local waste treatment. Previously, a significant proportion of the exported plastic waste has been shipped to China, but recent restrictions on imports of plastic waste into China are likely to further reduce exports from the EU [19]. This poses a risk of increased incineration and landfilling of plastic waste in Europe. Meanwhile, EU is trying to find circular and climatic ways of dealing with plastic waste.

The low share of plastic recycling in the EU means significant losses to the economy and the environment. It is estimated that 95% of plastic packaging material value represents a loss to the economy just after the short first use cycle. Worldwide, scientists estimate that plastic production and incineration in 2019 pumped more than 850 million tons of greenhouse gases into the atmosphere. By 2050, these emissions could rise to 2.8 billion tons, some part of which could be prevented by better recycling [20].

In order to find a way to recycle contaminated plastics, some companies are trying to introduce chemical recycling of plastics [21–26], however, these are still only short-term projects that have only recently been used on a commercial scale. For this reason, the representatives of recycling companies are very divided in their views on chemical recycling. When a sample of 57 European recyclers was interviewed by the McKinsey Agency, a quarter of mechanical recyclers surveyed saw chemical recycling as a potential competitor for raw materials, while 35 percent saw chemical recycling technologies as concurrent players or potential partners who could complement the recycling business environment. Another 23 percent saw chemical recycling as an interesting area for business growth, but most remained sceptical about its environmental footprint and economic viability, especially in short to medium term [27].

The main problems complicating plastic recycling are the quality and price of the recycled product compared to its non-recycled alternative. Plastics processors require large quantities of recycled plastic, manufactured to strictly controlled specifications and at a competitive price.

However, because plastics are so easily adapted to the needs – functional or aesthetic – of each manufacturer, the variety of raw materials complicates the recycling process, which is costly and affects the quality of the final product. As a result, the demand for recycled plastics is growing rapidly, although in 2018 it accounted for only 6% of plastics demand in Europe.

McKinsey Agency [17] has published a global forecast for the flow of plastics in the year 2030. It expects world production to be at 560 million tons of plastics and plastic waste at 440 million tons, of which 18% will be landfilled, 31% used for energy and 50% sorted for recycling. Mechanical recycling should attain 22% share, chemical recycling 17% share, of which demonomerization should contribute 4% and pyrolysis 13%. Process losses should reach 11%, with only one percent ending up in uncontrollable waste.

To promote plastic recycling, EU adopted a directive [28] in 2019 according to which all EU countries should integrate 25% of recycled plastic into clear plastic bottles by the year 2025 and 30% into all plastic beverage bottles by the year 2030. This mandatory minimum – already in force in Germany, Denmark, and Norway – adds value to plastic waste because plastics manufacturers need it and will pay for it. Further recycling support consists of the obligation for plastics producers to pay a fee of € 800 per ton of non-recycled plastic packaging waste from January 1, 2021 [13].

All these measures are intended to help address the three main barriers to plastic recycling in the EU:

1. insufficient standardization of recycled plastic products,
2. хэрэглэгчийн эрэлт тогтворгүй байдаг, болон
3. inefficient sorting processes [22].

4 CURRENT STATE OF RECYCLING IN MONGOLIA

Ulaanbaatar's recycling plants collect all types of plastic waste/input material primarily from collection centers and larger plastic waste producing factories or comapniescompanies. The main reason is to ensure regular quantity with high purity of input plastic/waste. The quality of the processed plastics is controlled by the agency (The General Agency for Specialized Inspec-tion) and the density and purity of the recycled plastic have the greatest influence on the ac-ceptability for the processing technology and thus the price. Table 2 shows the range of pur-chase prices of the most common types of plastics in Mongolia.

Table 2. Purchase prices for plastic waste [MNT/kg]

Plastic category	Average price (Spring 2021)
PET	100-450
HDPE	400-700
PE	300-600
LDPE, PVC, POLYOLEFIN	500-800

There is only one recycling site in place in Bulgan, which only collects the sorted plastic, accumulates it by pressing and crushing and transports it to Ulaanbaatar for recycling. A waste management facility planned to be built in Khishig-Undur in the scope of the Sustainable Plastic Recycling in Mongolia project is on the construction stage. Plastic recyclables except PET bottles will be shredded, washed, temporarily stored by type and color and recycled with sheetpress or extruder machines while PET bottles will be compressed and stored until they are taken to urban recyclers. At the time of writing this report, recycling technologies are available neither in Bulgan nor in Khishig-Undur. For this reason, no gap evaluation of recycling technologies will be carried out in these two localities.

