Market Analysis & Literature Review on Refuse Derived Fuel (RDF) from Residual Waste

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Executive Summary

The Zero Waste 2040 Strategic Plan provides a vision to make Vancouver a zero waste community by 2040, a community which supports sustainable resource use, a healthy economy, affordability, vibrant and inclusive neighborhoods, and equal opportunity through the elimination of solid waste. City of Vancouver adopted the Zero Waste 20240 Strategic Plan in 2018. This strategic plan calls for more diversion, recycling and reuse strategies to reduce waste disposed to landfill and incinerator. Although, significant efforts are being made towards reduction and diversions of different fractions of Municipal Solid Waste (MSW) such as organic waste through Green Bin program, recyclables through Blue Bin program, there is still a substantial fraction of Residual Waste, which is being disposed to the Vancouver Landfill (VLF). Furthermore, VLF is set to close by 2037, three years before the Zero Waste 2040 target. This paves the way to explore opportunities of energy recovery from Residual Waste in the form of Refuse Derived Fuel (RDF). This report includes a literature review on RDF and a market analysis of various industries in British Columbia where RDF can be used as an alternative fuel.

RDF and its Technology

Refuse Derived Fuel made from Residual Waste largely consists of combustible components such as plastics, paper, cardboard, textile and sometimes organics depending on requirement of end user. The other fractions of MSW, which do not contribute towards RDF, are metals, glass, sand any other type of inert material that does not have a calorific value. Primarily there are two types of RDF distinguishable by their composition, one is RDF without organics and other is RDF with organics. In terms of physical characteristics, RDFs can be produced as loose materials (fluff) or pelletised into denser products (pellets). The technology used to produce RDF is called Mechanical Biological Treatment (MBT). Depending on the requirements of the end user, MBT can be customized to get the desired RDF quality. As the name suggests MBT involves two types of processing, mechanical processing which includes sorting, separation, size reduction, sieving and biological processing which can be aerobic, anaerobic or another biological process that convert the biodegradable waste into stabilized organics.

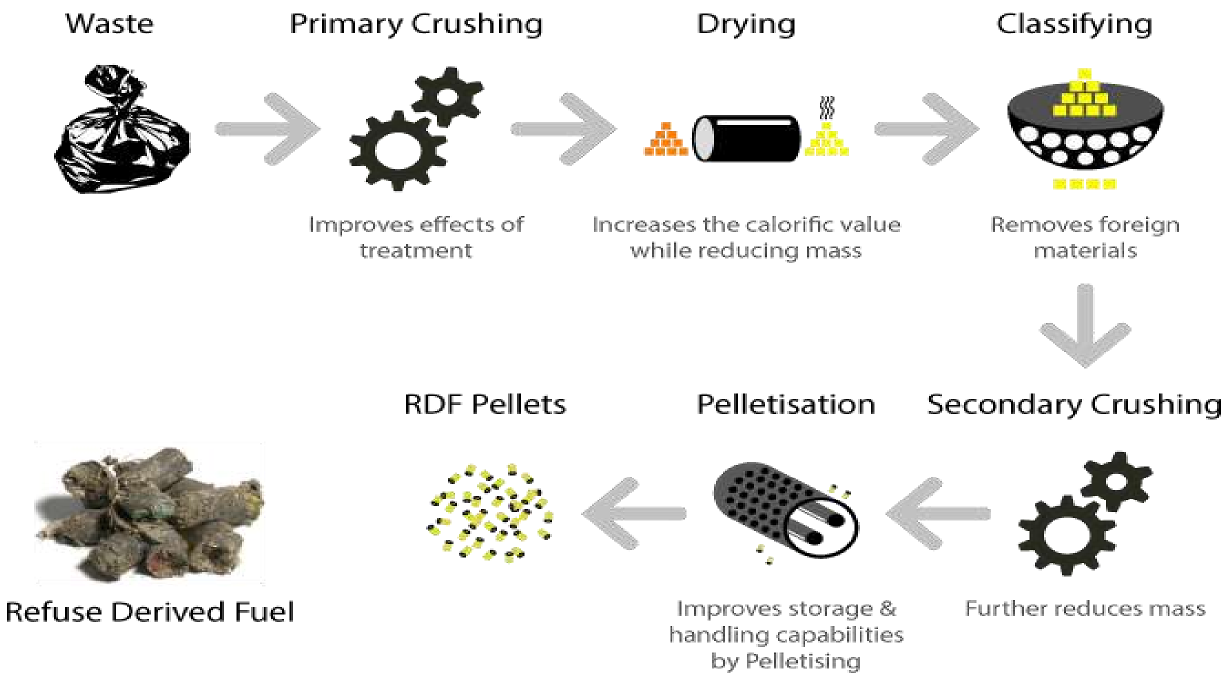

Figure 1. A schematic of processes involved in MBT [1]

RDF Manufacturing Potential

Estimated RDF manufacturing potential of City of Vancouver has been determined using the previous four years of disposal data available and the latest available waste composition studies. During the course of this research, it was found that there has been a steady decline in the waste generated and in 2020, approximately 111,056 tonnes of waste was disposed to VLF from Vancouver. The waste composition data of the City of Vancouver and Metro Vancouver highlighted approximately 84% of the Residual Waste can contribute towards RDF formation. Furthermore, this contribution consists of 23% paper, 22% plastics, 21% compostable organics, 4% textile, 14% Household hygiene and 16% inerts. Except for inerts, rest all can contribute towards the manufacturing of RDF. Through the findings of literature review, it is estimated that the MBT process has approximately 55% conversion rate which can potentially provide City of Vancouver **52,000 tonnes of RDF** per year as per 2020 residual waste generated data.

Market Analysis

The Market Analysis identified cement, pulp & paper and gasification industries as potential consumers of RDF as an alternate fuel for their heating requirements. During this research, interviews were conducted with two cement companies' representatives, Lafarge and Lehigh, operating out of western Canada. Both companies have two plants each, one in British Columbia and one in Alberta which are currently consuming approximately 193,000 tonnes of alternate fuel per year. From conducted interviews, it was determined that both the companies are interested in RDF to add into their fuel mix. They expect the RDF to reach necessary calorific value range between 12-15 GJ /tonne. Although they are receptive to RDF, they require a tipping fee from the supplier, which is subject to negotiation at the time of contract finalizations. In the future, the demand for alternative fuel is expected to reach 283,000 ton per year for the cement industry within western Canada.

The pulp and paper industry was also researched in terms of RDF consumption. It was found that approximately 90% of their energy requirement is already being met through renewable energy of which 70% is wood biomass and 20% is hydroelectricity. Furthermore, their plant boilers are not equipped to handle plastics or chlorinated compounds as they mostly use clean fuel such as bark, sawdust, hog fuel and other wood residue. Use of RDF would require significant retrofitting of thier Air Pollution Control unit to handle RDF emission, which is an expensive proposition for pulp and paper key players within BC.

Lastly, BC's gasification industry was analyzed for RDF utilization through research and an interview with Fortis BC representative. Fortis BC is encouraging entrepreneurs to setup waste to Renewable Natural Gas (RNG) plants either through anaerobic digestion or gasification by offering $30/GJ for offtake of RNG. As gasification is a feedstock agnostic technology which can convert any combustible organic or inorganic material such as RDF into Syngas which can further be converted to RNG, there is a tremendous opportunity for utilization of RDF in gasification plants. A company named REN Energy has signed an agreement with Fortis BC for supply of RNG from wood waste, the length of the supply contract is 20 years and the plant is proposed to be operational by 2023. As wood waste and RDF are of the same calorific value, they can be easily co-processed. Thus, the gasification industry is a promising industry where RDF can be utilized and converted into high priced biofuels.

Conclusion

It can be concluded that at present there is an existing market for the use of RDF in the cement industry where they have already made significant investments for alternative fuels utilization such as RDF. Currently, other RDF substitute fuels are meeting cement industry demand for alternative fuel. A long-term contract with cement plants for RDF supply can mutually assure RDF supply and demand. Simultaneously, a dialogue with gasification companies is recommend for future long-term utilization of potential future tonnages of RDF, especially if the gasification plant can be located at the landfill. A public private partnership investment model can be beneficial in which COV can provide RDF, the project developer can convert RDF to RNG and Fortis BC can offtake RNG at an assured price, a varied RDF consumer portfolio would be highly beneficial in terms of risk mitigation strategy. Finally, both cement industry and gasification plants looks to be the promising markets where Residual Waste RDF can be utilised and help City of Vancouver achieve the goal of Zero Waste by 2040.

Acknowledgements

Firstly, I would like to acknowledge that the work for this project took place on the unceded ancestral lands of the xwməθkwəy̓əm (Musqueam), Skwxwú7mesh (Squamish), Stó:lō and Səl̓ílwətaʔ/Selilwitulh (Tsleil- Waututh) Nations and I am extremely grateful for that.

The Greenest City Scholars Program turned out to be an extremely important milestone towards my personal and professional development. I gained a lot of knowledge on the waste reduction initiatives the City is undertaking in order to reach its goal of Zero Waste by 2040. The internship improved and enhanced my technical skills for future applications in technical engineering projects and zero waste initiatives.

Foremost, I would like to express my sincere gratitude to my mentor Mr. Farbod Diba for his continuous support, patience and subject knowledge which made this research project set up for success. His guidance kept me on the correct path, which was paramount to the timely completion of the project.

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Glossary and Acronyms

Acronyms/Abbreviation	Definition
AB	Alberta
AR	As Received
BC	British Columbia
C&D	Construction and Demolition
CoV	City of Vancouver
CTS	Coquitlam Transfer Station
EU	European Union
GJ	Giga Joules
GCAP	Greenest City Action Plan
GHG	Greenhouse Gas
IEA	International Energy Agency
IFC	International Financial Code
LPG	Liquified Petroleum Gas
MBT	Mechanical Biological Treatment
MB	Mechanical Biological
MJ	Mega Joules
MP	Mechanical Physical
MSW	Municipal Solid Waste
NCV	Net Calorific Value
PJ	Peta Joules
PPE	Personal Protective Equipment
RDF	Refuse Derived Fuels
RIP	Refuse Incineration Plant
RNG	Renewable Natural Gas
SRF	Solid Recovered Fuel
SSO	Source Separated Organics
SWOT	Strength, Weakness, Opportunity, Threat
STS	Surrey Transfer Station
US/USA	United States of America
VLF	Vancouver Landfill
VSTS	Vancouver South Transfer Station
WIO	Waste Incineration Ordinance
WTE	Waste to Energy

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1. Introduction

This project on "Market Analysis and Literature Review on Refuse Derived Fuel from Residual Waste" is part of the Greenest City Scholars Program of City of Vancouver in collaboration with the University of British Columbia's Sustainability Scholars program . Out of the 10 goals of The Greenest City Action Plan, this project supports the goal of Zero Waste which aims at diverting waste from landfill and solving today's climate crisis, moreover, VLF is also set to be closed by 2037. To address the issue of achieving Zero waste by 2040 and diversion of Residual Waste by 2037, this project was undertaken to analyze various avenues for Residual Waste Derived Fuel utilization by carbon and energy intensive industries within British Columbia.

1.1. Project Objective

The use of Refuse Derived Fuel commonly known as RDF as a heat energy source has been demonstrated in varying degrees around the world. The City of Vancouver staff (City staff) would like to better understand RDF products currently being produced around the world and identify key potential RDF consumer markets within British Columbia. The outcome of this project highlights exploratory options for City staff to determine the appropriate next steps for reaching Vancouver's zero waste goals and the City of Vancouver's future role in Metro Vancouver's future regional solid waste management plan.

1.2. Project Scope

This project consisted of the following task:

1. Conduct a literature review on the RDF to examine the best-suited technology for RDF production from Residual Waste, the fraction of Residual Waste which contributes towards the heat value of RDF, quantification of City of Vancouver's RDF production potential from Residual Waste and its estimated calorific value.
2. Identify Industries where RDF can be used as an alternate fuel.
3. Conduct interviews with the identified industries in order to perform a Market Analysis of RDF.
4. Analyze the local market dynamics in terms of supply vs demand of RDF, key drivers for the use of RDF in potential consumer industries, barriers to entry and growth potential for the alternate fuel market.
5. Compile and review the key buying criteria for the RDF in terms of product composition & quality, price for RDF, desired calorific value.
6. Highlight future trends of the RDF Market.

1.3. Methodology

The project involved a detailed literature review on RDF available on open access internet resources and academic papers. The literature included several research papers and reports made by various authors for Canada and different countries in the world. Few reports specifically targeting City of Vancouver and Metro Vancouver were also studied.

Based on the above reports and research papers, a questionnaire was developed for subject matter experts to gather information on market potential, expected quality, price and other related subjects.

Several meetings, interviews and project check-in meetings were attended throughout the project. From these meetings, information was gathered and opportunities for collaboration and synergies were discovered between City of Vancouver and other organizations, which can be explored further by City staff.

Finally, the Market Analysis was conducted through the lenses of technical and commercial feasibility, local market dynamics, key buying criteria and barriers to entry into the local market.

2. Background

The intent of the background section in this report is to provide industry definitions adopted throughout the report and provide an understanding of goals and initiative set out by the City of Vancouver.

2.1. Industry Definition

Carbon Tax: A Carbon Tax is a tax levied on the carbon emission required to produce goods and services. At present the Carbon Tax in BC is $45 per tonne of CO_2 or equivalent.

Mixed Waste Fuel: A mixture of wood waste, C&D waste, Tire RDF, non-recyclable plastics, carpets and mattresses typically used for cement production

MSW or Municipal Solid Waste: The refuse that originates from residential, commercial, institutional, demolition, land clearing or construction sources.

Residuals/ Residual Waste: The fraction of MSW that excludes Source Separated Organics, Source Separated Recyclable Material, and Source Separated Construction and Demolition waste.

Recyclable Material: It is a product or substance no longer usable in its current state that can be diverted or recovered from MSW and used in processing or manufacturing of a new product.

Source Separated Construction and Demolition Waste or **C&D:** It is the refuse that originates from construction or demolition sources, collected separate from other MSW.

Source Separated Organics or **SSO:** organic materials consist of food, food soiled paper, clean wood, paper tissue, paper napkins and towels, yard trimmings or any combination thereof, collected separate from MSW from residential, commercial or institutional sources for the purpose of processing for beneficial use.

Source Separated Recyclable Material: Recyclable Material collected separate from MSW from residential, commercial or institutional sources, for recycling.

Substitution Rate: It is the percentage of alternate fuel combusted for heating purposes.

Tipping Fee: A tipping fee or a gate fee is a fee paid by anyone who disposes waste to the entity who processes waste.

2.2. City of Vancouver Zero Waste Strategic Plan

Zero Waste 2040 Strategic Plan establishes a vision of Vancouver becoming a zero waste community by 2040 and provides a strategic framework to achieve that vision. The primary objective of the Strategic Plan is to eliminate the disposal of solid waste to landfill and incinerator by 2040, through alignment with an approach which includes the following, in order of priority:

1. **Avoid & Reduce:** Avoid the generation of waste and reduce the amount of waste that can't be avoided.
2. **Reuse:** Prioritize material reuse such as sharing, repurpose, repairing and refurbishing over recycling and disposal.
3. **Recycle & Energy Recovery:** Increase the total amount of material recycled, reduce emissions by maximizing the recovery of inedible food and green waste for composting and renewable energy recovery [2].

