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DESK STUDY ON THE POTENTIAL AND TECHNICAL REQUIREMENTS FOR UTILISATION OF REFUSE-DERIVED FUEL TECHNOLOGIES & RDF OFF-TAKERS IN INDONESIA: VOLUME 1: FRAMEWORK ANALYSIS FOR RDF DEPLOYMENT AND FINDINGS

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LIST OF ABBREVIATIONS

AF	Alternative Fuels
AFR	Alternative Fuels and Raw Materials
Bappenas	National Development Planning Agency
BSW	Bio-Stabilised Waste
CFB	Circulating Fluidized Bed
CFD	Computational Fluid Dynamic
COPPC	Code of Practice on Pollution Control
ECA	Energy Conservation Act
EF	Ecological Footprint
EIA	Environmental impact assessment
EPMA	Environmental Protection and Management Act
EPR	Extended Producer Responsibility
FIT	Feed-in tariff
GHG	Greenhouse Gas
GM	Gas Microturbines
IED	Industrial Emissions Directive
ITF	Intermediate Treatment Facilities
LCA	Life Cycle Assessment
LHV	Lower Heating Value
MBT	Mechanical and Biological Treatment
MoEF	Ministry of Environment and Forestry
MoPWH	Ministry of Public Works and Human Settlement
MoEMR	Ministry of Energy and Mineral Resources
MRF	Material Recovery Facilities
MSW	Municipal Solid Waste
MT	Mechanical Treatment
NEA	National Environment Agency
NDC	Nationally Determined Contribution
NPAP	National Plastic Action Partnership
PC	Pulverized Coal

LIST OF ABBREVIATIONS

PEF	Processed Engineered Fuel
PET	polyethylene terephthalate
PDU	Pusat Daur Ulang
PLTU	Coal-Fired Power Plant
PM	Particulate Matter
RDF	Refuse-Derived Fuels
RFTF	Recovery Factor Transform Function
ROI	Return On Investment
RPS	Renewable Portfolio Standard
SBI	PT Solusi Bangun Indonesia Tbk
SIIB	PT Semen Indonesia Industri Bangunan
SRF	Solid Recovered Fuels
SUP	Single-Use Plastics
TDF	Tire Derived Fuel
TRL	Technology Readiness Level
TSR	Thermal Substitution Rate
WtE	Waste-to-Energy

Executive Summary

In recent years, the world has witnessed a significant shift towards sustainable and environmentally friendly practices across various sectors. One such area of focus is the development and promotion of alternative energy sources, including the utilisation of refuse-derived fuels (RDFs). RDFs are produced from the processing of municipal solid waste (MSW) and industrial waste, which are otherwise destined for landfills. The conversion of waste into RDF not only helps in reducing the pressure on landfills but also contributes to lower greenhouse gas (GHG) emissions and supports circular economy principles.

Indonesia, being the fourth most populous country in the world, generates a substantial amount of waste daily. As urbanisation continues to accelerate, the need for effective waste management becomes increasingly urgent. The adoption of RDFs in Indonesia offers a promising solution for tackling waste management challenges while addressing the country's growing energy demand.

Indonesia is one of the largest producers of municipal solid waste (MSW) in Southeast Asia, 200,000 Mt of MSW is generated nationwide daily. On average, about 384 large cities in Indonesia generate about 2.2–2.7 kg of MSW per capita daily (Brotosusilo and Handayani, 2020). However, only about 60% of the MSW is collected and disposed of properly, while the rest is dumped in open landfills or burned in the open air. This causes serious environmental and health problems, such as air pollution, water contamination, soil degradation and disease transmission. Therefore, there is a need to develop alternative waste management solutions that may utilise the MSW as a valuable resource.

One of the potential solutions is to establish RDF off taking projects in Indonesia, which involve producing RDF from MSW and supplying it to end users who may use it as a fuel. However, before implementing such projects, it is important to evaluate their feasibility based on various criteria.

Refuse derived fuel (RDF) is a type of solid fuel that is produced from municipal solid waste (MSW) by sorting, shredding, drying and compacting the combustible fraction. RDF can be used as a substitute for fossil fuels in various industrial applications, such as cement kilns, power plants and boilers. RDF has several advantages over conventional fossil fuels, such as reducing greenhouse gas emissions, saving landfill space, creating employment opportunities and generating income from waste.

This desk study aims to explore the potential for Refuse-Derived Fuel (RDF) off takers in Indonesia, focusing on their readiness of various economic sectors for RDF off-taking and explores into investment potential for RDF facilities. It serves as a preliminary examination, providing key elements for developing RDF product standards, and offering recommendations for the technical specifications required for each industry sector.

The Study consists of two phases, the findings of each phase is outlined in two subsequent reports:

- Volume 1: Status Quo Analysis of RDF Technology implementation and Recommendations (first phase)
- Volume 2. Scoping Multi-Criteria Analysis of Potential RDF Utilisation Clusters (second phase)

Informed by international experiences, this study examines the role of financing and incentive systems, advocating for their development to support RDF activities. It discusses essential aspects, including environmental considerations, social aspect as well as economic aspects such as the role of waste collection fees, transportation costs, the manufacturing and processing of RDF production equipment, and the assurance of maintaining quality standards for RDFs.

This initial review aims to promote awareness and education regarding RDF, establish suggestions for a conducive policy and regulatory framework, propose investments in infrastructure development, encourage research and development, outline financial incentives and thus provide a basis to support, monitor and evaluate RDF projects.

The first phase concluded with a workshop on a Focus Group Discussion on the Potential and Technical Requirements of Refuse Derived Fuels in Indonesia which was held in Jakarta on 22 May 2023 in Jakarta which provided a set of recommendations focussing on awareness, the policy regulatory framework, infrastructure development, R&D, financial incentives and support, monitoring and evaluation and stakeholder engagement and partnerships.