The following problems (gap) in municipal plastic waste recycling associated with sorting are considered:

1. Laborious and costly sorting of municipal plastic waste;

2. Insufficient records, availability of data on production and management of plastics;

3. Insufficient support of local municipalities, consistent policy approach across regions;

4. Insufficient public participation in waste sorting and low efficiency of municipal plastic waste sorting, very low awareness;

5. Increased collection costs for some types of waste (e.g., transport from remote regions), no functional logistics;

6. Insufficient efficiency of take-back and involvement of packaging material producers – "producer responsibility" (production and use of recyclable materials only);

7. Insufficient purity of sorted plastic waste;

8. Insufficient availability of raw materials for recycling technologies and inconsistency of supplies.

5 ANALYSIS OF PLASTIC RECYCLING FACILITIES IN ULAANBAATAR

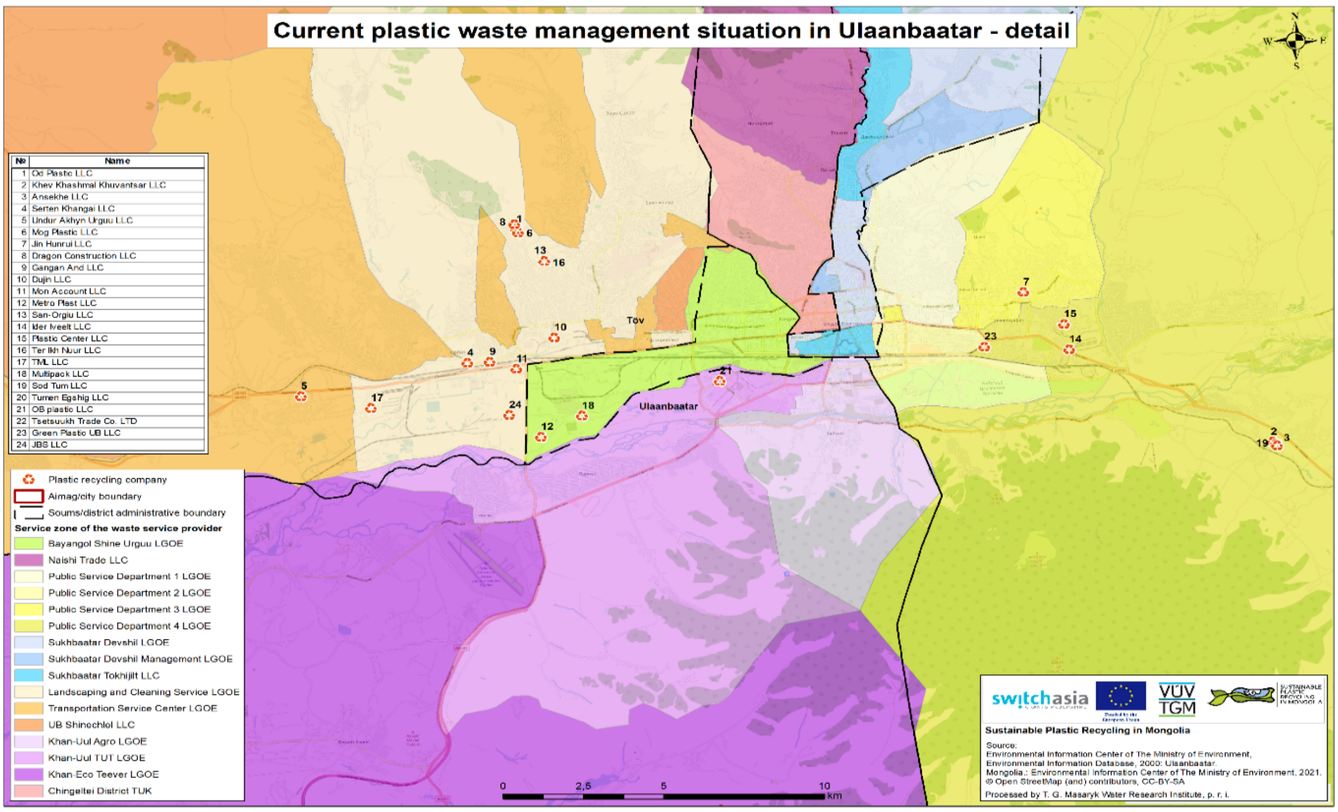
The terminology for plastic recycling is complex and sometimes confusing due to the wide range of recycling and recovery activities. There are four categories: primary (mechanical processing into a product with equivalent properties), secondary (mechanical processing into products requiring less demanding properties), tertiary (recovery of chemical components) and quaternary (recovery of energy). Primary recycling is often referred to as closed loop recycling and secondary recycling as quality reduction. Tertiary recycling is described as either chemical recycling or raw material recycling and is used when a polymer is depolymerized to its chemical components. Quaternary recycling is energy recovery, energy from waste or recovery.