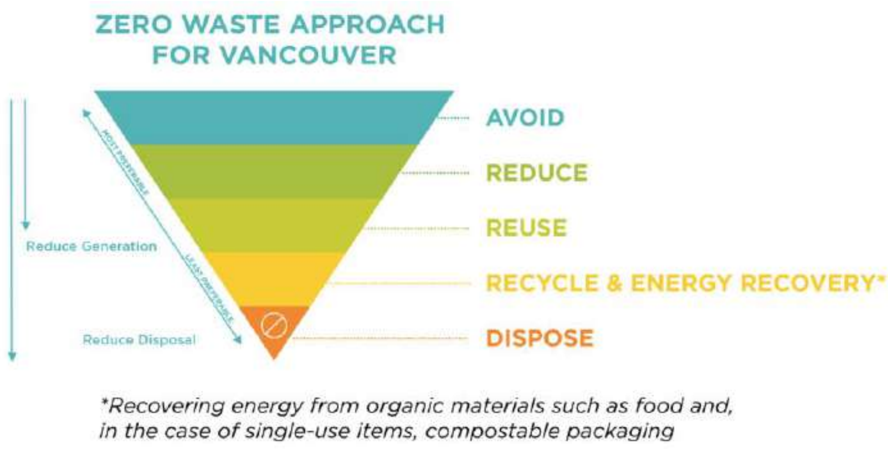

Figure 2. Zero Waste Hierarchy [3]

City of Vancouver aims to adhere to the zero waste hierarchy in its approach to reach its strategic goals described in its 2040 Plan. This research initiative on Residual Waste to RDF supports Priority Action No. 8 of the Zero Waste 2040 Plan which talks about strategies to develop new reduction, diversion and recovery of Residual Waste materials especially fractions of Paper and Plastics. In addition, this research provides a technological option to support the Transformative Action No. 1 of the plan which is focused on the implementation strategies for material recovery and energy recovery through biofuel production from Residual Waste. Thus, this research findings and recommendations are focused on the possibility of producing Refuse Derived Fuel to address significant quantities of non-recyclable plastics, paper and organics (significant portion of Residual Waste composition) which are currently being landfilled.

Additionally, the Vancouver Landfill, located in City of Delta is set to close by 2037. Since this Landfill is the only operating municipal solid waste landfill in the Metro Vancouver Region, preserving its capacity is of great importance to all parties. The combination of complying with Zero Waste 2040 Plan and closure of the Vancouver Landfill by 2037 makes exploring RDF as a method of processing Residual Waste to recover recyclable materials and extract energy from the remaining fraction of waste, a reasonable course of action.

3. Refused Derived Fuels – A Literature Review

3.1. Introduction

Refused Derived Fuels or commonly known as RDF are fuels derived from combustible fraction of solid waste such as plastic, wood, textile and/or organic waste other than chlorinated material in the form of pellets or fluffs produced by drying, shredding, dehydrating and compacting of the mentioned waste materials. RDFs are generally processed from non-hazardous mono or mixed waste streams to make them suitable feedstock for energy recovery. The fuel is then utilized for heat generation and co-processing in various industries such as cement, pulp & paper and other industries with high temperature furnace use. [3]

For the purposes of this research and its objectives, only the possibility of producing RDF from Vancouver's Residual Waste is explored. Wastes such as SSO, Recyclables, C&D waste are not part of this particular formula of RDF as they are already being processed through different methods & technologies.

3.2. Classification of RDF

Primarily there mainly two types of RDFs from Residual Waste. One is without organic fraction and one with organics fraction included. In the former type of RDF, the metals and inerts are removed and the organic fraction is screened out and composted. The remaining components, largely consisting of plastics, paper and textiles is processed into a RDF creating a product with high calorific value [5].

The other type of RDF is made from the same composition of residual waste but includes the organics, which becomes part of RDF through “bio-stabilisation” or “bio-drying” process. This process allows the organics to undergo a partial composting process without the addition of moisture. As composting is an exothermic process, the heat from partial composting dries out the material and oxidises the putrescible organic fraction, while retaining other organic matter intact. This bio-stabilised material is then mechanically processed through a number of screening stages to achieve the necessary size required to produce the desired RDF. The level of mechanical processing is driven by the fuel specifications for the combustion technology used by the RDF end consumer [5].

While there are two types of RDFs distinguishable by their composition, RDFs can be produced as loose material (fluff) or pelletised into a denser product. This is dependent on several factors including but not limited to : manufacturing unit’s proximity to end customer, the need to store the material prior to its use and the type of feed system of the combustion facility [5].

Generally, the quality of produced RDF fuel is determined by Consumers, based on their process characteristics. Additionally, there are no set global mandatory quality standards; however, there have been attempts to formulate an international standards for RDFs. Over the past number of years, there have been a few attempts to classify RDF as per a set of quality standard. For example, in Europe, standards have been developed to differentiate higher and lower quality RDF, they are termed as Solid Recovered Fuels (SRF). These standards are voluntary but provide customers with confidence in the product quality. The assurance & reliability of the product is an essential aspect of determining the potential impact on human and environmental health, on plant equipment, end users, public, and regulatory authorities’ acceptance [6].

3.3. RDF Production Technologies

There are various sorting technologies available for production of RDF, which can be implemented based on the Residual Waste feedstock characteristics. Some of these technologies are listed in the table below [6].

Table 1: Summary of key resource recovery technologies

Production Technology / Features	Clean Material Recovery Facility	Dirty Material Recovery Facility	Mechanical Biological Treatment	Mechanical Heat Treatment
Feedstock	Mixed/Commingled recyclables (Municipal & Commercial)	Mixed Residual Waste (Mainly C&D municipal & commercial waste)	Mixed putrescible residual waste (mostly municipal)	Mixed residual wastes (Municipal and Commercial)
Product/ Outputs	• Separated recyclable materials: paper, cardboard, plastics, glass, steel and aluminum. • Glass fines for potential further processing. • Light residuals-potential RDF. • Residual to landfill.	• Separated recyclable materials including paper, cardboard, plastics, glass, steel, aluminum, masonry product, soil, timber. • RDF. • Residuals to landfill.	• Low grade soil amendment/compost • Recyclable material including rigid plastics, steel and aluminum • RDF • Residuals to landfill	• Organic rich fiber-low grade soil amender, fuel • RDF from inorganic fraction-to thermal process • Recyclables(low grade)

Based on the waste composition of Residual Waste disposed at VLF (see section 4.2.3 for more details) , the Mechanical Biological Treatment is the most appropriate technology for mixed putrescible Residual Waste. The composition of the residual waste mainly comprises of inerts, inorganic non-recyclable waste and some fraction of organic waste, which was not segregated at source and ends up as Residual Waste composition .

3.3.1. Mechanical Biological Treatment

Mechanical Biological Treatment (MBT) is well established internationally. It was originally developed in Germany as a pre-treatment of putrescible wastes to landfills. Mechanical Biological Treatment is primarily used to treat mixed putrescible waste with a relatively high proportion of organics (mostly municipal) [7]. It can also allow the recovery of the organic fraction of mixed Residual Waste even if source separation collection system is not implemented. MBT comprises of a range of Residual Waste treatment options such as:

- **Mechanical Processing:** The process involves sorting, separation, size reduction and sieving technologies in various configurations to achieve a mechanical separation of waste into potentially useful products or streams for biological processing [7].
- **Biological Treatment:** The process involves aerobic or anaerobic biological process that convert the biodegradable waste into a stabilized organic or compost like output and in the case of processes incorporating an anaerobic digestion step, biogas is produced [7].

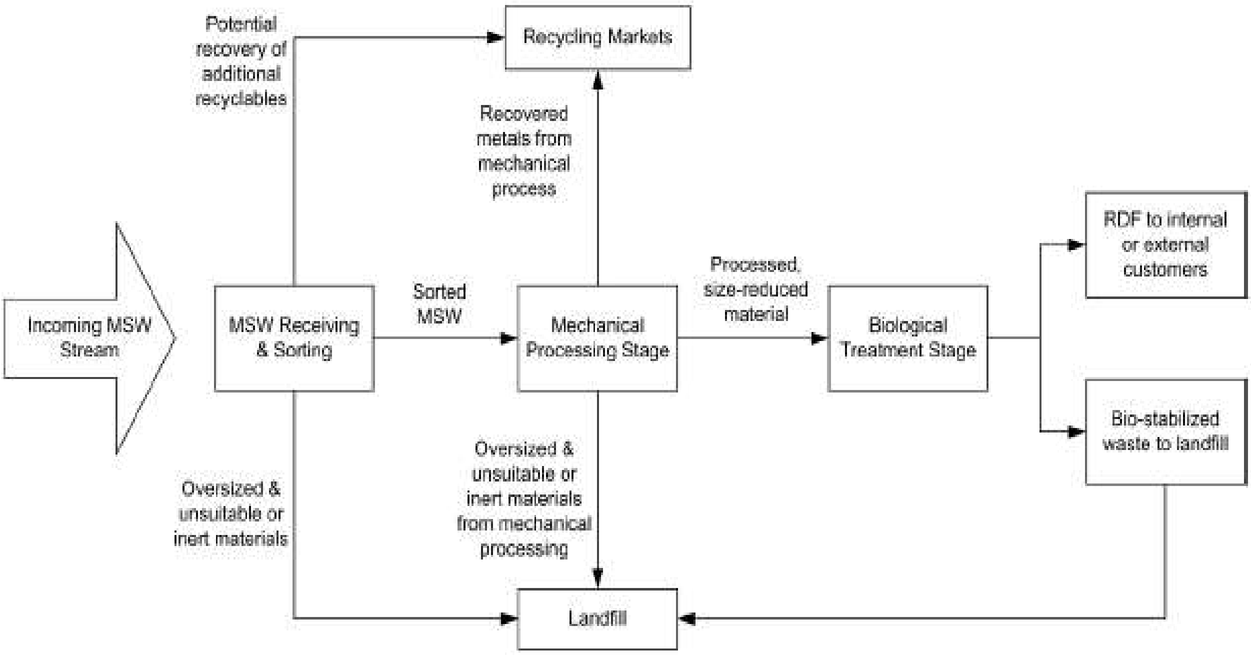

Figure 3. A generalised schematic flow diagram of Mechanical Biological Treatment [7]

MBT can be configured differently to achieve different goals, including the stabilisation of waste before landfilling, production of compost, diversion of in-organic recyclables and other materials, production of Refused Derived Fuel or a combination of these goals. Given the successful implementation of City of Vancouver's SSOs and Recycle BC's Blue Bin recyclable program (see section 4.2 for more details), the amount of organic fraction and recyclables in the Residual Waste is comparatively less to other global jurisdictions. Therefore, the most viable use for MBT is to stabilise the remaining waste and produce RDF.

All MBT options include the recovery of recycled materials during the mechanical sorting process. It is anticipated that ferrous or non-ferrous metals and some recyclable plastics may be recovered as well depending on RDF quality requirements[7].

3.3.2. Production Process of Refused Derived Fuel

MBT can be used to produce RDF by mechanically sorting the Residual Waste by using shredders, trommel screens, manual picking, magnets, eddy current separators and wind shifters. In this process, metals and other non-combustible materials are removed. Biological treatment improves the quality of the RDF by drying the organic portion of the material and provides an opportunity to tailor the RDF characteristics to the fuel specification of the end consumer [5]. The following lists the steps and required equipment for producing RDF [8].

1. **Residual Waste receiving, sampling, hand sorting and bag-opening area**: The MSW arriving in trucks or compactors is unloaded for collection of samples, hand sorting of large components and transported to the bag opening machines.
2. **A twin shaft primary shredder** is designed to shred Residual Waste to less than 100 mm
3. **Drying** process partially dries decayed organics under the sun, either by hot air or by combination of both. This process increases the calorific value of the material while also reducing the mass.
4. A **rotary trommel** is used for size separation which usually happens at two or more stages in the process. It is done by passing the waste through trommel screens, most commonly rolling drums with different mesh sizes. Trommels are attached to the conveyor belts at various stages of processing and are inclined to allow oversize materials to pass along them. The rest of the material is discharged onto the belt conveyor which carries the material for further processing. After the trommel, a belt for hand sorting (separation of recyclables) is placed.
5. **Magnetic separators** are used to remove any metals from the Residual Waste. The device makes use of eddy currents which created a powerful magnetic field to make the separation possible. Eddy current separator is applied to a conveyor belt carrying a layer of mixed waste. At the end of the conveyor belt is an eddy current rotor.
6. **Fans in air separation step** are used to create a column of air moving upwards. Light materials are blown upwards, and dense materials fall. The air carrying light materials, like paper and plastic bags, enters a separator where these items fall out of air stream. The quality of separation in this step depends on the strength of air currents and how

materials are introduced into the column. Moisture content is also critical as water may weigh down some materials or cause them to stick together.

7. **A twin-shaft secondary shredder** is designed to shred the material to less than 50 mm. Components include again a main drive motor, a reduction gear box, other integral components and a starter panel. Thereafter, a fine shredder is designed to reduce the size of the RDF fluff to less than 25mm after it has passed through the secondary shredder.
8. Finally, a **pellet press** (optional) is designed to produce fuel pellets with a 16 – 25 mm diameter by extrusion. Ground and conditioned material are fed to the pellet press by gravity feed. A roller presses the material through die holes and extrudes the material. A knife below the die press can adjust the size of pellets. The pellets are then cooled on a cooling conveyor and sent for storage.

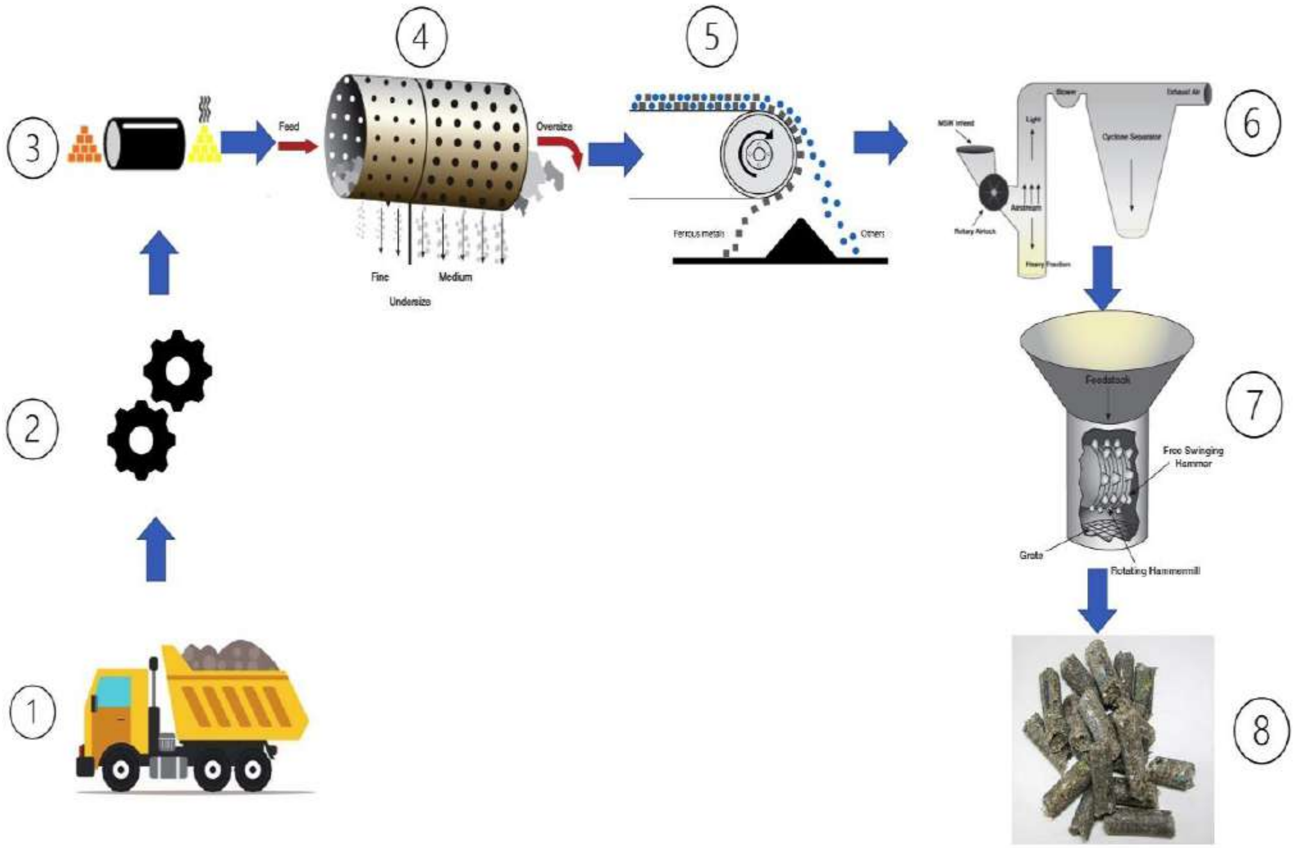

Figure 4. Standard components of an RDF plant

3.4. Required Feedstock Composition

As the purpose of RDF is energy recovery from the waste plastics, textiles, paper and organics from Residual Waste destined for landfill, it is desired that non-combustible contaminants like dirt, fines etc. are minimised so that an acceptable calorific value is achieved. The removal of metals, inerts and wet organic fraction results in a RDF product with higher calorific value. However, there are limitations to maximizing the calorific value such as feedstock waste composition. Furthermore, RDF calorific value is a key factor in meeting customer's quality requirement (moisture and chlorine content are other customer quality requirements) in comparison to MSW and other fuels. Table 2 below provides calorific values of different fuels [7].