In the second phase, potential off-taker industry outreach was organised, and the demand for RDF utilisation was assessed based on stakeholder interviews with industrial associations in Indonesia, and with the support of a survey of their respective members. In addition, available information was collected regarding various landfills as a screening phase for potential project development. A comprehensive multicriteria analysis was carried out to provide recommendations on priority locations for RDF from a perspective for potential offtake and suitability for RDF facility installations. This extensive evaluation clearly mapped f the potential distribution of industries that could become RDF customers, analysing potential RDF facilities and their proximity to potential off-takers.

Ultimately, the findings from both phases will paint a comprehensive picture of the readiness for RDF off-taking in the Indonesian industrial sector, guiding decisions on whether and how to proceed with RDF production and use. This guideline aims to provide a comprehensive framework for evaluating urban investment projects that focus on the use of RDFs in Indonesia. It is designed to help stakeholders, including policymakers, lenders, and project developers, to assess the feasibility, economic viability, and environmental benefits of RDF-based projects.

The successful implementation of RDF-based projects leads to significant economic and environmental benefits, such as reduced dependency on fossil fuels, lower GHG emissions, job creation, and improved waste management practices. This, in turn, will contribute to Indonesia's transition towards a circular economy and the achievement of its national and international sustainability goals.

Technical feasibility: the following is to be considered:

- The quality and quantity of the MSW available for RDF production. The MSW should have a high calorific value, low moisture content and low inert materials (such as metals, glass and ceramics) to ensure efficient RDF production.
- The location and capacity of the RDF production facility. The facility should be located near the source of MSW and have enough space and equipment to sort, shred, dry and compact

the MSW into RDF. Currently study applies 80 km radius to define a supply – demand cluster, following the methodology of ADB studies on RDF in Indonesia.

- The transportation mode and distance of RDF delivery. The RDF should be transported in a safe and cost-effective way to the end users. The transportation mode can be by road, (short distance) rail or sea/inland depending on the distance and infrastructure availability. This analysis needs to be implemented at the feasibility stage of a project development.
- The compatibility and performance of RDF with the end users' equipment. The RDF should meet the specifications and requirements of the end users' equipment, such as size, shape, moisture content, ash content and calorific value, as well as applicable industrial policies and regulations. The RDF should also have a consistent quality and supply to ensure reliable operation.

Economic feasibility: This criterion refers to the financial viability and profitability of the RDF off taking project. The following should be considered at the pre-feasibility and feasibility stages of a project cycle:

- The capital cost and operating cost of the RDF production facility. The capital cost includes the cost of land acquisition, construction, equipment installation and commissioning. The operating cost includes the cost of labor, maintenance, utilities, taxes and fees.
- The revenue and profit margin of the RDF off taking project. The revenue depends on the price and quantity of RDF sold to the end users. The profit margin depends on the difference between the revenue and the total cost.
- The payback period and return on investment (ROI) of the RDF off taking project. The payback period is the time required to recover the initial investment from the net cash flow. The ROI is the ratio of net profit to initial investment.
- Support from the government, such as national budget contribution, could be a consideration as well.

Environmental feasibility: This criterion refers to the environmental impact and benefit of the RDF off taking project. Some of the factors that should be considered are:

- The greenhouse gas emission reduction potential of the RDF off taking project. The RDF off taking project can reduce greenhouse gas emissions by diverting MSW from landfills or open burning and replacing fossil fuels with renewable fuels.
- The air quality improvement potential of the RDF off taking project. The RDF off taking project can improve air quality by reducing particulate matter (PM), sulphur dioxide (SO2), nitrogen oxides (NOx) and other pollutants emitted from landfills or open burning and fossil fuel combustion.
- The waste management improvement potential of the RDF off taking project. The RDF off taking project can improve waste management by reducing the volume and weight of MSW disposed in landfills or burned in open air and increasing the recycling rate of MSW.

Social feasibility: This criterion refers to the social impact and acceptance of the RDF off taking project. The following should be considered:

- The job creation potential of the RDF off taking project. The RDF off taking project can create direct and indirect jobs for local communities in various stages of RDF production and delivery.
- The income generation potential of the RDF off taking project. The RDF off taking project can generate income for local communities by selling MSW or RDF to producers.
- Improvement of quality of life and reduction in social displacement for people dependent from landfill informal economy.

In conclusion the first phase of this desk study indicated that:

- While RDF can help address municipal waste issues, it alone cannot solve the problem of plastic pollution and municipal waste residues. Burning RDF turns plastic pollution into airborne pollution. Without robust air pollution control measures, promoting RDF use on any scale may increase public health and environmental risks.
- RDF, particularly from organic waste, is one solution to municipal waste problems. When properly processed, high-calorific-value alternative fuels can be derived from waste or mixed waste residues. However, the production of RDF, whether from biomass or mixed waste, requires off-takers.
- In Indonesia, currently, only cement kilns are considered reliable off-takers and are regulated. Co-firing on coal fire plan industry is regulated not to exceed 5% in view of possible adverse effects on used boilers. Despite the existence of voluntary national standards for RDF biopellets and briquettes in these industries, co-firing and co-processing may still pose problems.
- Using RDF in industrial boilers and SMEs is not advised, as toxic emissions and bottom ash can create and spread new forms of toxic waste in communities. Siting criteria for MRFs combined with RDF production facilities are lacking.
- The current requirement under Minister of Environment and Forestry Regulation No.19 of 2017 mandates monitoring dioxin (PCDDs/PCDFs) emissions from cement kilns using mixed waste as alternative fuels once every four years. This regulation should be revised to necessitate annual monitoring instead. This provision specifically pertains to cement plants utilizing 100% RDF, as outlined in the attachment to the regulation. However, following discussions between the Indonesian Cement Association and the Ministry of Environment and Forestry in 2023, it was concluded that this regulation cannot be enforced due to the impracticality of cement plants achieving 100% RDF usage. For cement plants employing fuel mixtures, emission quality standards are determined by the Environmental Permit granted to each plant.
- Technologies and machinery for RDF production should be reviewed, and their technology readiness levels (TRLs) evaluated. Only proven technology (TRL 9) should be allowed for sale in the market.
- The primary goal of producing RDFs is to address municipal waste management issues. The same capital expenditures for RDF investment could be allocated to improve waste management systems and city landfills, and in recycling.
- The Focus Group Discussion on the Potential and Technical Requirements of Refuse Derived Fuels in Indonesia which was held in Jakarta in May 2023 in Jakarta, provided