All plants in Ulaanbaatar use mechanical recycling, which has been a proven technology for many years and is the most widespread method of recycling plastics in the world. However, like other technologies, mechanical recycling has its limits.

In theory, most thermoplastics can be recycled in a closed loop, but plastic packaging often uses a wide variety of polymers and other materials, such as metals, paper, pigments, inks, and adhesives, increasing the difficulty in closed loop recycling. Closed loop recycling is the most practical when the polymer component can be (i) effectively separated from sources of contamination and (ii) stabilized against degradation during the reprocessing and subsequent use. Ideally, the plastic waste stream for reprocessing should also consist of a narrow range of polymer types to reduce the difficulty of directly replacing the original resin. For example, all PET bottles are made from similar grades of PET suitable for both the bottle making process and processing into polyester fibers, while the HDPE used to blow bottles is less suitable for injection molding applications such as processing into polyester fibers.

In some cases, recycled plastic that is not suitable for recycling for the previous application is used to produce a new plastic product that will replace all or part of the original polymer resin – this can also be considered primary recycling. Examples are plastic crates and bins made of HDPE obtained, for example, from cosmetic packaging and

Figure 1 Current plastic waste management situation in Ulaanbaatar



PET fibers from recovered PET packaging. Quality reduction is a term sometimes used for recycling when recycled plastic is put into an application that would typically not utilize the original polymer – e.g., “plastic lumber” as an alternative to higher cost/shorter lifetime wood constitutes secondary recycling.

There are 24 plastics recycling plants in Ulaanbaatar, most of which are located in the western part of the capital city. See Figure 1.

All recycling companies use mechanical recycling of plastic waste. More than half of the plants use plastics extrusion technology, others useplastic waste injection moulding or drum bottle technologies. 42% of the plastic recycling plants only produce plastic granules (secondary raw materials or semi-finished products). Furthermore, 8% of the plastic recycling plants produce plastic products from these granules. Finally, 25% produces plastic products directly from plastic waste and the same number of plants produce both semi-finished products (granules) and final products. The specific products and capacities of the recycling plants in Ulaanbaatar are provided in Table 3.