Table 2: Calorific value of selected fuels

Fuel Type	**Calorific Value (GJ/tonne)**	
	Net	Gross
Coal	25.6	26.9
RDF	13.0	18.5
Wood	12.3	13.9
MSW	6.7	9.5

Solid Recovered Fuel

Solid Recovered Fuel or SRF are a subset of the larger family of Refused Derived Fuels, produced from non-hazardous waste streams, it differs from a "generic" RDF as it is a fuel that meets requirements defined by international standards. In other words, SRF is a regulated and RDF a non-regulated fuel. The added value of SRF lies in the fact that its characteristics and properties are known. However, this does not necessarily imply that SRF's quality is superior to RDF, but it implies that the quality is known, consistent and defined according to standards [4]. Figure 5 below illustrate the relationship between SRF and RDF.

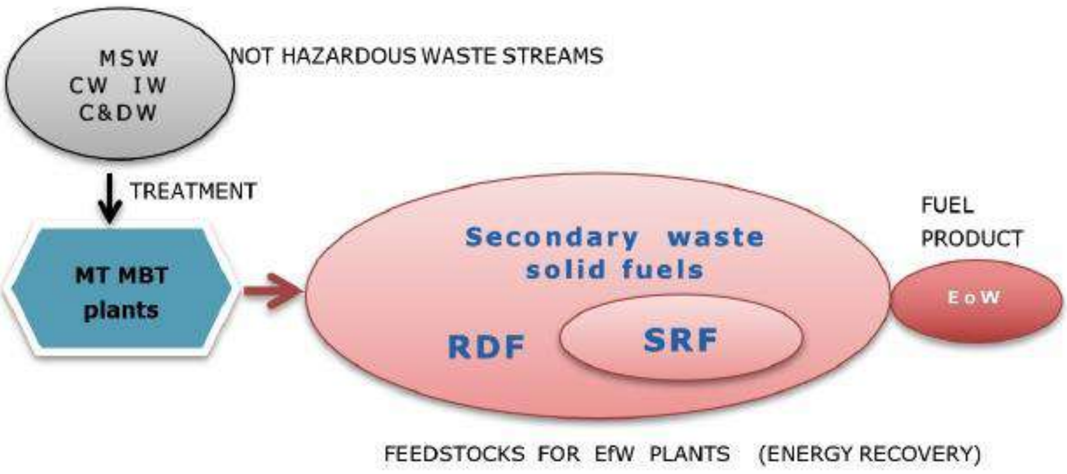

Figure 5. The value chain of energy recovery from wastes [4]

3.5. Case Study on Utilization of Residual Waste through MBT

Germany

Waste to energy plants accounts for a significant portion of electricity, heat and waste process capacity supplied in Germany and other EU countries with developed waste management systems. There have been several legislations and regulations which advocate for the promotion of recycling and other recovery of waste within the continent. Additionally, waste reduction and waste diversion goals are set to minimize the amount of landfilling [9].

Since 2005, municipal solid waste has to be pre-treated prior to landfilling. There are generally two technologies used in Germany for treatment of Residual Waste i.e. Incineration and Mechanical Biological Treatment. In Germany, local municipal bodies own plants with MBT technology, while ownership of Refuse Incineration Plants (RIP) are generally with private companies or as a public private corporation between municipalities and private companies. In Germany, MBT plants have been in operation since past 10 years where the waste treatment goal was originally oriented towards bio-stabilisation of waste before landfilling. However, there is now a paradigm shift towards maximising material and energy recovery in the form of RDF or SRF [9].

Hanover Region

The Hanover region, home to 1.1 million inhabitants in an area covering around 2,300 Km is one of the largest municipality in Germany. The waste management authority carries out the collection of waste and recyclables and runs various waste processing sites such as a composting facility, a MBT plant and three landfill sites as well as street cleaning and winter service for the City of Hanover.

In the Hanover region, approximately 750,000 tonnes of waste is generated per year. After separation of different fractions of recyclables and organic waste around 300,000 tonnes remains as Residual Waste for disposal. The Hanover MBT plant is approved for an annual capacity of 200,000 tonnes of Residual Waste per year [9].

Figure 6. Hanover Waste Treatment Centre. MBT Plant (Background), Composting facility (Centre),Incineration Plant (Front)[9]

Hanover MBT Plant

Mechanical Treatment:

During the mechanical processing step, the waste is conditioned for subsequent treatment steps by simple shredding and screening technologies to segregate waste components into inerts (glass, metals) and combustible fractions that will be converted to RDF.

The Flow Chart in Figure 7 illustrates the waste treatment procedure. Collection vehicle unloads mixed Residual Waste. Grabber places the waste in shredders. Impurities are removed and magnetic separators extract usable ferrous metals. Following the separators, screening drums (mesh size 60mm) separate the high calorific coarse fraction (containing any residuals of paper, wood or plastics) from the fine fraction, which contains most of the organic material suitable for fermentation. On average, a fraction equating to 55 percent are separated from waste input as fine fraction. The high calorific coarse fraction is used thermally in the nearby incineration plant. Further screening (mesh size 15mm) and a subsequent airstream separation is used to divert 15 to 60mm size materials such as stones, glass and sand. The fraction that is less than 15mm goes for fermentation [9].

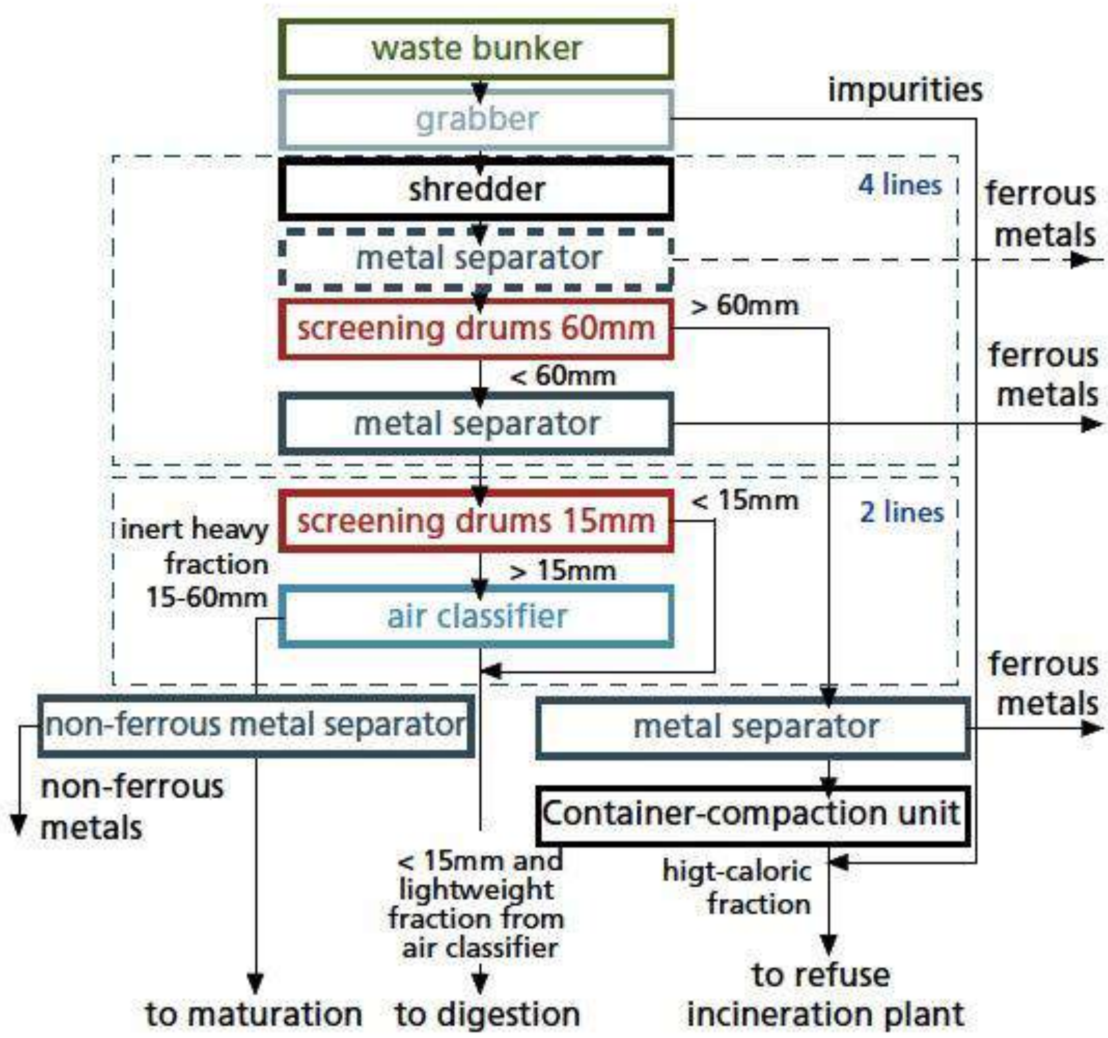

Figure 7. Process flow chart of Mechanical Waste Treatment Facility [9]

Biological Treatment

The organic fraction is further treated in the biological process units. Biological treatment involves three stages: fermentation, aeration and maturation. The light fraction resulting from air separation enters the fermentation process otherwise known as Anaerobic Digestion. Anaerobic Digestion process takes place under mesophilic temperature (35 to 42 C). Biogas produced by the process is released and remaining digestate is further composted under aerobic conditions.

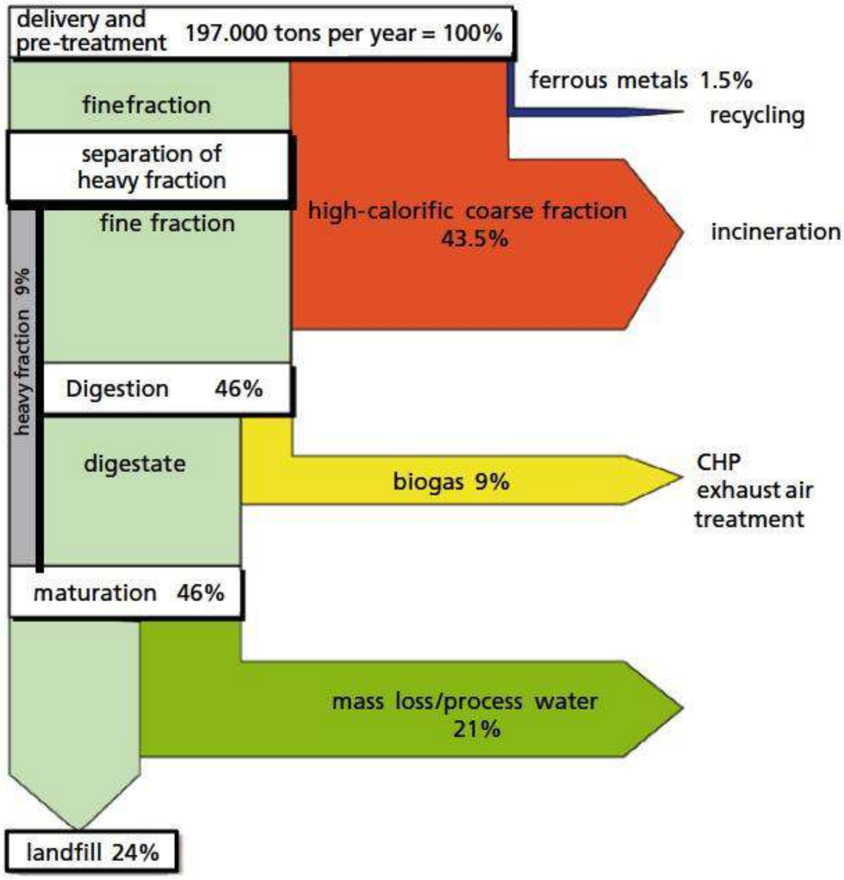

Figure 8. Mass balance of Hanover MBT plant[9]

RDF

Higher calorific value depends on the composition and properties of the content of waste rather than the raw waste mixture. High calorific fractions arise after the first screening usually mesh size of >60mm. This group is enriched with plastics, paper and wood having an energy content usually greater than 11 GJ/ tonne. Figure 8 shows that about 44% of the Residual Waste to Hanover MBT plant can be recovered by simple shredding and screening technology. A promising optimization measure would be to further use the MBT residual output instead of landfilling. Additional RDF could be generated through biological drying and conditioning of the bio-stabilised material. Waste heat from the engine or from exhaust gas of the cogeneration plants could be used for drying purposes of organics matter. Figure 9 shows the process of further preparation of fine fraction <60mm after fermentation and biological stabilisation by drying of the digestate the material is conditioned by screening. This dried organic content can be mixed materials >60mm and used as RDF. Thereafter, only small fraction of heavy mineral particle remains to be landfilled [9].

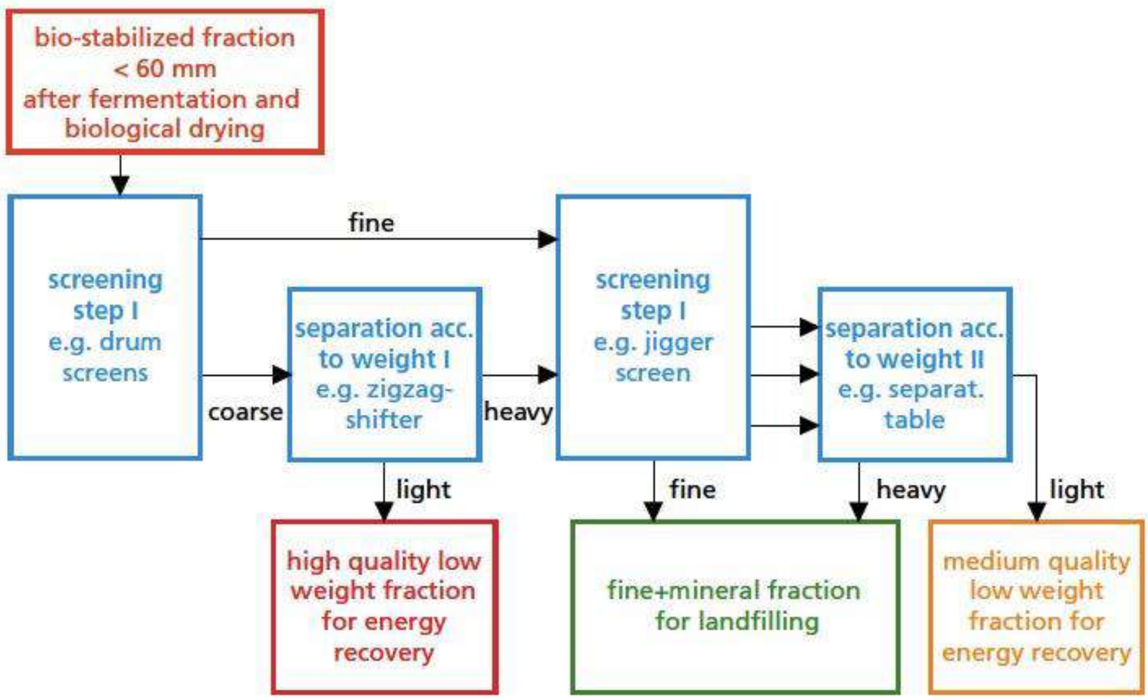

Figure 9. Production of bio-stabilized RDF [9]

3.6. Global Trend of Co-Processing RDF and its Standards

Co-firing coal with biomass and/or RDF has been considered more as a way to decrease reliance on coal and its associated impacts. Co-firing can be achieved via three methods: direct co-firing, parallel co-firing and indirect co-firing. The potential environmental benefits of using RDF and/or biomass as a co-firing fuel in industries are carbon emission reductions and other types of air pollutants reductions owing to their low nitrogen and sulphur content [8].