for a set of recommendation for further steps on how to integrate RDF production into the overall waste management system of Indonesia.

- Industry interviews and stakeholder survey took place in October and November 2023 and served the basis for the second phase of this study (see volume 2).

Awareness and education:

- Develop and implement public awareness campaigns to educate the general population about the benefits and potential of refuse derived fuels (RDF).

Policy and regulatory framework:

- Establish clear policies and regulations that promote the production and utilisation of RDF in Indonesia, including incentives and support mechanisms for businesses and organisations involved in RDF production.
- Collaborate with relevant ministries and government agencies to develop comprehensive waste management policies that prioritise RDF as once of a sustainable alternative to traditional waste disposal methods.
- Ensure that the legal framework addresses environmental concerns, such as emissions standards and air pollution control measures, to ensure the safe and sustainable use of RDF.

Infrastructure development:

- Invest in the development of modern waste-to-energy facilities and RDF production plants, utilizing advanced technologies to maximise energy recovery from waste.
- Encourage public-private partnerships to facilitate the construction and operation of RDF facilities, leveraging private sector expertise and resources.
- Improve waste collection and segregation systems to ensure a steady supply of suitable waste materials for RDF production.

Research and development:

- Foster collaboration between research institutions, industry stakeholders, and government agencies to promote knowledge sharing and the development of innovative RDF solutions.

Financial incentives and support:

- Establish funding mechanisms and support programs to assist smaller enterprises and community-based initiatives in adopting RDF technologies.
- Explore opportunities for international cooperation and access to climate finance mechanisms to support RDF projects in Indonesia.

Monitoring and evaluation:

- Develop a robust monitoring and evaluation framework to assess the environmental, social, and economic impacts of RDF projects.
- Regularly monitor emissions and air quality to ensure compliance with environmental standards.

- Conduct periodic assessments of RDF projects to evaluate their efficiency, effectiveness, and contribution to waste management and renewable energy goals.

Stakeholder engagement and partnerships:

- Foster collaboration between the government, private sector, local communities, and NGOs to promote the sustainable production and utilisation of RDF.
- Encourage partnerships between waste management companies, energy producers, and other relevant stakeholders to establish integrated waste management systems that incorporate RDF as a valuable resource.
- Involve local communities in decision-making processes and engage them in the planning and implementation of RDF projects, ensuring their concerns and interests are addressed.

Introduction

This note outlines the potential use of Refuse Derived Fuels (RDF) in the Indonesian context and seeks to both outline the potential as well as and technical requirements for the utilisation of RDF by various industrial sectors in Indonesia. Information on the current potential of these practices across Indonesia as well as on potential policies to promote the production and use of RDFs and respective regulatory suggestions are made in this note.

Increasing population and changing consumption patterns have led to a rise in municipal solid waste volume, types, and characteristics in Indonesia. Current waste management practices are not in line with environmentally sound methods and techniques, causing negative impacts on public health and the environment. Solid waste has become a national issue, and waste management must be comprehensive and integrated to provide economic benefits, a healthy society, a safe environment, and behavioural changes. To reduce landfill waste, the government considers waste-to-energy initiatives, such as processing waste into RDF as an alternative fuel.

Municipal solid waste in Indonesia has a high potential to be used as an alternative energy source. Already high calorific fractions from processed municipal solid waste and industrial wastes are being used both in dedicated energy-to-waste plants and as fuel substitutes in industrial processes in Indonesia. The Refuse Derived Fuel Technology is viewed by the Indonesian Government as a cornerstone in its efforts to reduce greenhouse gas emissions, and thus contributing to the Zero Emission Target and the NDCs.

The Indonesian government has enacted several waste management regulations to address these issues, which focus on the acceleration of waste-to-energy projects based on environmentally friendly technology. The government and relevant stakeholders continue to consider technology selection for the best value for money and government benefit, including RDF technologies.

PT Sarana Multi Infrastruktur (PT SMI), as a special mission vehicle of the Ministry of Finance, accelerates infrastructure development and receives assignments related to project development in various sectors, including municipal solid waste, as part of its engagement to develop financing products and project preparation activities for new sectors such as solid waste. With this note, PT SMI intends to provide additional information for an intersectoral assessment on the use of RDF technologies to further the decision-making process with Indonesian ministries, municipalities and the private sector.

PT SMI and KfW signed a Grant Agreement to implement a program Support for Infrastructure Investment in Indonesia (S4I) on December 2nd, 2020 funded by the EU. The purpose of the S4I programme is support development of sustainable urban infrastructure, and renewable energies. This fits into the S4I framework, as it addresses the municipal waste problem through analysing the potential off-taker of RDF in order to encourage using RDF as one of solution to solve waste problem in Indonesia and to prepare and facilitate future projects in municipal infrastructure and renewable energy facilitation of Indonesia ‘s SDGs fulfilment.