Table 3 Recycling companies in Ulaanbaatar

Name of recycling company	Date of establishment	Type of plastic secondary raw material	End products
Od Plastic LLC	2015	HDPE, PE, LDPE	HDPE pellet and bin bags
Khev Khashmal Khuvantsar LLC	2011	HDPE, PP, PE	PP, PE pelety different types of molded plastic products, including construction spacer moldings, chair, household goods, souviner
Ansekhe LLC	2013	HDPE, PP, PE	Electrical conduit, (HDPE), HDPE pellet and big bags
Serten Khangai LLC	2017	HDPE, PE, LDPE	HDPE pellet, big bag
Undur Akhyn Urguu	2018	HDPE, PP, PE, PET	PET wire/string, HDPE, PP, PE, HDPE pellet /export/
Mog Plastic LLC	2014	HDPE, LDPE	HDPE, LDPE pellet
Jin Hunrui LLC	2003	PET, LDPE	PET wire/string /export/
Dragon Construction LLC	2017	PET	PET pellet
Gangan And LLC	2006	PET, LDPE	PET wire/string /export/
Dujin LLC	2006	PET, LDPE	PET wire/string /export/
Mon Account LLC	2006	PET, LDPE	PET wire/string /export/
Metro Plast LLC	2008	НИПЭ, ПП	vacuum window frame, water pipeline
San-Orgiu LLC	2005	PE, LDPE	chair, fences, trash bins, trench cover and road speed reducer etc.
Ider Iveelt LLC	2018	HDPE, LDPE	HDPE pellet and bin bag
Plastic Center LLC	2016	PE, LDPE	Latrine lining, public chair, well equipment, trench cover, plastic floor, different types of molded plastic products
Ter Ikh Nuur LLC	2004	PVC	Water pipeline
TML LLC	2018	PET, LDPE, HDPE (aluminium can, alloy; cardboard)	PET container, test tube
Multipack LLC	2010	LDPE, PE	plastic shrink wrap
Sod Tum LLC	2015	HDPE, PE, PP	Electrical conduit, (HDPE)
OB plastic LLC	2005	LDPE, PE	Plastic bags and packaging printed and shrink wrap
Green Plastic UB XXK	2019	PE, LDPE	big bag, plastic packaging
JBS LLC	2016	PE, LDPE	Plastic shrink wrap
Tsetsuukh Trade Co. LTD	2020	LDPE, HDPE, PP, bag	pellet

Tumen Egshig LLC	2019	HDPE, LDPE, PP, PE	pellet

The annual production capacity of all recycling plants is **44,420 tons of plastics.** Due to the expected annual production of plastic waste, **this capacity is insufficient.**
Of the 22 companies that participated in the survey, 14 companies, or 64%, said they would increase their recycling capacity, expand their product range, and modernize their facilities. Some of them are looking for bank loans and looking for investments in erecting their own factory building instead of renting, modernizing their equipment and producing final products instead of semi-finished products.

However, the remaining 6 companies, or 27%, do not plan to increase their recycling capacity because they have never reached its design capacity due to insufficient quantities of secondary raw materials, market competition, and the issue of secondary raw material price increase
.

As a problem (gap) of recycling facilities associated with recycling/processing, the following may be considered:

1) Insufficient capacity of recycling plants;
2) Lack of cooperation between recycling companies;
3) Lack of technologies for processing of poorer quality plastics;
4) Low competitiveness of some recycled plastic products against products made of virgin materials in price and quality;
5) Insufficient capacity of storage areas for plastic waste, for which recycling/recovery technology is currently not suitable;
6) Lack of government and political support from the municipality and a lack ofconsistent support for recycling and circular economy policy;
7) Insufficient cooperation between the private sector and the municipality (e.g., provision of waste treatment facilities, buying part of the products, etc.), lack of local technologies focused on local municipal resources;
8) Insufficient data collection system and information system on production and waste management methods.

Table 4 – SWOT analysis for the City of Ulaanbaatar

Strengths (S)	**Weaknesses (W)**
• Development of the waste collection system - activity of private waste collectors •Increasing efficiency of sorting plastics • Introduced recycling technologies	• Support from the municipality • Citizens' lack of information • Not maintaining records of production and waste management • Lack of facilities for the use of lower quality plastics
Opportunities (O)	**Threats (T)**
• Integration of private waste collectors into the system • Possible use of other components of municipal waste • Use of lower quality plastic waste for joint recycling with other types of waste • Inspiration for waste plastic management from abroad (examples of good practice)	• Use of illegal landfills • Plastic incineration in domestic heating • Disproportionately rising costs for plastic collection and recycling associated with system fragmentation

PROPOSAL PART

GENERAL

If advanced recycling is to be successful, more cooperation is needed throughout the supply chain. The economic benefits must flow throughout the recycling chain.