European Union

Within each member state of the European Union, SRF/ RDF production and its application is more or less established. SRF and RDF are traded like a commodity across borders [8]. A view of the SRF/RDF market in some of the EU countries is described herewith.

Germany

Until 2005, landfilling was an option available for waste disposal in Germany, post which it was banned. However, before setting a ban on landfilling it took Germany more than 10 years from 1993 to 2005 to come up with regulatory framework on recycling and RDF/SRF production. This gave way to other treatment technologies, other than incineration, like Mechanical Biological Treatment (MBT) for the production of SRF or RDF. Driven by commercial and environmental considerations , potential SRF customers such as power plants, steel mills and cement factories accepted SRF as an alternate fuel. During peak time, SRF went as high as 30-50 Euros/ton, current prices hovers around -20 to +20 Euros/ton. The

German government has approved plans to abandon lignite-based power generation, which is another factor in favour of SRF/RDF. By 2008, Germany had replaced 54% of its conventional fuel used in cement industry with RDF [8].

The term SRF in Germany is used for fuel which is specifically made of municipal waste streams that has been treated adequately for being used mainly in co-processing plants. Solid Recovered Fuels that comply with a defined standardized quality – defined by the German RAL-GZ 724 (see Appendix 1, Table A1) – are now protected in Germany by brand names BPG™ and SBS™ [4].

The BPG™ label identifies an SRF produced only from source sorted industrial and commercial waste. Three qualitative categories of BPGTM are defined as BPG 1™ (power plants), BPG 2™ (cement kilns) and BPG 3™ (lime kilns). The SBS™ label identifies an SRF produced from municipal waste streams and from construction and demolition (C&D) wastes. Two qualitative categories of SBS™ are defined as SBS 1™ (lignite power plants) and SBS 2™ (coal power plants and cement kilns). Appendix 1, Table A2 shows the quality requirements set in Germany for these recovered fuels [4].

Poland

Like the German framework, the Polish RDF/SRF market was also driven by the regulatory framework which was complemented by the EU directive after the accession of Poland into European Union in 2004. In Poland, the use of alternative fuel sources for industrial processing experienced a rapid growth in the last two decades making the cement industry the largest contributor to the nation’s waste reduction targets [8]. This trend can be explained mainly by two key factors.

- Increased regulations and taxes on waste management: To conform to relevant European Union directives, Polish waste regulations were steadily enforced since the 1990s (e.g. Waste Framework Directive, Waste Incineration Directive, Landfill Directive). These entailed the multiplication of state taxes on landfilling MSW and a landfilling ban on separately collected combustible waste in 2013 which put increased pressure on waste management companies to invest in alternative solutions. At the same time, subsidies from the European Union and domestic funds facilitated the creation of necessary infrastructure, for instance, implementation of waste shredding lines for RDF production [10].

- Willingness of private sector: Prompted by the new tax regulations, Polish waste management companies extensively invested in co-processing infrastructure. Additionally, the cement industry in Poland actively encouraged waste management companies to develop facilities that treat MSW to produce RDF. In some cases, these investments were shared between cement plants and RDF preparation plants and new partnerships between local entrepreneurs, international companies and investment funds emerged. Long-term contracts between waste management companies and cement industry further ensured planning security, which fostered an investment-friendly environment [10].

The current thermal substitution rate of Poland's cement industry is currently above 60% – with some cement plants using up to 85% alternative fuels – out of which 70-80% is of MSW origin (the remaining alternative fuels are made of tyres and sewage sludge). This rate is far exceeding the global and EU average of RDF use [10, 11]. The cement industry is the largest consumer of processed waste as a fuel in Poland, with nearly 1.5 million tonnes annually, a number which is expected to further increase to 2 million tonnes in the coming years. Itis projected that the cement industry will absorb around one third of the total expected future RDF processing capacity in Poland [11]. To remain competitive, Polish cement plants are investing in new technologies and innovative solutions to further decrease RDF preparation costs and strengthen the use of less-prepared waste [9]. In 2016, an estimated 1 million tonnes of coal was replaced by RDF in Poland's cement production accounting for an emission reduction of 2.5 million tonnes of CO_2 per year [11].

Austria

Co-incineration of plastic-rich SRF has become an important tool in waste management in Austria. Lafarge Austria first began to use alternative fuels in one of its plant in 1996, since then Austrian cement industry has achieved substitution rates of up to 80 % for fossil fuels. The requirements for legal compliance, guarantee of supply, product quality as well as quality assurance (based on the guidelines CEN/TC 343 – Solid Recovered Fuels) are important pre-conditions for the use of SRF in the cement industry [8].

In Austria, the definition of "Waste Fuels" or "Refuse Derived Fuels" (RDF) is given in the legally binding Waste Incineration Ordinance (WIO), 2010. After adequate and extensive pre-treatment in different processing plants and applying strictly defined quality assurance measures, various non-hazardous and/or hazardous waste materials from households, commerce, and industry can be used as RDF in co-incineration plants [4]. The above-mentioned Austrian Ordinance legally sets quality requirements that apply to different uses of a generic solid waste fuel or an SRF. Various values of mandatory limits are reported in Table A3 within Appendix A.

Japan

Japan relies mostly on thermal treatment of MSW (incineration and gasification, 81% of the almost 43 million tonnes MSW generated in 2015) [7].

RDFs produced in Japan from the so called "general waste" includes household and commercial wastes, according to the national legislation on waste. This RDF is dried by adding chemicals and is pelletized which complies with requirements set in a dedicated national standard (NCV >12,500 kJ/kg, moisture content <10% or ash content < 20%) [3]. RDF produced in Japan is essentially intended to be used in urban Waste to Energy WTE facilities, e.g. mainly power generation plants to satisfy the local demand for electricity but other end-users include cement and pulp and paper industries, and district heating facilities.

A further secondary fuel named RPF (Refuse derived Paper and Plastics Densified Fuel), is also produced in Japan. RPF is a pelletized waste fuel produced from dry and non-hazardous paper and plastic waste from industrial origin (residual wood, textile and rubber waste streams are admitted too as long as the standardized fuel quality requirement are met). The national standards, well recognized and applied by all the operators, regulate RPF matter, of which the JIS Z7311:2010 classifies it in four qualitative “classes”. One of them is the so-called RPF-coke which is defined by a high quality RPF with a calorific value >33 MJ/kg (i.e. lower values for moisture and ash content; higher calorific values). The specification of this fuel can be found in Table A4 within Appendix A[3].

3.7. Summary Table

Table 3*:* Literature review findings summary on RDF production

<table>
<tr><th>Types of RDF</th><th>Source</th><th>Composition</th><th>Calorific Value (GJ/ton)</th><th>Manufacturing Technologies</th><th>Standard Components of RDF Plant</th><th colspan="2">Example Plants Operating & Producing RDF</th></tr>
<tr><td rowspan="2">RDF with Organics</td><td rowspan="3">Residual Waste going to Landfills</td><td rowspan="2">• Non-Recyclable Plastics
• Paper
• Textiles
• Dried Organics</td><td rowspan="2">13-15</td><td rowspan="3">Mechanical Biological Treatment</td><td rowspan="3">• Residual Waste Receiving Area
• Twin Shaft Shredder
• Rotary Trommel
• Magnetic Separator
• Air density separator & dryer
• Twin shaft secondary fine shredder
• Pellet Press</td><th>Slovenia</th><th>United Kingdom</th></tr>
<tr><td rowspan="2">Facility Name: Snaga
Location: Ljubjana, Slovenia
Technology Used: MBT
Feedstock: MSW
Annual Capacity: 150,000 Tonnes of Waste per year
Output: 60,000 Tonns of SRF
Biogas into 17,000 MWh of electricity and 36,000 MWh of Heat.
7000 Tonnes of Compost.
Commissioned: 2015
Website: http://www.rcero-ljubljana.eu/</td><td rowspan="2">Facility Name: GMWDA & Viridor Laing.
Location: Bury, United Kingdom
Technology Used: MBT
Feedstock: MSW
Annual Capacity: 1.35 million Tonnes of waste per year.
Output: 275,000 Tonnes of SRF
Commissioned: 2016
Website:https://www.laing.com/what-we-do/sectors/environmental_infrastructure.html</td></tr>
<tr><td>RDF without Organics</td><td>• Non-Recyclable Plastics
• Paper
• Textiles</td><td>13-15</td></tr>
</table>

4. RDF Landscape of City of Vancouver

4.1. City of Vancouver- An Overview

The City's mission statement is to "create a great city of communities that cares about our people, our environment, and our opportunities to live, work, and prosper" [3]. To achieve this mission, the City has created three core City-wide strategies that work together to support people, the environment, and the economy: the Healthy City Strategy, the Greenest City Action Plan (GCAP), and the Economic Development Strategy" [3].

Figure 10. City of Vancouver Zero Waste Strategy Venn Diagram[3]

The City's primary waste management responsibility has traditionally been service delivery including:

- Compostable organics (green bin) and garbage (Residual Waste) collection service, primarily to single family and a minority of other types of properties,
- Collection of litter from parks, streets and sidewalks.
- Public drop-off depots for recycling.
- Communication and education to support diversion programs and litter reduction.
- Waste transfer and disposal services.

- Programs and by-laws for regulating waste collection and disposal.

4.2. Municipal Solid Waste Landscape

In British Columbia, cities, regional governments and provinces are involved in the management and regulation of Municipal Solid Waste (MSW). Vancouver is part of a regional waste system managed by the Metro Vancouver Regional District, under provincial regulation and oversight. Metro Vancouver is responsible for the long term planning and disposal of solid waste generated in the region through plans, policies, bylaws and strategies, and many of Vancouver's solid waste management activities are shaped by what is implemented at the regional level. City of Vancouver works closely with Metro Vancouver on planning, implementation and operations of various regional solid waste policies and programs, as well as with the City of Delta on the Vancouver Landfill's operation and environmental protection systems.

The City owns and operates VSTS, the Zero Waste Centre and VLF, which is located in the City of Delta. VLF receives waste materials from across the Metro Vancouver region.

4.2.1. Methods of Collection, Utilization and Disposal

Vancouver's waste fraction can be broken down into three parts, which are Source Separated Organics, Recyclables and Residual Waste. All these three types of wastes are handled differently as follows:

Organic Waste: Compostable organics waste is collected by the City under the Green Bin Program. Segregation of organic waste is the responsibility of the households. Once segregated, the organic waste is collected and processed into compost through a contract with a private sector facility operator. Metro Vancouver and member municipalities enforce food scraps recycling because it diverts the material from VLF, reduces methane contribution, and creates valuable compost and bioenergy.

The organics disposal ban applies to everyone in the region. Food scraps & yard trimming separation has been made mandatory for residents and businesses in Metro Vancouver since January 2015, this applies to apartments, condos and detached homes. Disposal ban means organics are banned as Residual Waste and a penalty is charged on loads of waste that contain excessive amount of visible food scraps. Waste is inspected when it is delivered to a regional disposal facility and if it contains excessive amount of food scraps, the hauler has to pay a surcharge of 50% on the cost of disposal.

Composting is nature's way of recycling, turning organic waste (like food scraps) into a natural humus, which looks a lot like soil. This process requires natural micro-organisms like fungi, bacteria and oxygen and results in humus, some heat and a small amount of CO_2. Sending food scraps to a composting facility or using a backyard composter allows the natural recycling process to happen, returning nutrients to the soil and helping in mitigation of harmful greenhouse gases [29].

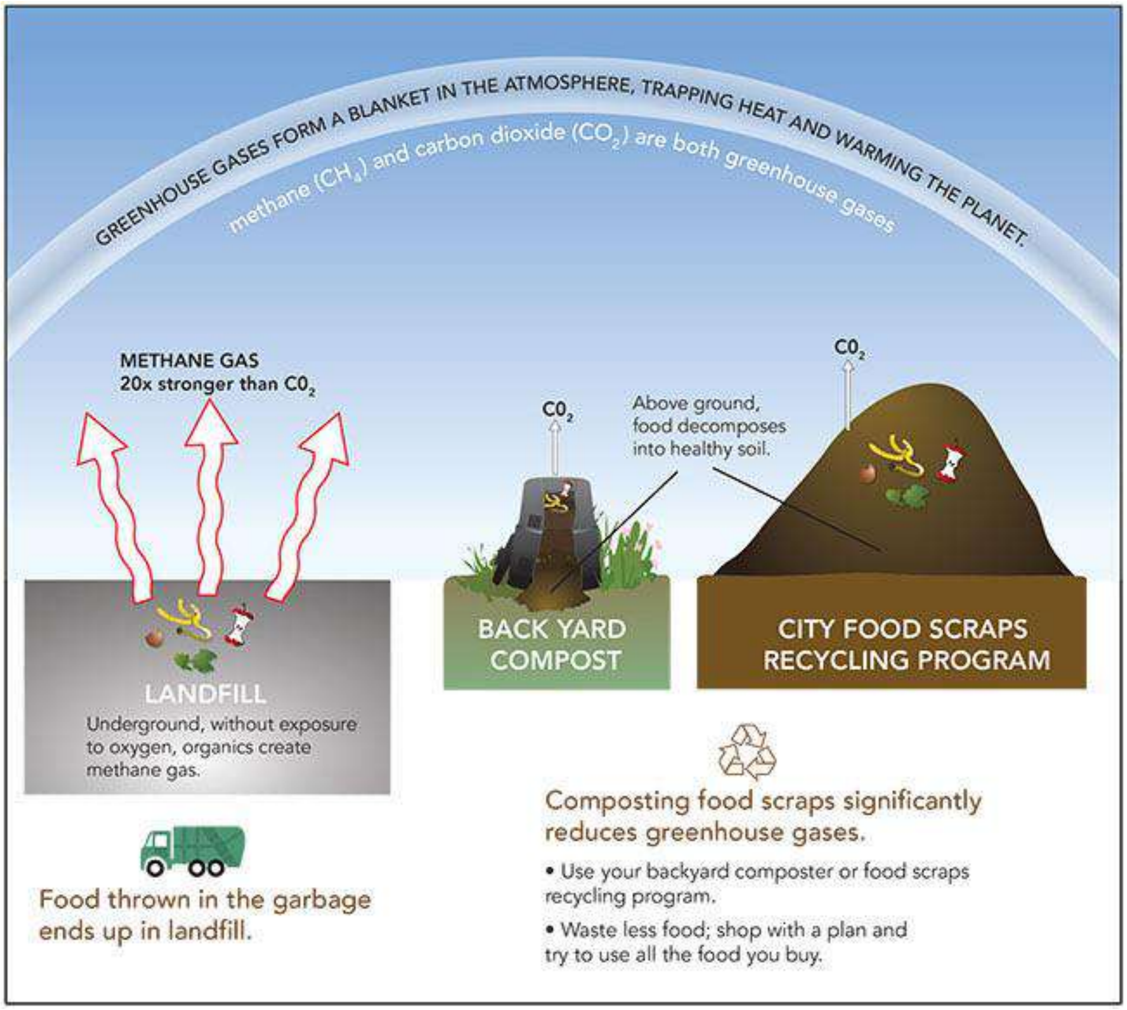

Figure 11. Comparisons between landfilling & composting of organic waste [29]

Recyclable Waste: Collection and processing of Recyclables such as plastics, paper, metals and glass are part of the extended producers responsibility under **Recycle BC** program**.** Recycle BC is a not-for-profit organisation delivering residential recycling service for packaging and paper to 1.87 million households across British Columbia. Initiated in 2014, the Recycle BC program is the only full producer responsibility program for packaging and paper in North America which is fully financed and operated by stewards that supply packaging and paper to residents. As a result of businesses assuming responsibility for recycling services, the cost for delivering residential recycling is shifted from local governments and taxpayers to producers. British Columbia's full producers responsibility model is often recognised as a best-in-class model for efficient and effective management of residential packaging and paper. Recycle BC has consistently achieved its recovery rate, which was 75% for the period of 2014-2019 and 77% beginning in 2020, while growing to provide service to 99% of BC residents [16].