1. Scope of This Analysis

1.1 Long-Term Objectives

An integrative analysis has been carried out to synthesise the state-of-the-art of RDF strategies in Indonesia, a country faced with challenges such as reducing the share of fossil energy and the volume of waste, intending to:

- Outline the opportunities, complexities and risks related to the use of RDF.
- Indicate potential environmental impacts as well as the economic aspects of RDF use.
- Provide suggestions for the participation of Indonesian industrial-, municipal-, and academic structures in developing the RDF.
- Provides a set of criteria that would allow stakeholders to evaluate the feasibility of potential off taking projects in Indonesia, and
- Present a set of conclusions and recommendations.

1.2 Short-Term Objectives

The objective of the assignment is to provide an early analysis of the potential of selected economic sectors to act as offtakes of RDF from municipal solid waste facilities in Indonesia in order to minimise the dumping to landfills, to minimise pollution, and to reduce greenhouse gas emissions. The assignment:

- Provides an overview about the current practices of production and use of refuse derived fuel (RDF) in Indonesia, considering the current legal and policy framework of RDF production and use.
- Outlines the opportunities, complexities and risks related to the use of RDF, providing benchmark inputs for screening, and assessing investment projects using RDF technology-
- Indicate both potential environmental impacts as well as economic aspects of RDF use including suggestions for investments into alternative outlets for RDF.
- Provide suggestions for the participation of Indonesian industrial-, municipal-, and academic structures in developing further the off-take of RDF, and
- Formulate a set of recommendations on how to relate the use of RDF to wider environmental objectives such as the limitation of greenhouse gases and to the concept of circular economy.

It is assumed that the assignment be followed up by additional studies on technical, economical, and financial needs to become part of a comprehensive national waste-to-RDF process, based on an in-depth understanding to critical supply aspects as a basis for defining the potential demand for RDF off-takers, including the technical demand limitations by the respective off-taking sectors.

2. Aim of the Analysis

A set of recommendations on RDF technologies for the Indonesian MoEF addresses key aspects to ensure that the RDF technologies have been formulated as a result of this study, which are appropriate, cost-effective, and environmentally sound. Some of the key aspects that were addressed include:

- **Waste Characterisations:** An analysis of the composition and quality of the solid waste stream in Indonesia, including information on the types and quantities of waste generated, and the potential for RDF production.
- **RDF technologies:** An analysis of the different RDF technologies that are currently available, including information on the process, equipment, and costs of each technology, as well as the environmental and social impacts of each technology.
- **RDF off taking sectors:** An analysis of which sectors can act as RDF off including information on the technical requirements and capacity of those sector, gaps or challenges and required technological modifications needed by those sectors.
- **Regulations and policies:** A review of the current national and local regulations and policies related to RDF in Indonesia, including information on permits, standards, and compliance requirements.
- **International comparison:** A comparison of RDF production and use in other countries, including information on best practices and lessons learned. and
- **Future trends and projections:** An analysis of future trends and projections for RDF production and use, including information on expected growth and potential challenges.

3. Context

As a form of commitment to the world in combating climate change, on 23 September 2022 the Indonesian government presented a document on the Extended Nationally Determined Contribution (NDC), which includes a target to reduce greenhouse gas emissions in the waste sector by 2030, namely the reduction of greenhouse gas emissions (GHG) by 40 Mt CO2eq in CM1 and 43,5 million tons of CO2eq at CM2. To reduce greenhouse gas emissions from the waste sector, especially for solid household waste (waste), various mitigation efforts are needed to reduce the generation of waste stored in landfills by optimizing waste processing facilities, including waste-to-discharged fuel (RDF) processing facilities.

RDF is a type of fuel produced from the organic fraction of municipal solid waste (MSW) that cannot be recycled or composted. It is created by shredding and drying the waste, and then processing it to remove any non-combustible materials. The resulting product is a high-calorific fuel that are used in various industrial applications, including cement kilns and power plants. RDF is a sustainable and cost-effective alternative to fossil fuels, as it reduces the dependence on non-renewable resources and diverts waste from landfills.

Primary energy consumption and demographic growth, i.e. population- plus industrial growth with massive urbanisation, as seen in parts of Indonesia are among major contributors to greenhouse gas (GHG) emissions and deterioration of ecosystem services. Traditionally, Indonesia uses conventional thermoelectric power plants to produce energy with associated financial and environmental costs).

Indonesia is undergoing a process of rapid urbanisation that will be one of the key drivers that shape its economic prospects and will also put heavy pressure on the provision of basic services and infrastructure. Despite their importance in future economic development, urban areas have suffered from an “infrastructure gap” with severe under-investment overall.

Solid waste management is increasingly being viewed as critical for the rapidly developing Indonesian economy, even for the solid waste that is collected by formal systems, the consequences of widespread open dumping and unsanitary landfills has been acknowledged. Concerns about Indonesia's solid waste management are increasingly high on the national agenda and subsequently Indonesian governments have made commitments to improve performance. Solid waste management has been included as the third most important sector in Indonesia's Nationally Determined Contribution (INDC) prepared for the 2015 Paris Climate Change Conference.

Despite not being the primary implementers, the national government's advisory and regulatory roles of sub-national governments are critical to realizing improved sector performance. The role of the Indonesian Ministry of Public Works and Housing is limited to providing technical advice, promoting pilot projects, and supervising large-scale off-site solid waste facilities. The Ministry of Environment and Forestry of Indonesia has an important responsibility for developing policies, formulating regulations, and coordinating efforts in pollution control.

Funds allocated by local governments generally have been critically insufficient for both investment and operational costs. Also, synchronizing the various Indonesian Ministry's Programs would make respective initiative more successful.

Municipal solid waste in Indonesia has a potential to be used as an alternative energy source. One of the methods is by producing refuse-derived fuel (RDF) as coal substitution.