We recommend developing an application for the inhabitants of communities for their gradual wider involvement in the waste management system. For example, reporting of containers, collection points that need to be emptied/tipped. As a rule, it is necessary to check the location at the third identical report. This application can also be used to report inappropriate waste management, e.g., illegal dumps. Website contacts or the telephone number for reporting must be provided on each collection container, in educational/promotional materials and a map application.

For education and promotion of sorting/recycling, it is necessary to choose a simple, clear, and uniform way of communicating waste management in all communities and parts of the system of the entire specific region (school and preschool facilities and public spaces). Allocate space in the local media for regular communication with citizens and, in particular, for publishing the results of waste management.

(1) Records of produced and collected waste can be designed in several ways: (1) for a fee/charge collection service, distribute tokens that would be placed on the to be emptied container, (2) color-coded bag/sack with a marking (for example a QR code) and of a uniform volume, which the collector/service TUK, TUA would enter into a mobile application connected with central registration. Citizens should, in any case, always be motivated to sort and eventually take individually selected sorted components to a selected place. Individual discounts for sorting/participation in the recycling system should be calculated based on a central register for citizens with a higher share of sorting of selected components. It is important to combine rewards with fees so that they are truly motivating, and mixed municipal waste is minimized as much as possible.

The fees for the handling/collection and recycling of waste must be set at an amount fully covering the actual costs. Discounts from the full price of the fee are calculated for each "extra" activity, for example sorting of municipal waste components, bringing sorted waste into a container or a collection point, use of a return system (beverage packaging) etc. Sorting and delivery for the elderly and handicapped citizens can be provided by motivated schoolchildren who would also be connected to the rewards system (options selected by the fee administrator such as a discount on local transport, competitions for popular electronic devices – mobile phones, 3D printers, etc.).

When implementing a sorting system to obtain the cleanest possible waste plastic, it is appropriate to create conditions for the sorting of individual types of plastic waste such as PET (beverage packaging), HDPE (drugstore packaging), and sort only the residue on manual sorting lines, which are cheaper than optical sorting lines and equally efficient. At the same time, try to sort as many types of municipal waste components as possible and thus reduce the quantity of landfilled waste. It is necessary to create a network of simple collection points for sorted components, which will be mainly accessible and will be gradually technically improved from the obtained funds.

A modern system and education for citizens supported by real discounts, based on the motivation of citizens, increase the share of preferred sorted components (including plastics), their constant availability for processors, who can strategically plan on this assured supply. At the same time, there is a reduction in the amount of mixed municipal waste, a reduction in the frequency of its collection, and an overall reduction in the quantity landfilled.

1 ULAANBAATAR

According to the study, Ulaanbaatar actually has sufficient recycling potential and capacity for the current amount of sorted plastic waste (expanding the existing capacity is faster than securing sufficient new sources of plastic waste) as well as the experience of local recycling companies. They are able to reprocess all sorted plastic waste; however, some of them stated that they do not plan to expand their capacities and technologies. This is mainly due to the fact that large "local players" have contracted the largest deliveries of collected plastics, which are easily traded, and the other processors share the rest. Most of the technologies are concentrated in Ulaanbaatar as the capital city. This is a major shortcoming of the overall strategy, as capacity needs to be built at the regional level as well.

An important aspect of ensuring the optimal quantity of good and clean plastic is the integration of private collectors (who could be financed from the incentive system and also by processors) into the system and keeping records at least of the input and output of recycling technology. The city administration must create conditions for a system of monitoring and evaluation of waste recycling performance, monitoring and evaluation of waste management costs, respectively plastic recycling in Ulaanbaatar, and assistance in providing professional service of collection points/ yards, recycling technologies and also management and control of the municipal waste management.

2 BULGAN

Due to the system being implemented for both plastic waste sorting and recycling technologies, there is a great potential for setting up a functional system.

According to the available sources and after recalculation, the population can produce 860 tons of plastics per year. This amount is effective and suitable for the local economy. There is no need to transport this waste anywhere. It is advisable to set up a recycling line on location. This line would also be supplied with sorted waste from the surrounding communities. The service range would be about 30 to 60 km. Support for sorting and motivation of producers for individual import/delivery to collection yards will ensure the lowest possible collection costs and the possibility to provide incentives (producers' rewards for participating in the collection system). Involvement of private collectors in the system, who would regularly collect sorted plastic waste from producers in bags and sacks on the streets in front of houses on a certain day. It is necessary to ensure regularity. During collection, they would keep simple records and at the same time check the purity of sorted plastic waste. The city can manage the collection by using a system with a combination of collectors, publicly available collection containers and yards. Sorting can also be managed thanks to collectors, who should be supported in their activities and introduced into the system. The number of components of municipal waste to be sorted depends on the strength of the market.