Figure 12. Recycle BC collection summary [16]

Residual Waste: The fraction of waste which is neither composted nor recycled is disposed at VLF located in Delta as well as to the waste to energy plant in Burnaby. The waste constitutes mainly of non-recycle plastics, paper, textile, metals, inerts, non-diverted recyclables and organics. Waste disposed at VLF is either hauled directly, transferred through the VSTS or from one of Metro Vancouver's transfer stations.

4.2.2. Waste Diversion and Disposal

Organic Waste: As per available data, City of Vancouver collected 48,286 Tonnes of organic waste in 2019, under the Green Bin program. This quantity include the yard trimmings and food scraps collected primarily from single family and duplex residential properties. Over the past five year organics waste recovery has been consistent.

Recyclables: In 2020, the total material collection stood at 221,870 tonnes out of which 199,856 tonnes was shipped to recycling end markets. Furthermore, the recovery rate was 85.8%, a significant increase from the 2019 recovery rate of 77.4%. This sharp increase was likely because BC residents were spending more time at home due to Covid 19 pandemic and generated an increased volume of recyclable. The tonnage of material managed by energy recovery as Engineered Fuel was 9,485 tonnes and disposed was 20,987 tonnes [16].

Landfill: In 2020, 654,531 tonnes of Residual Waste was disposed of at VLF. 131,253 tonnes was transferred through the VSTS and 362,573 tonnes was transferred from the regional transfer stations. 11,215 tonnes was also received as non-recyclable residuals from licensed transfer stations and material recovery facilities in the region (known as demo garbage). The following table provides us with the total waste disposed of to the landfill from Metro Vancouver and City of Vancouver.

Table 4: Tonnes of Residual Waste disposed at VLF [17]

Source	2013	2014	2015	2016	2017	2018	2019	2020
Total	607,872	584,742	550,168	693,446	736,405	717,906	721,507	654,531
Vancouver[1]	145,028	134,184	131,465	147,634	129,733	129,093	115,862	111,056

4.2.3. Residual Waste Composition

Metro Vancouver publishes waste composition study reports for the region and City of Vancouver contributes as a partner by coordinating waste audits at VSTS. In 2020, Metro Testing and Engineering Ltd. analysed the waste material composition, estimated disposal rates, quantities of personal protective equipment (PPE) and single use items in each sector [20]. The data is distributed among the following sectors:

- Single family residential waste
- Multi-family residential waste
- Commercial/ institutional waste and
- Small loads waste (formerly known as residential drop off waste)

The study was completed at five facilities in the Metro Vancouver region. Waste samples were taken at the following locations:

- Coquitlam Recycling and Waste Centre (formerly Coquitlam Transfer Station)
- North Surrey Recycling and Waste Centre (formerly Surrey Transfer Station)
- Vancouver South Transfer station
- North Shore Recycling and Waste Centre(formerly North Shore Transfer Station)
- Metro Vancouver Waste to Energy Facility in Burnaby.

[1] From The Vancovuer Landfill Annual Report, Sum of City of Vancouver's residential collections, public works, and private sector commercial hauler

Table 5: Summarised waste composition, Metro Vancouver, 2020

Materials	Combined Average %	Single Family %	Multi Family %	Commercial & Institution %	Small Load %
Paper	14.2	15.4	18	15.2	2.8
Plastic	18.5	26	23.4	14.9	8.4
Compostable Plastic	<0.1	0.1	0.1	0.1	0.1
Compostable Organics	19.8	17	21.5	21.6	15.3
Non Compostable Organics	15.9	7.6	10.7	16.4	36.3
Metal	4.5	5.6	4.2	5.1	2.2
Glass	2.2	2	1.9	2	3.4
Building Material	9.8	7.1	5.4	12.5	15
Electronic Waste	1.9	0.9	2.7	2.4	0.6
Household Hazardous	1.1	1	0.2	2.1	0.5
Household Hygiene	7.9	15.9	10.6	4.4	0.6
Bulky Objects	3.4	0	0.7	2.8	14.8
Fines	0.7	1.5	0.7	0.5	0.1
Total	100	100	100	100	100
Residuals contributing to RDF	**76.4**	**82**	**84.3**	**72.6**	**63.5**

The largest component of the combined results are the compostable organics (19.8%) followed by plastic (18.5%) and non-compostable organics (15.9%). Compostable organics is mainly food waste (12.4% of total waste) of which 6.9% of composition was considered unavoidable food waste and 5.5% was avoidable. Plastic mainly consists of films (6.5%) and synthetic textiles (5.2%). Non -compostable organics is mainly composed of treated and painted wood (12.1%).

Due to Covid-19 pandemic, 2020 waste composition results are not typical when compared to previous years. Therefore, for the purposes of RDF analysis, the 2018 waste composition was considered to be the best representation of Residual Waste composition. In 2018, TRI Environmental Consulting (TRI) presented the waste composition report of Residual Waste in the Metro Vancouver region for Single Family residential waste, multi-family residential waste, Commercial/ Institutional(C/I) waste, Drop-off(DO) or self-haul and streetscape waste.

This study was completed at four (4) facilities in the Metro Vancouver region. Waste samples were taken at VSTS, the Coquitlam Transfer Station (CTS), the Surrey Transfer Station (STS) and the Metro Vancouver Waste to Energy Facility in Burnaby (WTE) [13].

Table 6: Summarised waste composition, Metro Vancouver 2018

Materials	**Combined Average %**	**Single Family %**	**Multi Family %**	**Commercial & Institution %**	**Drop Off %**
Paper	18.1	17.3	21.4	21.6	3
Plastic	16.4	21.6	21.7	14.6	6.4
Compostable Plastic	0.0	0.0	0.0	0.0	0.0
Compostable Organics	26.0	23.1	25.8	32.0	11.9
Non Compostable Organics	16.4	6.6	5.6	15.3	49.7
Metal	3.8	3.1	4.8	3.6	3.8
Glass	2.4	1.9	1.7	1.9	5.4
Building Material	5.6	3.1	1.9	5.2	16.2
Electronic Waste	1.0	1.0	2.0	0.7	0.3
Household Hazardous	0.9	0.8	1.2	1.0	0.2
Household Hygiene	7.4	18.2	11.9	3.0	0.0
Bulky Objects	0.5	0	0.0	0.1	3.2
Fines	1.5	3.2	2.1	0.9	0.0
Total	100	100	100	100	100

Materials	Combined Average %	Single Family %	Multi Family %	Commercial & Institution %	Drop Off %
Residuals contributing to RDF	**84.3**	**86.8**	**86.4**	**86.5**	**71**

In addition to the above study of waste composition within Metro Vancouver, TRI also conducted a waste composition study specifically for City of Vancouver. The report details the data for the waste generated within City of Vancouver. Waste samples were taken at VSTS and VLF [14].

The following sectors were selected for the City of Vancouver waste composition study:

- Single Family residential waste
- Multi-Family residential waste
- Litter cans from street and parks

The above sector samples were sorted into thirteen (13) primary categories.

Table 7: Summarised waste composition, City of Vancouver, 2018

Components	Combined Average %	Single Family %	Multi Family %	Sidewalk Litter Bin %	Park Litter Bin %
Paper	23.315	21.79	19.9	30.07	21.5
Plastic	22.4675	25.66	22.62	15.67	25.92
Compostable Plastic	0.03	0.01	0	0.05	0.06
Compostable Organics	20.9825	20.61	22.2	31.48	9.64
Non Compostable Organics	4.7825	5.54	5.58	2.08	5.93
Metal	2.1075	2.81	2.01	2.19	1.42
Glass	2.1975	1.65	1.21	4.75	1.18
Building Material	1.8375	2.12	0.82	0.39	4.02
Electronic Waste	0.7175	1.1	0.84	0.57	0.36
Household Hazardous	3.0875	1.24	0.7	0.56	9.85
Household Hygiene	14.66	14.64	19.51	8.65	15.84
Bulky Objects	0.005	0.02	0	0	0
Fines	3.675	2.28	4.6	3.54	4.28
Total	100	100	100	100	100
Residuals contributing to RDF	**86.2**	**88.2**	**89.8**	**88.0**	**78.8**

4.3. Residual Waste contributing to RDF

According to the RDF literature review, plastics, papers , organics and textiles are the main fractions of Residual Waste with heat value. Therefore from the above tables the categories contributing towards RDF are:

- Paper
- Plastics

- Compostable Plastics
- Compostable Organics
- Non Compostable Organics
- Household Hygiene

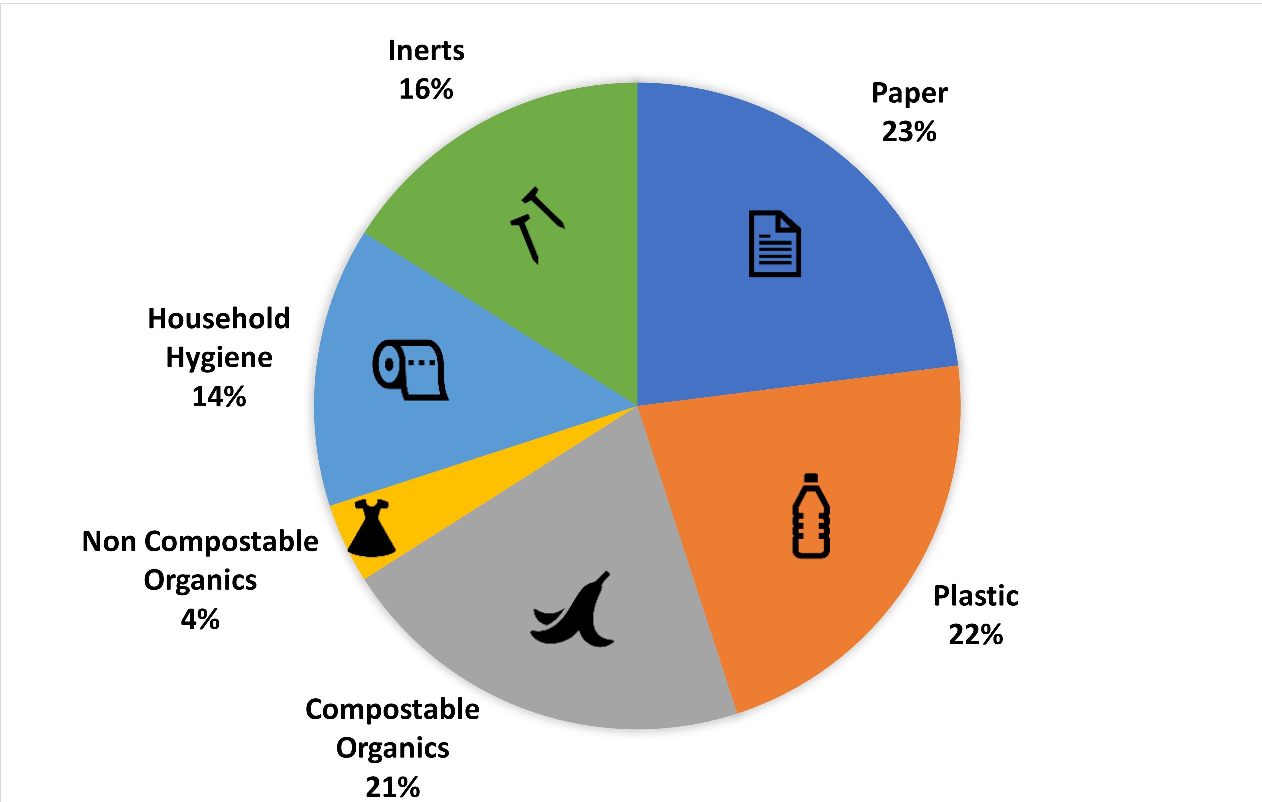

Figure 13. Fractions of Residual Waste and its percentage, 2018 Metro Vancouver

From Table 5, it is found that the combined average percentage of residual waste which will contribute towards RDF is 76.4% whereas for 2018 it is 84.3% (Table 6). Since the 2020 waste composition data is atypical data compared to previous studies, the Metro Vancouver waste composition report of 2015 and 2016 was also analysed and it was found that the potential percentage of Residual Waste materials' contribution to RDF feedstock are 82% and 85% respectively. This proves that 2020's waste composition report doesn't accurately reflect the actual waste composition generated year after year for Metro Vancouver. 2018 City of Vancouver waste composition data specifically illustrated that combined average of materials contributing to RDF production is 86% (Table 7), which is comparable to Metro Vancouver's 84.3% average.

Hence, it is safe to assume that percentage of Residual waste materials contribution towards RDF will be in the range of 82-86%.

According to the MBT process, approximately 55% of the original mass is transferred to RDF. The reduction in tonnage is due to the recovery of some additional metals, removal of inerts and mass reduction through moisture loss in organic degradation. Assuming 82-86% contribution rate from Residual Waste materials and a RDF conversion rate of 55% , the total potential to produce RDF from Vancouver's Residual Waste can approximate to **50,0086**- **52,530 Tonnes per year**.

Calorific Value of RDF

The calorific value of RDF is representative of the Dry Matter amount of different fractions of Residual Waste and total moisture content. Obviously, the lower moisture content amount, the greater RDF thermal energy content. It is assumed that after the bio-drying process, the moisture content in RDF will be less than 20% which cement and pulp and paper industries desire. Moisture can also be reduced by using bulking agents such as pruning waste or sawdust. Through several studies and practical experience, adding bulking agents can significantly improve moisture reduction as well as increase the calorific value of RDF. The various fractions of Residual Waste have different calorific values. The following table shows the calorific value of major waste types which make up the majority of Residual Waste Composition:

Table 8: Expected calorific value of proposed RDF

Components	**Heating Value(GJ/tonne, d.b)**	**Heat Value (GJ/ton) with 20% Moisture**	**% of Waste contributing to RDF from Table 3**	**Calorific Value of RDF (GJ/ton) with 20% moisture**
Plastics	46.5	37.2	22%	8
Paper + Household hygiene	15.8	12.6	37%	4
Organics	21.8	17.4	20%	3
Total				**15**

The above table demonstrates that the average RDF calorific value with 20% moisture will be around 15 GJ/ton. Non-Recyclable Plastics have the highest calorific value followed by organics and papers. Thus, if the percentage of various mentioned materials are increased or decreased in Residual Waste, it will have a proportional effect on the calorific value of RDF. This value of 15GJ/ton has also been vitrified by with industry experts who have experience in utilizing RDF in their plants.

5. RDF Market Analysis

The target markets and industries in this research were constricted to RDF utilization as an alternate fuel. Residual Waste RDF typically has calorific value in the range of 12-15 GJ/tonne when combusted in high temperature furnaces. Therefore, this research focused on the cement, pulp & paper and gasification industries.