Waste-to-energy (WtE) technology is a waste treatment that converts waste into alternative fuels to produce energy. Waste-to-energy transforms waste into energy or raw materials that are more beneficial, environmentally friendly and significantly reduce waste volume. It is considered to solve waste problems quickly while at the same time producing energy resources to achieve a reduction in greenhouse gas emissions. Most waste-to-energy technologies require some method of waste processing to maximise the performance and potential of energy generation. Therefore, the majority of waste-to-energy facilities are located near a material recovery facility or landfill.

The biggest obstacles of municipal solid waste-to-energy treatment are the high-water content, heterogeneous shapes and sizes, and the mixed conditions of organic waste, plastic waste, and other materials in waste that made them difficult to be sorted. Direct utilisation of waste in thermal installations such as incineration is hard to apply because of this high-water content condition as municipal solid waste in Indonesia has high-water content characteristics – above 50%, requiring a pre-treatment method to reduce its water content before being processed to produce energy.

Already high calorific fractions from processed municipal solid waste and industrial wastes are being used both in dedicated energy-to-waste plants and as fuel substitutes in industrial processes in Indonesia. There is no detailed information on the current scale of these practices across Indonesia. There is also a need for environmental assessment information about these practices - the economics driving the production and utilisation of RDF need also to be better understood.

3.1 Current State of Municipal Waste Management in Indonesia

In 2020, the country generated 67.8 million metric tons (Mt) of waste, a figure expected to grow substantially in the foreseeable future. However, the expansion of solid waste management infrastructure and its financing has not kept pace with waste generation. Consequently, a large amount of unmanaged waste pollutes Indonesia's land, rivers, and oceans.

The Indonesian government has recognized the importance of waste management and has developed policies and regulations aimed at reducing waste generation and promoting environmentally friendly waste disposal methods. Currently, Indonesia's Municipal Waste Management is regulated under the Minister of Public Works Regulation Number 03/PRT/M Year 2013. This regulation details waste processing procedures and the required technologies. However, implementation of these policies and regulations has been a challenge due to a lack of resources, inadequate infrastructure, and poor waste management practices.

The most common method of waste disposal in Indonesia is open dumping, which poses a significant risk to public health and the environment. It is estimated that only 39% of the waste generated in Indonesia is collected and transported to proper landfills, while the remaining 61% is disposed of through open dumping, burning, or thrown into water bodies. This practice results in the release of harmful chemicals and greenhouse gases into the atmosphere, soil, and water, causing environmental degradation and health hazards.

The poor waste management practices in Indonesia have also led to the problem of plastic waste pollution. While plastic waste on land is undeniably a concern, a large percentage of plastic that is not recycled, incinerated, or sent to landfills ultimately ends up in the oceans, Indonesia is among the largest contributors to marine plastic pollution, with an estimated 1.29 million tons of plastic waste entering the ocean each year.

Table 1 Top-10 Countries that Release the Most Plastic into the Ocean (tons 2021)

Philippines	356,371
India	126,513
Malaysia	73,098
China	70,707
Indonesia	56,333
Brazil	37,799
Vietnam	28,221
Bangladesh	24,640
Thailand	22,806
Nigeria	18,640

(Source: Worldpopulationreview.com)

The excessive use of single-use plastics, inadequate waste collection and disposal, and poor waste management practices have contributed to this problem. To address these challenges, the Indonesian government has launched several initiatives aimed at improving waste management practices. The National Mid-term Development Plan (RPJMN) for 2020-2024 includes a goal to increase waste collection and improve waste management infrastructure. The government has also launched the National Action Plan on Marine Debris to reduce plastic waste pollution in the ocean.

To enhance solid waste management in Indonesia, the Solid Waste Management Act No. 18/2008 was introduced, aiming to cease all open dump waste disposal by 2013. However, this ambitious goal was not met, as the Ministry of Environment and Forestry recently reported that 198 open dump waste disposal facilities continue to operate. In 2020, at least 20 landfills were nearing capacity and required closure, expansion, or replacement with new sites. The proportion of managed waste in Indonesia remains low at 56.57%.

Indonesia has indeed recognized the importance of waste management and has initiated several actions and policies to address this issue such as the

- National Plastic Action Partnership: In 2020, Indonesia launched the National Plastic Action Partnership (NPAP) in collaboration with the Global Plastic Action Partnership (GPAP). The goal of this initiative is to reduce Indonesia's marine plastic debris by 70% by 2025, while also transitioning toward a circular economy for plastics.
- Presidential Regulation No. 97/2017: This regulation focuses on the management of waste from household and similar waste. It aims to increase the volume of waste that is reused or recycled.
- Jakarta's "Zero Waste to Landfill" strategy: The capital city has its own waste management strategy that aims to divert waste from landfills by increasing recycling and waste processing.
- Single-Use Plastic Ban: Some regions in Indonesia, such as Bali, have banned single-use plastics (including plastic bags, straws, and styrofoam) to reduce the amount of plastic waste that enters the environment.
- Community-Based Waste Management: The government has also initiated and supported community-based waste management efforts. These programs often involve composting organic waste, recycling inorganic waste, and educating community members about waste management.
- Waste-to-Energy Projects: Indonesia has been working on several waste-to-energy projects to help manage waste while also generating electricity. In 2018, the government announced plans to build waste-to-energy plants in several cities, including Jakarta, Bandung, and Surabaya.