In order to set up and motivate delivery, the cooperation of municipalities and at the same time of interested local entrepreneurs is necessary; the entrepreneurs would either just process the plastic waste for transport to a more suitable facility, for example in Ulaanbaatar, or even process it into their own plastic products.

Experience shows that 50% of large plastic parts interesting for the market can be recycled. About a fifth of the plastics produced are difficult to recycle mechanically. The technology aimed at processing these remaining plastics together with other components of municipal waste is available. Extending existing recycling technology or adding additional recycling technology depends on the size of the potential demand/sales for the products that would be produced using these technologies.

3 COMMUNITIES OF THE SIZE OF KHISHIG-UNDUR OR SMALLER

In these municipalities, the recycling system would start with sorting, collection of produced plastic waste and end with the removal of cleaned, crushed, and mechanically compressed plastics. Crushing and compressing would be provided by a contracted private entrepreneur who would, at regular intervals, serve the communities around a large city with recycling facilities within a radius of 30 to 60 km.

SUMMARY FOR ALL AREAS

The aim of the system is to collect the largest possible quantity, in the highest possible purity, of the largest possible number of types of municipal waste. Motivation to prevent waste and ensure returns is part of educational and promotional activities.

The transport of waste plastics, especially from local and regional sources for further processing without basic processing is disadvantageous. For this reason, it is essential that at least sorting lines/sites are built in local communities, where possible and particularly whereadvantageous.

The sorting lines should have sufficient storage space for the individual sorted components, the current number of which would be determined by market demand. From the experience of companies dealing with real-world recycling, we propose to separate waste plastics only of those types with actual commercial potential (PET, HDPE, LDPE, PP) – in the Czech Republic it is about 40% (first group), and focus on the separation of those components that cannot be effectively processed at all with the current state of knowledge (PVC, wood, paper, metals, etc.) and that constitute about 25 to 30% (second group). The rest (third group), i.e., about 30% of plastics, can still be processed, even if they are combined plastics.

1) The first group is very important regarding the functioning of the entire waste plastics management system (within the entire municipal waste management system). If the system is developed, there is and will be great interest in these raw materials and the processors themselves will continue to transport them from other sources at market prices. The more of these types of plastics are separated from the total quantity, the more funding the system will generate. After sorting, this part only requires compaction (compression) so that the waste plastics are transported for further treatment/processing as efficiently as possible. The compaction technology does not have to be a permanent part of a local plant's capacity, it can be shared with other regions and used only when needed. We therefore recommend that joint negotiations on waste plastic collection, recycling, and disposal always take place at the level of neighboring regions, who can share not only specific expensive processing and transport facilities, but also waste plastics management principles or systems, as they can bring great savings to each partner while using the results of good practice and creating local economies.

2) The second group of waste plastics, including other admixtures that cannot be used for recycling, can only be used for energy recovery, if facilities are available, or landfilled for the time being.

3) The third group can be used for processing into products that can find application at the local and also on regional level. This is the production of, for example, road curbs, paving, ducts for underground utilities etc. (see e.g. [29–32]) This trend is currently expanding, but its effective application cannot occur without the already mentioned support of local businesses by local governments.

The citizens will carry plastic waste properly to the chosen place and, if they have the opportunity to do so and especially if they are motivated, they will also sort the waste. The business entity, local self-government, or both in cooperation will ensure its delivery to the sorting line and another business entity in possible cooperation with the local self-government will ensure the sorting, disposal or recycling of plastic waste, provided that products manufactured from this group of plastics are directly used by the local government, local businesses and even citizens, for example, in the construction of local roads or the construction of other buildings.