To identify key technical, economic and environmental challenges and considerations related to RDF use in these three potential industries, several interviews were conducted with respective industry experts and representatives to accumulate the market analysis findings. Topics below were discussed during the mentioned interviews:

- Current fuel mix composition
- Annual fuel consumption
- Current alternate fuel use
- Maximum RDF substitution rate possible
- Willing to take Residual Waste RDF as an alternate fuel
- Composition, quantity, quality and form of RDF required
- Total operating days per year
- Minimum calorific value needed for manufacturing process
- Future increase in fuel demand
- Price/Tipping fee for RDF
- General concerns about RDF use
- Incentives for cement industry for RDF use as an alternative fuel.

5.1. Cement Industry Profile in BC

The cement manufacturing industry is both energy and carbon intensive. The industry contributes to approximately 5% of global, man-made CO2 emissions. For example, a Canada located dry process cement plant needs roughly 1,600,000 tonnes of raw materials and 150,000 tonnes of fuel (high quality coal) to produce 1,000,000 tonnes of Portland cement clinker per year [18]. As a result, there is great interest amongst governments and the cement plants themselves to look for fossil fuel alternatives in order to respond to climate change challenges.

While governments across North America grapple with taking action to address climate change, British Columbia (BC) is moving in advance of other Canadian jurisdictions in establishing a stringent price for greenhouse gas emissions. The introduction of BC carbon tax is a step towards mitigation of GHGs emissions and tackling climate change. However, this may significantly affect the competitiveness of BC's cement industry negatively compared to global cement industry, and increase imports from other jurisdictions, namely Asia. Under this scenario, when emissions resulting from the transportation of imported cement are taken into account, this will lead to net increases, rather than decreases, in global greenhouse gas emissions. This paves the way to look for alternate fuels such as RDF which can help in offsetting fossil fuels and reduce GHG emissions [19].

Two major Cement companies operating in Western Canada are Lafarge and Lehigh Hanson. Together, they operate four production facilities, Lafarge operate facilities in Richmond, British Columbia and Exshaw, Albera. Lehigh Hanson operate facilities in Delta, British Columbia and Edmonton, Alberta. The total annual energy consumed by these four plants is 6.6 Million GJ/ Year. Currently more than 50% of their energy requirement is met through resources such as Coal and Natural Gas. In terms of proximity, the closest cement facilities to VLF are Lafarge's Richmond plant and Lehigh's Delta plant. The Alberta plants are a bit far from VLF however, both companies are open to taking Residual Waste RDF at Alberta facilities as well.

Table 9: Cement plants and their location in western Canada

Cement Company	Location	Energy Consumption (GJ/year)	Distance from Delta Landfill
Lafarge	Richmond, BC	1.5 Million	15 Km
	Exshaw, AB	2.86 Million	890 Km
Lehigh	Delta, BC	1.2 Million	9 Km
	Edmonton, AB	2.0 Million	1164 Km

In a cement plant, the kiln process consumes close to 90% of the cement manufacturing energy. The remaining 10% is consumed in almost equal amounts by activities related to fuel and raw materials preparation, grinding of clinker and the blending of materials to prepare the finished cement products.

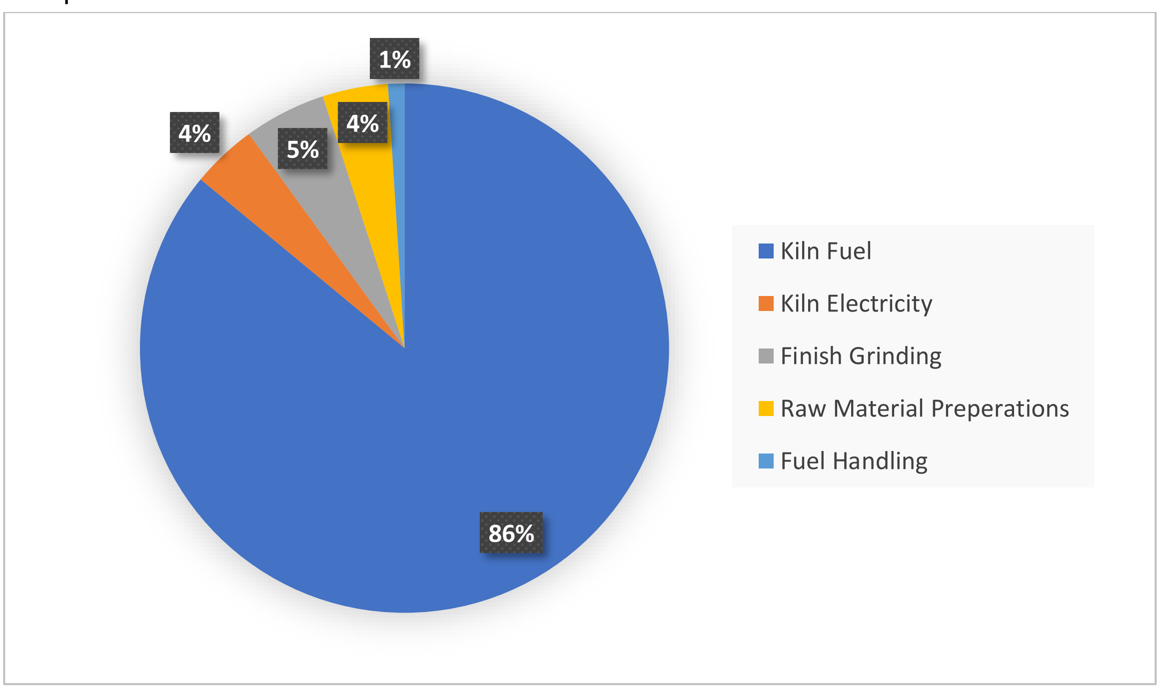

Figure 14. Total energy breakdown of cement manufacturing process.

It is estimated that the sum of these energy inputs is about 39% of the annual operating cost of the cement manufacturing facility, making energy the largest cost component of the cement manufacturing process [18]. The above overview on the energy demand of the cement industry demonstrates that the maximum energy amount is consumed by the kiln process using the thermal energy. Thus, using RDF or alternative fuels in the kiln process have the greatest potential to meet the energy requirements and a great reduction impact in terms of GHG emissions.

5.1.1. Local Market Dynamics - RDF in Cement Industry

Market Size and Growth Potential

Lafarge:

Geocycle, a subsidiary of Lafarge, provides technical expertise and management of alternative fuel selection and procurement for Lafarge cement plants. Lafarge current fuel usage can be classified into two fuel types: conventional fuels such as coal and natural gas; and the other as non-convectional fuels or alternate fuels which are in the form of Asphalt Shingles, non-recyclable plastics, C&D waste, tire RDF, wood dust, carpets and mattresses. The quantification of the fuel required in not based on tonnage basis but on the calorific value basis. Both Lafarge plants are equipped to combust 45-50% of alternate fuels to produce the total energy required for cement production. Richmond and Exshaw plants are currently consuming 60,000 tonnes and 110,000 tonnes of alternate fuel per year respectively. Since the calorific value of alternate fuel is between 12-15GJ /tonne which is approximately half of Coal's calorific value. Thus, fuel requirements for Richmond plant is 1.5 Million GJ/year and 2.86 Million for Exshaw plant. It is important to note that alternative fuel demand for both their plants is already being met through RDF fuels substitute such as wood residue, tire RDF, C&D waste and there are no further expansion plans to increase alternate fuel demand.

Lehigh Hanson:

Lehigh Hanson operates two cement plants in Western Canada, one in Delta, British Columbia and Edmonton, Alberta. Each plant has a nominal cement production capacity of 1.2 Million tonnes per year. The Delta unit is currently equipped to take in alternative fuel in combination of fossil fuels, this fuel mix includes coal, natural gas, tire RDF, mixed waste fuel including non-recyclable plastics, C&D RDF, ICI RDF, sawmill wood waste and residual tire fibre. Whereas, the Edmonton plant does not use any alternate fuels.

At the Delta plant, the substitution rate is around 25% which turns out to be 20,000 Tonne (22%) of mixed waste fuel and 3,500 tonnes (3%) of Tire RDF. There are plans to increase the substitution rate to 35% by 2023, which would require an additional 10,000 tonnes per annum of mixed waste fuel. Moreover, the company plans to reach 50% substitution rate by 2023-2025 at Edmonton plant which increases alternative fuel usage to 80,000 tonnes per year.

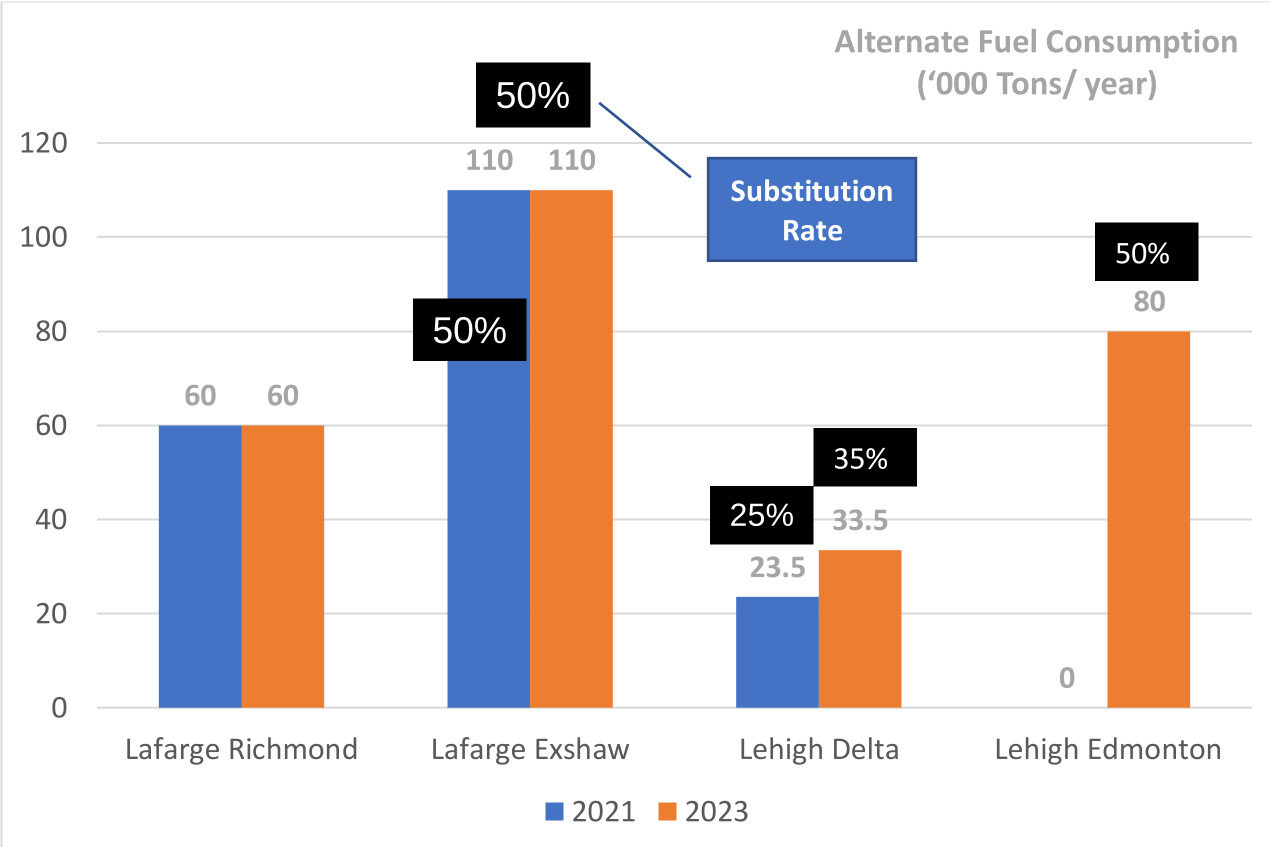

Figure 15. Lafarge & Lehigh substitution rate

Seasonality

On average, cement plants operate 280 days per year. Therefore, appropriate scheduling of alternative fuels supply has to be maintained which includes RDF and other alternative fuels to be stored when plants are not in operation. As RDF manufacturing is a continuous process, Large storage area for RDF needs to be considered. Based on the conducted expert interviews, there are scheduled shutdowns for cement plants which require flexibility in alternative fuel supply and long term storage in case of possible unforeseen shutdowns.

5.1.2. Factor Affecting RDF Buying Criteria

Product Composition and Quality

The main objective of Cement Industries is to produce high quality cement and that cannot be compromised at any cost. The quality of potential combustion of RDF for heat has a direct impact on the cement being manufactured as fuels become the part of the cement clinkers. Therefore, RDF should be free from any above limit contaminants concentrations such as Chlorine which should be in the range of 0.1%-0.15%. This threshold can be increased to 0.5% to 1.1% if Chlorine

Bypass unit is installed which may requires an investment of $10 Million. The moisture level should be kept below 20% as moisture is inversely proportional to the Calorific Value of the fuel. The technical specs for the Alternative Fuels are as follows:

1. Fuel must not be classified "Hazardous Waste" as defined in the Environmental Management Act, Hazardous Waste Regulation (BC Teg. 63/88) [20].
2. Physical and chemical specification (all specification on as received basis) meeting requirements outlined in Table 10.
3. Fuel should not contain PVC plastic.

Table 10: Physical & chemical specifications of alternate fuel in cement plants

Parameters	**Tolerance**	**Notes**
Net Heat Value	>15 GJ/tonne	Also referred to as Low Heat Value
Ash Content	<20%	May depend on chemical composition of ash.
Density	>0.15 loose & <0.20 packed	Guideline Only-expressed as tonnes/m^3
Granulometry (1)	2D: 95%<30mm & 100%<40mm 3D: 95%<0.5mm & 100%<1 mm	For materials<<1 mm thick e.g. film, paper etc, depending on the combustion characteristics.
Granulometry (2)	2D: 95%<15mm & 100%<25mm 3D: 95%<5mm & 100%<10mm	For all other material types

Parameters	Tolerance	Notes
Granulometry (3)	<20% 3D particles, Max 10x10X10 mm	For all material types
Moisture	>5% & <25%	Minimum moisture for control of dust. Guideline only
Sulphur	<1.5%	-
Chlorine	<0.5%	-

It has to be noted that a production penalty would be applied to a supplier if the fuel supplied doesn't meet the required standards. However, the details of the agreements would be negotiated at the time of the final contract.

Calorific Value

Both Lafarge and Lehigh are quite willing to use Residual Waste RDF as an alternative fuel if the calorific value is in the range of 12-15 GJ/tonne. Preference will be given to the RDF supplier that can provide RDF in pellet form. If the supplied RDF has a calorific value of more than 21GJ/ tonne then it can be used in the main burner of the cement plant which increases the current substitution rate of alternate fuel.

Market Price

Both cement companies emphasized that there shall be no payment made for RDF supplied instead, a tipping fee would be applied. This indicates that if the City of Vancouver produce any RDF in the future, the Net Present Value (NPV) of RDF project would be negative since there would be no revenues associated with the sale of RDF. The exact NPV of potential RDF production would be determined during the final agreement between all parties.

5.1.3. Drivers for RDF Use in Cement Industry

Through literature review and interviews conducted, the following drivers were found for RDF usage in cement industry:

- Tipping fee for using RDF will make it a cost negative fuel for the cement plant owners, giving them significant financial benefit as 39% of their operation cost is energy costs.

- As no Carbon Tax is levied on the emission from RDF, there will be an added advantage over consumption of fossil fuel.
- If Residual Waste RDF is determined to be a biogenic fuel, then benefits of carbon credits can also be acquired by the cement plant operators.