The implementation of these policies is an ongoing process. The situation is exacerbated by the limited availability of plastic and plastic recycling industries, which are mainly found on Indonesia's major islands, such as Java and Sumatra. Moreover, a 2020 survey by the Ministry of Environment and Forestry showed that approximately 17.6% of the nation's total waste generation is plastic waste, with households contributing to around 38.2% of waste production. However, waste generation varies between large and small cities in Indonesia. The World Bank estimates a waste generation rate of 3.57 litres/capita/day or 0.87 kg/capita/day, with plastic waste constituting 0.07 kg of plastic waste/capita/day or about 8% of the total waste generation rate. Waste recycling in Indonesia, which primarily depends on the informal sector and accounts for less than 5% of generated waste, has a plastic recycling rate of only 7%.

The National Plastic Action Partnership (NPAP) report disclosed that Indonesia's plastic recycling rate in 2020 was roughly 10% of the total plastic waste generation, or 6.8 million tonnes. The study also found that about 4.2 million tonnes, or 61%, of post-consumer plastic waste are not collected by waste collectors or management systems, resulting in leakage into the environment, while the remainder ends up in landfills.

The challenge of municipal waste management in Indonesia remains significant. There is a need for better waste management infrastructure, increased public awareness, and a more efficient waste collection and disposal system. The private sector can also play a greater role in waste management by investing in innovative waste management technologies and promoting sustainable waste disposal practices.

3.2 Waste Generation and Plastic Waste

The World Bank estimates that roughly three million people are involved in waste recycling in Indonesia, including informal collection, waste picking, collection, processing, and trade. On Java, informal collection of recyclables is around 10%, but this figure is lower on other islands due to transportation costs and limited local trade and treatment capacities. Waste pickers primarily collect plastics, metals, and cardboard, with prices per kilogram ranging from $0.04 to $1.19, depending on the product type, source, and collection level.

Only about 2% of recycling occurs through waste banks, which involve voluntary segregated collection at the community level. Meanwhile, around 8% of recycling comes from the sorting of mixed waste, including household composting. The Ministry of Environment and Forestry has established a national action plan to reduce waste by up to 30% and ensure proper management of up to 70% of waste by 2025. This plan also aims to reduce plastic waste leakage into the ocean by 0.075 to 0.18 million tonnes per year. According to the national policy and strategy outlined in Law No. 18/2008 and Presidential Decree No. 97/2017, three main approaches are being pursued to address waste in Indonesia:

- Waste minimisation integrated into an eco-living lifestyle;
- Circular economy; and
- Services and technology.

Key objectives for waste minimisation include behavioural changes and the minimisation, prevention, or restriction of waste generation. Presidential Decree No. 97/2017 sets a primary target of reducing single-use plastic bags, plastic cutlery (including plastic straws), and Styrofoam packaging by 30% by 2029, which might impact the composition of future raw materials for RDF production.

Many subnational and local governments have adopted the waste minimisation approach by prohibiting the production and use of single-use plastics (SUPs). Before the COVID-19 pandemic, over 20 cities and provincial governments had already enacted local regulations prohibiting SUPs and implemented regulations supporting Zero Waste Cities. By the end of 2021, two provinces (Bali and Jakarta) and 75 cities and regencies had issued local regulations banning SUPs.

In pursuit of a circular economy, the Ministry of Environment and Forestry (MoEF), the Ministry of Public Works and Human Settlement (MoPWHS), and the National Development Planning

Agency (Bappenas) have focused on fostering behavioural change by providing enabling systems to support redesign, reuse, and recycling in specific sectors. To achieve this goal, the MoEF has developed a Circular Economy ecosystem and support systems, including end-users of recycled products, recycling industries, garbage bank communities, 3R MRF, recycling centers (Pusat Daur Ulang/PDU, Material Recovery Facilities/MRF, Intermediate Treatment Facilities/ITF), the involvement of informal sector players (scavengers), and social entrepreneurs.

Complementing the MoEF, the Ministry of Public Works has issued technical guidance for establishing 3R MRFs, based on a 2013 regulation, and Bappenas has introduced a circular economy policy encompassing five priority sectors. Environmental factors supporting a circular economy include fiscal incentives for the recycling industry, sourcing scraps for industrial materials from both domestic and imported sources, and incorporating recycled content in packaging or products. By mid-2020, data indicated that only 9-11% of post-consumer plastic was being recycled.

Policies have been issued and revised several times to support the importation of scraps, particularly for paper, plastic, metals, rubber, glass, and fabric/rugs, in order to comply with the Basel Convention provisions and new amendments regarding plastic waste trade. A roadmap to phase down the importation of scraps and enable infrastructures to increase recycling rates in Indonesia has been discussed among various stakeholders.

The MoEF has enacted a policy outlining extended producer responsibility (EPR), which mandates corporations, retailers, and packaging producers to develop strategies to reduce the plastic content of their products and packaging by 30% by 2030, as specified in the Ministry of Environment & Forestry Regulation No. P.75/2019.

For recycled products, the Indonesian Food and Drugs Administration (BPOM) has issued a standard for food-contact recycled PET plastics to guide PET recyclers and ensure consumer safety.

There is a significant distinction between different types of plastic. Rigid plastics, like polyethylene terephthalate (PET) bottles, are more valuable to recyclers and create less pollution. However, some flexible plastics, particularly multi-layered plastics or sachets, are not economically viable for recycling. Approximately three-quarters of the plastic waste entering the environment consists of these multi-layered plastics and sachets.

3.3 Challenges to Municipal Waste Management in Indonesia

The major challenges of MSW management in Indonesia comprise:

Lack of Infrastructure and Resources

Many cities and municipalities lack the necessary equipment, technology, and manpower to collect and dispose of waste properly. The result is that much of the waste ends up in landfills, causing environmental and health hazards. Moreover, the limited financial resources available to local governments often mean that waste management is not a priority. As a result, waste management facilities are often underfunded, and the cost of implementing proper waste management practices is often too high for low-income households and small businesses.