Within the EU, great attention is paid to recycling. However, in the future, the actual recycling of sorted municipal waste components requires building the following linkages:

CITIZEN – LOCAL GOVERNMENT – LOCAL BUSINESSES

Local government is the most important player and creates the conditions for:

a) Proper sorting by citizens – creates the infrastructure for sorting;
b) Emergence of local economies for waste processing – supporting local businesses;
c) Motivating citizens for proper waste management and sorting – maintaining awareness, but above all build an incentive system to reward those who sort better;
d) Mutual communication of all involved;
e) Own use of products from local economies focused on plastic recycling.

Unless there are opportunities for the use of products made from recycled materials, it will not be possible to achieve a high degree of recycling.

Plastic waste processing technologies themselves are widely available in Mongolia, like anywhere else, as evidenced by the variety of technologies already available in Ulaanbaatar. It is possible to only complement these technologies by other equipment, such as presses and molds for pressing specific products. .

The biggest obstacle to more substantial recycling lies in the inexperience and ignorance of the design and use of waste plastic products on a massive scale.

By producing suitable products from plastic waste, it is possible to achieve a competitive product even in local conditions without having to use non-renewable resources.

These products are designed by specialized companies with regard to local conditions and needs; this will be their know-how.

The above-mentioned technologies also need to be placed at the regional level, as the collection and transport of plastic waste is extremely expensive. For specific regions, it is possible to prepare the principle of multi-stage efficient processing of plastic waste, where the final technologies focused on the manufacture of products for which there is demand are located on sites where it is possible to concentrate about 1,000 tons of waste plastic (this is the third group of plastic waste). These processing technologies import not only the pressed plastics from individual regional sources (sorting lines), but plastic semi-finished products, for example in the form of granules, which are more efficiently transported, stored and processed.

GLOSSARY

Additives	Additives are used in polymers to eliminate their shortcomings or improve their processability. These shortcomings include, in par-ticular, their low resistance to degradation, high flammability, electrostatic charge on the surface, low toughness and hardness, limited chemical resistance, low heat hardness, etc. Depending on the effect, additives can be divided into additives modifying the physical properties of plastics or additives with a protective effect against degradation. Additives must ensure the stability of the plastic under operating conditions; they must be sufficiently effective. They must not have adverse effects on the properties of polymers and the envi-ronment. They can also bring economic savings.
Anaerobic digestion	Method of processing biodegradable plastics by microbial conversion of organic substances without access to air to produce biogas.
Chemical recycling	Полимер хаягдал эсвэл полимерийн найрлагад шууд нөлөөлж, тэдгээрийг анAny reprocessing technology that directly affects either the formulation of the polymeric waste or the polymer itself and converts them into chemical substances and/or products whether for the original or other purposes, excluding energy recovery.
Depolymerazition	The process of converting a polymer to a monomer or mixture of monomers.
Gasifiaction	Thermal conversion of carbonaceous material (i.e., plastic) into flammable gases by the action of gasification media (oxygen, hydrogen or their mixtures, e.g., water vapour + oxygen).
Hexabromocyclodecan	Flame retardant organic bromine compound (HBCD). Invented in the 1970s, it was produced on tens of thousands of tons per year and was used in polystyrene insulation boards for house facades, textiles and plastics in electronic devices. It has been banned worldwide since 2014. Plastics containing HBCD are not recycled in Switzerland and the Czech Republic but must be destroyed during waste incineration.
Injection molding	The process of injecting molten plastic material into a metal tool which then cools and ejects a plastic part from the machine.
Pyrolysis	Physico-chemical process belonging to the group of thermal processes. This is the thermal decomposition of organic materials in the absence of media containing oxygen (especially air). The essence is the heating of the input material above the thermal stability limit of the present organic substances, which leads to their decomposition to form stable low molecular weight products (gaseous and liquid) and solid residue.
Thermoplastic	A type of plastic made up of polymer resins that becomes a soft material when it is heated and becomes hard when it is cooled.
Thermoset	A polymer that is obtained by irreversibly hardening (“curing”) a soft solid or viscous liquid prepolymer (resin). Curing is induced by heat or suitable radiation and may be promoted by high pres-sure, or mixing with a catalyst.

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