5.1.4. Competitive Landscape

Although both the cement companies have shown a positive response to consuming Residual Waste RDF, however it should be noted that their demand for alternative fuel is already being met and there are no shortage of fuels like wood residue, tire RDF and other types of wastes fuels within Metro Vancouver region. One key advantage of these alternate fuels over Residual Waste RDF is that they are homogenous in their composition whereas the composition of Residual Waste RDF is heterogeneous. Therefore, in order for cement plants to consume Residual Waste RDF as an alternative fuel, some financial incentives (tipping fees) will have to provided.

5.1.5. Barriers to Entry

Should City of Vancouver wish to pursue with the production of RDF for cement manufacturing market, some important barriers need to be considered which include but not limited to:

- **Preprocessing**: In order to assure supply and to eliminate fluctuations in availability of RDF, sufficient stockpiles needs to be maintained offsite and should be delivered, as cement plants require. RDF in pellet form is preferred to negate issues with transportation and handling. The produced RDF should also be odor free.
- **Emission and permitting**: Stack emissions from cement kilns are subject to regulatory limits. The RDF would need to be tested to ensure that combustion would meet emission norms. Chlorine and Sulphur content in the RDF are of particular concern for relation to the cement plants.
- **Product quality:** As fuel is co-processed with raw material and becomes part of the cement, it is important to ensure that the structural properties of the cement is not adversely affected by the composition of RDF. Therefore, appropriate RDF specifications will have to developed and test trial will need to be conducted.
- **Fuel consistency:** Since RDF will replace fossil fuels, consistency in the quality of RDF is needed so that the calorific values can be predicted and managed by blending various fuels appropriately.
- **Acceptance by the cement plants:** In the past, cement kiln operators in Canada have been reluctant to use RDF as an alternate fuel because of inconsistency in RDF quality. Cement

plants need to be assured that RDF quality and more importantly its calorific value can be maintained.

5.2. Pulp and Paper Industry Profile in BC

The pulp and paper sector processes as much as 50% of the total volume of timber harvested each year in British Columbia (B.C.) mainly in the form of residual chips, shavings, sawdust and hog fuel. The conversion of these residuals and lower valued fibre into high-valued pulp and paper products results in about $4 billion in sales annually to markets in China, the Unites States, Japan, and other Asian and European countries [21].

The pulp and paper industry is committed to make its facilities globally competitive to grow, sustainable pulp and paper market segments. By leveraging the integrated advantages of the B.C. forest products sector to create low-carbon, fibre-based bio-products and renewable energy solutions from wood residual, the following benefits will be shared throughout British Columbia:

- Economically (funding re-investment, employment and rural community well-being);
- Environmentally (reducing B.C.'s carbon footprint and growing clean power capacity); and
- Socially (becoming a global leader of high-value, fiber-based bio-products).

B.C. currently operates 13 pulp facilities (nine in the interior, four on the coast) and five paper mills (one in the interior, four on the coast). The BC paper and pulp industry has become one of the largest users of clean bioenergy producers from biomass in North America, and a main driver for GHG reduction. It has numerous biomass energy purchase agreements with BC Hydro, and has the capability to expand biomass generation to better utilize fibre and meet the objectives of the B.C. Climate Leadership Plan. P

ulp and paper facilities have the infrastructure and biomass handling capabilities needed to host co-generation and other new technology investments such as bio-products. With these initiatives, the pulp and paper sector working collaboratively with government and others, B.C. can become a leader in the production of low-carbon, sustainable products [21].

5.2.1. Local Market Dynamics – RDF in Pulp and Paper Industry

Market Size and Growth Potential

Over the past two decades, energy demand and production from Canada's pulp and paper industry has fallen significantly. In 1997, annual energy demand from the pulp and paper industry totalled around 415 petajoules (PJ). Pulp and paper industry is ranked first in industrial energy usage at 20% of total industrial energy demand in Canada. By 2017, the energy demand came down to 231 PJ and only 8% of all industrial energy demand. Similarly, in British Columbia the annual energy demand dropped down to 190 PJ in 2018 from 281.5 PJ in 2000. This reduction in demand is the result of decreasing exports along with introduction of efficient manufacturing process within the pulp and paper industry. Moreover, it was found that approximately 90% of energy demand were met by using from Biomass fuels and Electricity (Hydroelectricity in BC); both being renewable energy (Table 11). Looking at the current energy mix, it is evident that majority of the Pulp and Paper mills' energy requirements are met through renewable fuels and thus there is not much market share to be captured by Residual Waste RDF. Along with economic hurdles, there are technical factors to consider, which makes Residual Waste RDF unsuitable to be co-processed with the existing fuels. These factors are discussed further in section 5.2.4 [22].

Table 11: Pulp and paper secondary energy use and GHG emissions [22]

	2000	**2017**	**2018**
Total Pulp and Paper Energy Use (PJ)	281.5	195.4	190.4
Energy Use by Energy Source(PJ)			
Electricity	53	37	35.7
Natural Gas	44.2	26.4	25.5
Diesel Fuel Oil, Light Fuel Oil and Kerosene	-	-	0.5
Heavy Fuel Oil	-	-	0.2
Still Gas and Petroleum Coke	0.0	0.0	0.0
LPG and Gas Plant NGL	0.0	-	0.1
Coal	0.0	0.0	0.0
Coke and Coke oven Gas	0.0	0.0	0.0
Wood Waste and Pulping Liquor	174.4	131.0	128.4
Others	-	0.0	0.0
Share (%)			
Electricity	18.8	18.9	18.7
Natural Gas	15.7	13.5	13.4
Diesel Fuel Oil, Light Fuel Oil and Kerosene	-	-	0.3
Heavy Fuel Oil	-	-	0.1
Still Gas and Petroleum Coke	0.0	0.0	0.0
LPG and Gas Plant NGL	0.0	-	0.0

	2000	2017	2018
Coal	0.0	0.0	0.0
Coke and Coke oven Gas	0.0	0.0	0.0
Wood Waste and Pulping Liquor	62.0	67.1	67.4
Others	-	0.0	0.0
GHG Emissions by Energy Source (Mt to CO2e)			
Electricity	-	-	-
Natural Gas	2.3	1.3	1.3
Diesel Fuel Oil, Light Fuel Oil and Kerosene	-	-	0.0
Heavy Fuel Oil	-	-	0.0
Still Gas and Petroleum Coke	0.0	0.0	0.0
LPG and Gas Plant NGL	0.0	-	0.0
Coal	0.0	0.0	0.0
Coke and Coke oven Gas	0.0	0.0	0.0
Wood Waste and Pulping Liquor	0.1	0.0	0.0
Others	-	0.0	0.0

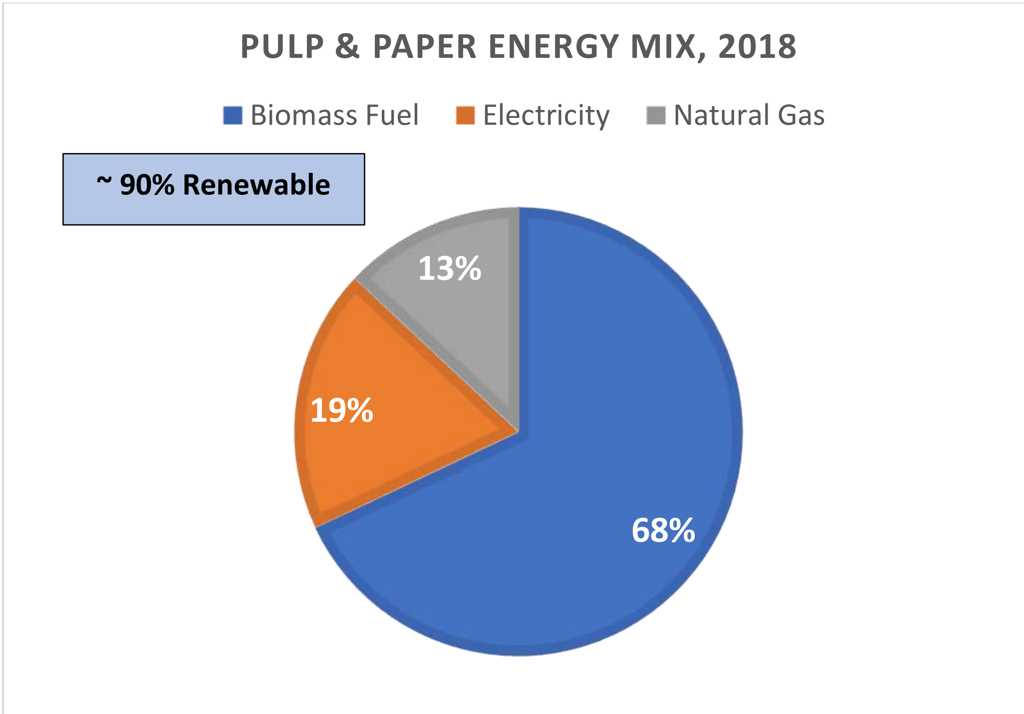

Figure 16. Current energy resource mix of pulp and paper Industry in BC

5.2.2. Feasibility of RDF Utilization in Pulp & Paper Industry

Energy Consumption and Self Sufficiency

On average, pulp mill in BC consumes 300,000 MWH of power per year. However, the industry generates over 70% of its energy requirements from within the pulping process. In addition to satisfying their own energy needs, several mills in BC sell steam or electricity to the grid, residential and commercial use in the province. The BC pulp sector is currently self-generating substantial energy for internal use and many mills in the province have achieved energy self-sufficiency [21].

In 2009, the Government of Canada took decisive action to improve the sustainability of pulp and paper mills by creating a $1-billion Pulp and Paper Green Transformation Program (PPGTP). This program has significantly improved the environmental performance of Canada's pulp and paper industry through record level of investment in green technologies. pulp and paper mills have been transformed, opening up access to new revenue streams from their production of renewable energy while reducing costs through energy efficiency improvements [24]. Under this program, several projects were undertaken to increase the amount of renewable energy generated by recipient mills, including converting fossil fuel boilers to biomass, installing new turbines and /or generators and upgrading recovery boilers. Producing energy supports Canada's goal of becoming a clean energy leader. It also offsets the production of energy from Greenhouse gas (GHG)-intensive fossil fuels by conventional power plants. The types of renewable energy generated by PPGTP projects included thermal and electrical energy from the combustion of biofuels, such as hog fuel and black liquor.

The pulp and paper industry key players have a tremendous social responsibility to take care for the air and the water on which their mills rely upon and they have already made significant improvements towards sustainable of pulp and paper production. As the opportunity for further improvement is small in terms of GHG reduction, it would be not be feasible for pulp and paper mills to utilize RDF.

5.2.3. Drivers for RDF Use in Pulp and Paper Industry

Although it would very difficult to convince the pulp and paper industry to use RDF, however there are some advantages for them to consider Residual Waste RDF as an alternate fuel such as:

- Tipping fee for using RDF will make it a cost negative fuel for the pulp and paper mills, which would give them some financial benefit; however, there would be an initial investment required to the boilers emission control system.
- Pulp and paper mills are constrained by supply of fiber and fuel can benefit from using RDF to meet their energy demands.
- Some pulp and paper mills have installed a gasification unit to gasify wood waste into syngas for electricity production. Gasification is a feedstock agnostic technology which can combust both organic and inorganics material such as RDF to produce Syngas. However, this possibility needs further exploration in terms of conducting trials on conversion of RDF to Syngas and then into electricity.

5.2.4. Barriers to Entry

There are a number of constraints on use of RDF in combustion boilers. The new waste based fuels needs to be of similar type to the design fuel source intended for the boiler. There are issues around calorific value, moisture content and the presence of contaminants. Other barrier for use of RDF in pulp and paper industry are:

- **Captive power plants:** Almost 70% of the requirement of Pulp and paper mill is self-generated through biomass fuels. Moreover, several mills are having surplus wood residues available and they are net exporters of electricity.
- **Boilers not equipped to handle RDF:** Pulp and paper mills mostly use clean homogenous fuels such as bark, sawdust, hog fuel, and other wood residues, therefore their boilers are not equipped to handle plastics or chlorinated organic compounds. Since they use clean fuels, there are no existing systems to control acid or toxic gases, produced by burning plastics.

- **Retrofitting:** If the pulp and papers mills are convinced to use RDF in their energy mix, their air pollution control system would require significant retrofitting in order to handle emissions from RDF. This is an expensive proposition for pulp and paper mills.

5.3. Gasification Industry Profile in BC

Biomass energy generation has been well established in British Columbia, given the abundance of carbonaceous substance such as solid and wood residue present in BC. Biomass technologies are generally considered to be renewable and carbon neutral. This is due to the short processing cycle involved, combined with the generation of carbon through replanting, referred to as biogenic carbon. The most common technology used today is conventional boilers in combustion with steam turbines to generate electricity. The conventional boiler vaporises water to make steam, which is then used to produce electricity through a backpressure, condenser or extraction turbine.

However, gasification is an emerging technology in Canada. The process of gasification breaks down nearly any carbon based feedstock into its basic constituents allowing easy removals of pollutants. It uses heat, pressure and steam to convert materials directly into gas composed of primarily Carbon Monoxide and Hydrogen. Materials that can be gasified include coal, pet coke, heavy oils, chemical wastes, biomass and municipal solid waste. These fuel materials are gasified with a steady rate of oxygen supplied to make synthetic gas or syngas. The Syngas can be transported via a pipeline or oxidised to an adjacent vessel, then utilised directly as heat or converted into steam in a heat exchanger. The steam can then be used to generate electricity via a steam turbine, similar to the conventional boiler technology. Syngas can also be cleaned to the point that it can directly fire a gas turbine or reciprocating engine. This process can also produce feedstocks for high-value chemical products, clean transportation fuels like RNG, LNG and hydrogen for near zero emission power generation [25]

The advantages of gasification plants include simple design, low emissions similar to natural gas, high fuel flexibility, and low operating and maintenance cost. If the gasifier is designed to use syngas directly to fire an engine then it has much lower operating costs.

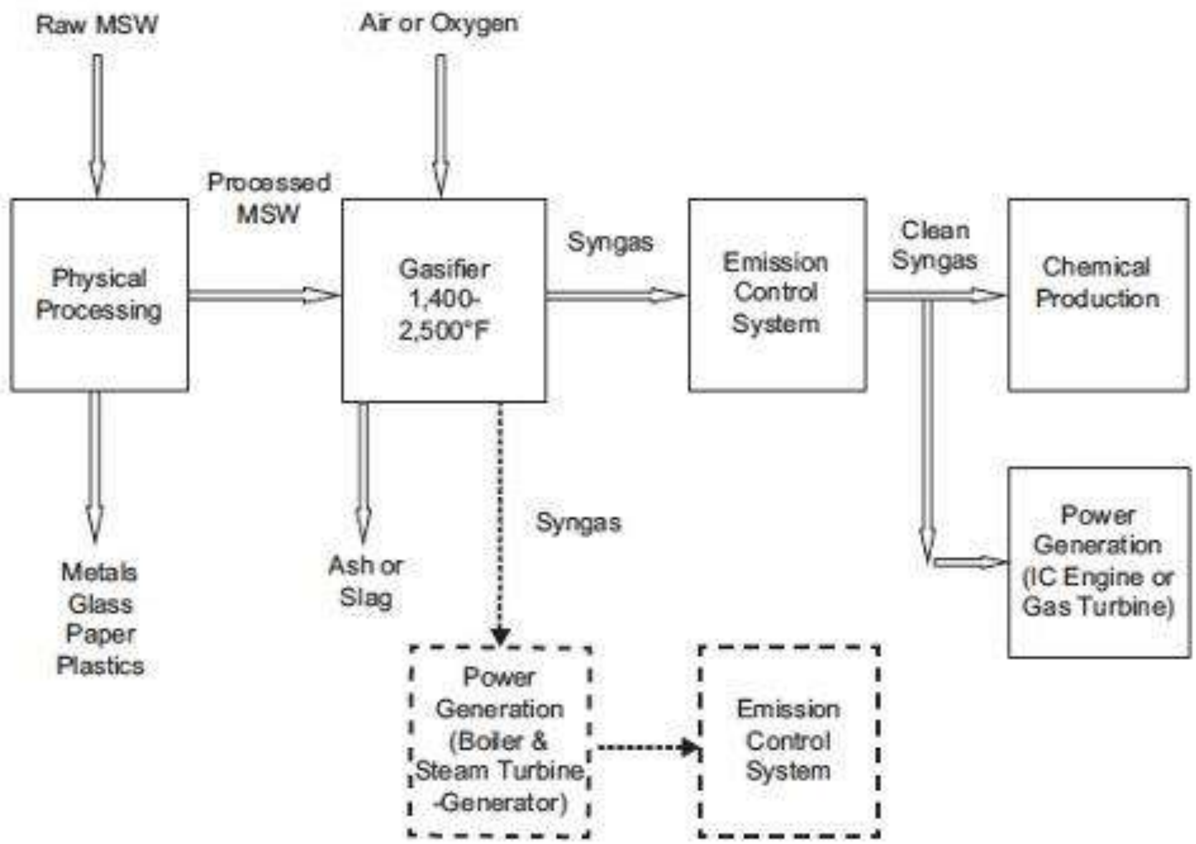

Figure 17: Process flow of a gasification plant for power or chemical production

Syngas to Biofuels Potential in BC

There are estimated 30 million tonnes of forest residues available each year at British Columbia, which can be converted to high value biofuels or chemicals. Additionally, both Federal and Provincial government are looking to reduce GHG emissions which encourages entrepreneurs to setup gasification plants to convert forest wood residues as well as RDF into Syngas and Renewable Natural Gas (RNG). Displacing natural gas in British Columbia will effectively help BC government reach its GHG reduction targets.