Lack of Public Awareness

Many people are still unaware of the importance of waste management practices such as waste segregation and recycling. In addition, there is still a lack of understanding about the proper disposal of hazardous waste. As a result, hazardous waste is often mixed with other types of waste and ends up in landfills, causing environmental and health risks.

Illegal Dumping and Open Burning

Illegal dumping and open burning, particularly in urban areas, are often the result of a lack of access to waste management services, particularly in low-income neighbourhoods.

Limited Land Fill Space

As the population continues to grow and urbanisation increases, the demand for landfill space is increasing. The cost of establishing new landfills is often high, making it difficult for local governments to establish new waste management facilities.

The Lack of Recycling Infrastructure

While some cities have started to implement recycling programs, the infrastructure is still underdeveloped, and the collection and processing of recyclable materials are often insufficient. Furthermore, there is still a lack of incentive for households and businesses to recycle.

4. RDF Technologies

4.1 RDF and SRF Terminology

Refuse Derived Fuel (RDF) is a combustible material sourced from waste through sorting and pre-treatment processes. It mainly consists of municipal solid waste (MSW), including biodegradable materials and shredded plastics. Valuable waste components like recyclable paper, metal, and glass are separated for recycling before RDF production.

RDF varies in content and quality, typically boasting a high calorific value and low chlorine content. It finds application as a substitute for fossil fuels in various processes, including co-incineration in power plants and cement kilns.

Solid Recovered Fuel (SRF) is a solid fuel made from non-hazardous waste meeting specific standards, like the European EN 15359. SRF undergoes rigorous classification, detailing its calorific value, chlorine, and mercury content. It's traded under EWC code 191210 and adheres to quality requirements outlined in standards like EN15539.

SRF is derived from industrial and commercial waste, undergoing several processing steps to enhance its quality. It's strictly regulated and differs significantly from RDF, offering more uniform properties and fewer impurities.

The key difference lies in their constituent materials: SRF is more uniform, while RDF's composition is diverse and influenced by raw materials. End-users of SRF, such as cement kilns and power plants, often require specific quality agreements with producers to meet their economic and technological needs.

Waste-to-SRF technologies vary but generally produce particles less than 30 mm with low moisture content and high calorific value. SRF's price is higher than RDF's due to its adherence to quality parameters, requiring specialized equipment for processing and quality control.

In contrast, RDF adheres to less stringent quality requirements or displays greater quality variation. The waste used for RDF production is more diverse, while SRF is typically a selection of specific types of waste with higher calorific value.

4.2 Current Processing Technologies in Indonesia

Currently MSW utilisation in Indonesia follows two main processes: RDF processing and SRF processing. In the SRF process, MSW undergoes size reduction and separation into biodegradable and dry fractions. The dry fraction undergoes air classification to separate the light (SRF) and heavy (heavy rejects) fractions. Ferrous and non-ferrous metals are removed and sent to recovery plants. SRF and heavy rejects are densified or shredded for easier handling and transport. The biodegradable fraction undergoes metal removal and aerobic biodegradation in a bio-stabilisation basin. The stabilized output is sieved to separate stabilisation rejects from bio-stabilised waste (BSW). Both outputs are currently landfilled, as quality requirements for BSW use have not been issued at the national or regional level.

4.3 Type of Processing Technologies for RDFs

The choice of RDF processing technology is a function of factors such as the type and quantity of waste materials, the desired end use of the RDF, and the regulatory environment in

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Indonesia. There are several processing technologies that may be used to convert MSW into RDF:

- **Mechanical sorting:** This process involves using mechanical equipment such as screens, shredders, and air classifiers to sort and separate different types of waste materials. The resulting RDF is typically used for energy recovery in waste-to-energy facilities.
- **Pelletisation:** This involves compressing RDF into pellets to be used as a fuel in various industries.

In addition, there are advanced thermal processes using MSW or RDF as fuel to produce more advance products than RDF, namely syngas, oil, char and others:

- **Plasma arc gasification:** This is an advanced thermal conversion technology that uses high-temperature plasma to break down waste materials into their constituent elements.
- **Pyrolysis:** This is a thermal process that involves heating waste materials in the absence of oxygen to produce a gas and a solid residue.
- **Gasification:** This process involves heating waste materials in the presence of a limited amount of oxygen to produce a gas that may be used for energy recovery.

4.4 RDF Characteristics and in Which Context Can They Be Used

There are several types of Refuse-Derived Fuels (RDF) to be produced from municipal solid waste (MSW) and other types of refuse.

Low-grade RDF is typically produced through mechanical sorting. It is characterized by a relatively low energy content, typically between 10-18 MJ/kg, and a high ash content. Low-grade RDF can be used as a fuel in cement kilns.

Medium-grade RDF is produced through more advanced processing technologies such as gasification and pyrolysis. It has a higher energy content, typically between 18-25 MJ/kg, and a lower ash content than low-grade RDF. Medium-grade RDF can be used as a fuel in power plants and other energy recovery facilities.

High-grade RDF is produced through advanced processing technologies such as plasma arc gasification. It has a very high energy content, typically between 25-35 MJ/kg, and a very low ash content. High-grade RDF can be used as a fuel in high-efficiency power plants and other advanced energy recovery facilities.

5. Operational Aspects

Indonesia is among the largest producers of municipal solid waste (MSW) in the ASEAN region. Inappropriate waste treatment result in the dispersion of pollutants in the air and water, as well as soil contamination, which highlights the need for selective waste collection as a primary alternative to traditional waste management processes.

Another option for managing waste is to utilise refuse-derived fuel (RDF), which is a fuel fraction obtained from various sources of non-hazardous solid waste, including organic matter in MSW, different types of plastics, biodegradable waste, and substantial amounts of inorganic material such as metal and glass. To standardise information about MSW generation and management in Indonesia, there is a need to establish a standard for solid waste, where RDF would be classified as combustible waste.