Some of the pulp and paper companies in BC have already installed gasification plants to convert wood residue and black liquor (a by-product of Kraft pulping process) into carbon neutral energy products, such as electricity and steam for use in the pulping plant and liquid biofuels.

Some of installed gasification plants in BC are:

- **University of British Columbia**: A renewable waste, mostly wood waste, to energy combined heat and power plant has been installed in UBC, Vancouver campus. The gasification plant combined with an internal combustion engine produces 2 megawatts of clean renewable electricity from syngas and generate 2 megawatts of thermal energy to heat the campus.

- **Kruger Products Paper Mill**: This gasification plant was installed in 2009, which converts locally sourced wood waste into clean burning syngas to produce 40, 000 lbs/ hour of steam that is directly fired into the boiler in place of natural gas.
- **Tolko Industries Plywood Mill**: Located in Kamloops, BC, this gasification plant converts low value wood waste into syngas for natural gas replacement. The plant reduces greenhouse gas emissions at the plant by 12,000 tonnes annually.
- **Dockside Green Residential Development**: Located on the upper Harbour in Victoria, BC, this gasification unit produces heat and hot water for Dockside Green residential and commercial development using locally sourced wood residues [26].

5.3.1. Local Market Dynamics – RDF in Gasification Industry

Based on an interview with Fortis BC's Subject Matter Expert (SME), hydrogen and renewable natural gas (RNG) were found to be most viable products when RDFs are gasified.

Furthermore, the Greenhouse Gas Reduction Regulation (GGRR) of the Clean Energy Act provides set targets to reduce 30% of BC's GHG emissions from 2005 levels by the year 2030 (30by30 goal). Fortis BC has aligned their strategies to achieve this GHG reduction goal and one of the ways they are trying to achieve this is through blending of Natural Gas with RNG by 15%. Fortis BC is exploring possibilities of blending Hydrogen into its pipeline network, that will help them further in reaching the GHG reduction goals. In order to meet these targets, approximately 200 PJ of RNG will be required annually by 2030.

Recently, Fortis BC made agreements with a private project developer, REN Energy for procuring Renewable Natural Gas from wood waste though gasification. It is expected that this facility will produce one million Gigajoules (GJ) of RNG per year from 100,000 tonnes of wood waste. The plant will be built in Fruitville, BC, a prime location in terms of its proximity to sawmill, logging sites and ither wood product manufacturers. two other gasification companies, Bradam and GreenShield, were identified during the interview with Fortis BC's SME which use mixed municipal solid waste feedstock. Green Shield also has a pilot plant which uses mixed municipal solid waste and medical hazardous waste. As the calorific value of RDF is similar to wood residues (13-15GJ/tonnes), it can be co-processed together with wood biomass in gasification plants and will yield similar output. Therefore, if 52,000 tonnes per year of RDF is gasified it has a potential to produce approximately 520,000 GJ of RNG per year.

At present Fortis BC is procuring RNG from project developers at $30/ GJ which is much higher in comparison to natural gas priced at 2.60$/ GJ. This shows BC government's commitment to reduce GHG emissions. It is known that if RDF is consumed in the cement industry, a tipping fee will be charged to the supplier of RDF on account of disposal of Residual Waste. However, the option to convert RDF to RNG could make manufacturing RDF an economically viable solution, If

Fortis BC agrees to accept the produced RNG at an assured price of $30/GJ. Unfortunately, there is some ambiguity in terms of how the various fractions of RDF are construed as biogenic and non-biogenic. The Methane produced through the organic fraction of RDF will be accounted as RNG but Methane produced by gasifying plastics might not be considered RNG but natural gas as it is still derived from a fossil-based resource. This issue needs to be clarified by regulatory authorities as it will affect the economic viability of RDF to RNG.

5.3.2. Drivers for RDF Use in Gasification Industry

In 2018, Fortis BC developed its Clean Growth Pathway to 2050 which outlined actions the company would take to help British Columbia achieve its greenhouse gas (GHG) emissions targets. The pathway is a diversified and flexible approach that supports BC's energy needs and GHG reduction targets which includes fuels like Renewable Natural Gas (RNG), Low carbon hydrogen and synthetic methane developed from biomass and RDF.

As per "Pathways for BC to achieve its GHG Reduction Goals" report prepared by Guidehouse for Fortis BC, by 2050, 73% (136 Peta Joules) of end-use natural gas demand will be served by renewable gases (mix of hydrogen, RNG and synthetic methane)[26]. This proves that Synthetic methane or Methane through gasification technology will play a major role in the renewable gases mix in the future if GHG reduction target are to be met by 2030 and 2050. In the coming years , a growth of numerous gasification plants can be predicted in BC and this will create a demand for RDF utilization in gasification plants.

5.3.3. Barriers to Entry

- **Technology Selection:** To date, the gasification industry has seen mixed levels of both success and failures. Since a lot of new advancement are being made in this space, it is important to find the appropriate gasification technology, which works best for Residual Waste RDF. Pilot trials will be required initially to conduct proof of concept for RDF to RNG conversion.
- **Alternate Feedstock:** There is no shortage of homogenous and consistent feedstock such as wood residue for the gasification plants. Some significant incentives will have to be provided to the project developers to use Residual Waste RDF as a feedstock.
- **RDF to RNG:** As Residual Waste RDF is a new type of fuel for future in gasification plants in Canada, regulatory authorities needs to clarify whether the conversion of RDF's Plastic fraction to methane will be considered RNG or not.

5.4. RDF for Global Markets

Residual waste generation is a burgeoning problem worldwide and nations across the globe are trying to achieve Zero Waste targets and eliminate landfilling, one feasible way of achieving these targets is converting Residual Waste to RDF or SRF. Currently, countries like United Kingdom and Ireland are exporting RDF and SRF to Netherlands and Germany. This is due to lack of facilities to process SRF/ RDF within their jurisdictions and high landfilling taxes in UK and Ireland. United Kingdom exports around 800,000 tonnes of RDF annually to Germany.

If the possibility of RDF exportation is to be considered from BC, it has to be evaluated economically and environmentally (carbon footprint). The nearest export market to Canada is the United States (US). Currently, the cement industry is a leader in US's thermal substitution rate i.e. the use of alternate fuels to meet their energy demands. Thus, RDF can be used to meet this demand in the US. However, as all industries look to RDF as an energy recovery of Residuals, it will lead to tipping fee charges for RDF & other alternative fuel suppliers. Adding the cost of manufacturing RDF, paying a tipping fee and significant transportation costs, the exports of RDF will not be economically viable option. Moreover, one of the main objective of producing RDF from Residual Waste is also to protect our environment from harmful effects of GHGs. Therefore, a complete life cycle analysis from cradle to grave of RDF will be needed to determine GHG emissions and reductions from sinks and reservoirs of exporting RDF.

6. Recommendations and Next Steps

It can be concluded that alternate fuel like RDF can be consumed by the cement industry in British Columbia and Alberta. At present, the alternate fuel demand of cement industry in western Canada is 193,000 tonnes per annum met through wood residue, tire RDF, C&D waste. The two companies operating in western Canada, Lafarge and Lehigh, have already made significant investments in their existing burners to meet the technical requirements for RDF utilization. Thus, RDF produced in the future will be used by cement industry consumers. It has to be noted that other alternative fuels will compete for market share as well. Therefore, a binding long term contract with cement plants for assured offtake of RDF will be beneficial.

The other promising industry where RDF can be consumed is the gasification Industry. gasification is a feed agnostic technology, which can convert both organic and inorganic materials into biofuels such as RNG, a feedstock like RDF, which has both organic and inorganic fractions, is a perfect feedstock for this technology. Project developers and technology partners are encouraged to build gasification plants to produce RNG priced at $30/GJ price. With a demand of 200 PJ of RNG by 2030, wood residues and Residual Waste RDF will play a significant role as suitable feedstocks in the coming years. Additionally, since RDF and Wood Biomass have similar calorific values in the range of 12-15 GJ/tonne, they can be easily co-processed. The market analysis of RDF can be summarised in term of SWOT analysis.

Table 12: SWOT Analysis of RDF

Strength	Opportunity	Weakness	Threat
• RDF is considered as a renewable fuel. • It does not levy BC Carbon Tax. • Proven solution for Residual Waste utilization.	• Demand for RDF from BC Cement Industry • Possibility to convert RDF to RNG	• Quality and consistency of Fuel due to variation in Residual waste fraction. • Meeting the required Calorific Value can be challenging. • Not as homogenous as compared to Wood biomass.	• Alternate fuel consumer demand is currently being met. • Direct RDF substitute fuels are available

Going forward, it is recommended that cement plants should be prioritized for consumption of RDF. Concurrently, an introductory dialogue can be initiated with key players in gasification industry to evaluate their interest in setting up a gasification plant near VLF to utilize the RDF produced from Residual Waste as feedstock. An investment model of public private partnership would be beneficial with a project developer where City of Vancouver would supply RDF while gasification of RDF and the production of RNG can be done by the project developer. Finally, by potentially supplying RDF to both cement and gasification plants in the future, City of Vancouver will be able to achieve the goal of Zero Waste by 2040.

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Appendix 1

Table A 1: German fuel quality standards based on the national RAL-GZ724 Stds [4]. (d: Dry Basis)

Key Parameter	Limit Value(median)	Limit Value	Unit
As	0.31	0.81	mg/MJ, d
Cd	0.25	0.56	mg/MJ, d
Co	0.38	0.75	mg/MJ, d
Cr	7.8	16	mg/MJ, d
Hg	0.038	0.075	mg/MJ, d
Mn	16	31	mg/MJ, d
Ni	5	10	mg/MJ, d
Pb	12	25	mg/MJ, d
Sb	3.1	7.5	mg/MJ, d
Sn	1.9	4.4	mg/MJ, d
Tl	0.063	0.13	mg/MJ, d
V	0.63	1.6	mg/MJ, d

Table A 2 Quality requirements for different SRFs of BPG™ and SBS™

Key Parameters (Unit)	BPG™ 1 Value	BPG™ 2 Value	BPG™ 3 Value	SBS™1 Value	SBS™2 Value
NCV (MJ/kg,ar)	16-20	20-24	23-27	13-18	18-23
Moisture (%ar)	<35	<20	<12.5	<35	<20
Ash (Mg/kg d)	<20	<15	<9	<20	<15
Cl (%,dm)	<1.0	<1.0	<1.0	<0.7	<1.0
F (%,dm)	<0.05	<0.05	<0.05	<0.05	<0.05
S (%,dm)	<0.2	<0.3	<0.3	<0.5	<0.8
As (mg/kg, d)	<10	<10	<10	<10	<10
Be (mg/kg, d)	<1.0	<1.0	<1.0	<1.0	<1.0
Cd (mg/kg, d)	<9.0	<9	<9	<9	<9
Co (mg/kg, d)	<12	<12	<12	<12	<12
Cr (mg/kg, d)	<120	<120	<120	<250	<250
Cu (mg/kg, d)	<400	<400	<400	<1000	<1000
Hg (mg/kg, d)	<0.5	<0.5	<0.5	<1.0	<1.0
Mn (mg/kg, d)	<100	<100	<100	<400	<400
Ni (mg/kg, d)	<50	<50	<50	<50	<50
Pb (mg/kg, d)	<100	<100	<100	<400	<400
Sb (mg/kg, d)	<120	<120	<120	<120	<120
Se (mg/kg, d)	<4	<4	<4	<5	<5
Sn (mg/kg, d)	<70	<70	<70	<70	<70
Te (mg/kg, d)	<4	<4	<4	<5	<5
Tl (mg/kg, d)	<1	<1	<1	<1	<1
V (mg/kg, d)	<15	<15	<15	<25	<25
Feedstock Origin	Residue from paper production rejects, punching, photograph paper, blocks wet strengths paper, cellulose, cloth etc.	Paper Wastes as BPG™ 1, plastics (resins, polyacrylic, polyester, polyolefin), fibre fabrics, carpets, etc.	Low ash plastics resins, polyacrylic, polyester, polyolefin	Different high calorific fractions from MSW demolitions wastes	As SBS™ 1
Customer (end-use)	Power Plants	Cement Kiln	Lime Kiln	Coal(lignite) power plant	Coal (hard coal) power plant cement kilns

Table A 3: End-use-Coal co-combustion in cement kiln & power plant

Key Parameter (mg/MJ, d)	Cement Kiln	Power Plant	
		Limit Value (Proportion of thermal output =< 10%)	Limit Value (Proportion of thermal output =<15%)
Sb (Median)	7	7	7
Sb(80th Perc)	10	10	10
Ab (Median)	2	2	2
Ab(80th Perc)	3	3	3
Pb (Median)	20	23	15
Pb (80th Perc)	36	41	27
Cd (Median)	0.23	0.27	0.17
Cd(80th Perc)	0.46	0.54	0.34
Cr (Median)	25	31	19
Cr(80th Perc)	37	46	28
Co (Median)	1.5	1.4	0.9
Co(80th Perc)	2.7	2.5	1.6
Ni (Median)	10	11	7
Ni (80th Perc)	18	19	12
Hg (Median)	0.075	0.075	0.075
Hg (80th Perc)	0.15	0.15	0.15

These are the key properties and mandatory limit values for waste fuels set in the Austrian legislation (d: dry basis)[4].

Table A 4: Classification system and fuel quality in the Japanese standard JIS Z 7311

Key Parameter	Mean Value RPF-coke	Mean Value RPF class A	Mean Value RPF class B	Mean Value RPF class C	Customer (End-users)
NCV (MJ/kg,ar)	>=33	>=25	>=25	>=25	Coal co-combustion (cement kiln, power plants) Incineration, and Co-incineration
Moisture (%,ar)	=<3	=<5	=<5	=<5	
Ash (%,d)	=<5	=<10	=<10	=<10	
Residual Cl (%, ar)	=<0.6	=<0.3	>0.3 to =<0.6	>0.6 to =<2.0	

These are the requirements of waste derived fuels named RPF (Refuse derived paper and plastics densify ed fuel) and RPF-coke (RPF with coke-level gross calorific value). (ar: as received; d: dry basis) [4].