5.1 Composition of MSW

The composition of MSW depends on such factors such as population density, economic activities, cultural practices, and waste management infrastructure. In general, MSW can be categorized into several main components:

Organic Waste: This includes food scraps, yard waste, and other biodegradable materials. Organic waste can account for a significant portion of MSW and has the potential to be composted or converted into energy through anaerobic digestion.

Paper and Cardboard: This category encompasses various paper products such as newspapers, magazines, cardboard boxes, and packaging materials. Recycling paper and cardboard helps reduce the demand for virgin materials.

Plastics: Plastics come in various forms, including bottles, containers, bags, and packaging materials. Recycling rates for plastics vary widely due to challenges related to sorting and processing different types of plastic.

Metals: Metals like aluminium, steel, and tin cans are often included in MSW. These materials are highly recyclable and can be reprocessed into new products with less energy compared to using virgin materials.

Glass: Glass containers from beverages and food products contribute to the glass waste fraction. Glass can also be recycled and reused in various applications.

Textiles: Clothing, fabrics, and other textile items make up a portion of MSW. While some textiles can be donated or repurposed, a significant amount ends up as waste.

The composition of MSW significantly affects the potential for the production of Refuse-Derived Fuel (RDF).

Plastics and dry paper are ideal for RDF because they have high calorific values, meaning they produce a lot of heat when burned. Organic materials, on the other hand, often have high moisture content, which can lower the calorific value of the RDF. Therefore, these are often separated from the rest of the waste during the RDF production process. However, organic materials can be separately processed into compost or biofuels.

Metals and glass are typically removed during RDF production as they do not burn and can cause damage to the equipment. These can be separately recycled.

Others such as textiles and rubber could be included in RDF depending on their calorific value and the specific requirements of the RDF plant.

The respective proportions of different waste categories in Indonesia follow a sequence with average percentages as follows: 27.50% for food waste, 20.42% for mixture waste, 19.41% for plastic waste, 14.54% for paper waste, 9.25% for wood waste, 4.90% for textile waste, and 3.98% for non-combustible waste. Notably, the influence of seasonal changes on the composition of MSW in Indonesia is minimal. The moisture content of each waste type exceeds 30%, and the lower heating value of the overall municipal solid waste, calculated on a wet basis, measures 8.6 MJ/kg. This value comfortably surpasses the World Bank's recommended threshold of 6 MJ/kg for effective utilisation in thermochemical conversion processes. These findings demonstrate the substantial potential within Indonesian municipal solid waste for transforming waste into renewable energy or other valuable energy-related products. (*Li, Xiaodong, Experimental study on characteristics of municipal solid waste (MSW) in typical cites of Indonesia 10.18282/pef.v8i1.716 - Progress in Energy & Fuels (2020)).*

By adjusting the composition of the MSW, the quality of the RDF can be further optimized for specific usage, such as burning in cement kilns.

5.2 The Caloric Value of MSW in Indonesia

One of the key issues in the management of MSW is the low energy content of the waste, which has limited the development of energy recovery projects. This waster composition in Indonesia is prevailed by organic waste is the waste stream.

The caloric value of MSW mix in Indonesia is relatively low, with an average value of around 1,000 kcal/kg. This is due to the high proportion of organic waste in the waste stream, which has a low energy content compared to other materials such as plastics and paper. In addition, the high moisture content of the waste reduces its energy content and makes it more difficult to recover energy.

Despite the low energy content of MSW in Indonesia, there is still potential for energy recovery from this waste. One approach to energy recovery is the use of refuse-derived fuels (RDF), which are derived from MSW and have a higher energy content than the original waste. RDF is typically produced by processing MSW to remove non-combustible materials such as metals and glass, and then shredding the remaining material to produce a homogeneous fuel.

The high moisture content of MSW in Indonesia is a significant barrier to energy recovery, as it reduces the energy content of the waste and makes it more difficult to process. However, there are several technologies in place to overcome this barrier. One approach is to dry the waste before processing it, which can significantly increase its energy content. Another approach is to use anaerobic digestion to produce biogas from the organic fraction of the waste, which can be used to generate electricity or heat.

In addition to the low energy content of MSW in landfills, another challenge is the high level of contamination in the waste stream. To address the challenge of contamination in MSW, there is a need for better waste segregation and management practices. This can include the implementation of waste separation programs at the source, as well as the development of recycling and hazardous waste management facilities. In addition, there is a need for greater awareness and education among the public about the importance of waste management and the impact of waste on the environment.

The use of RDF can increase the energy content of the waste and provide a valuable source of energy. However, the high moisture content and contamination of the waste stream pose significant challenges to energy recovery. Addressing these challenges will require the development of new technologies, leading to the development of mechanical and biological treatment (MBT) methods to reduce hazardous substances and create high-quality RDF. The need for quality standards for RDF has led to the development of RDF quality classes, such as SRF in Europe. Indonesia currently lacks a national standard for RDF quality but is working to establish one.

6. RDF Production Technologies

National regulations are required for setting high quality standards for RDF, so that it can be readily accepted as a substitute or auxiliary fuel in most combustion system with minor modifications. However, production of high calorific value RDF asks for complex production lines leading to a low mass efficiency, intended as the ratio of produced RDF mass to the inlet untreated waste mass. With the higher desired LHV, there are a greater number of separation steps and a lower mass of output RDF, given the same inlet quantity of MSW. This leads to high production costs which reduce the market appeal of the product. Scrap tires may also be mixed to MSW to reach the prescribed LHV value, but this may represent an added cost.

The current policies in Indonesia regulations strongly advocate for a reduction of landfilled mass resorting to separate waste collection and thermal utilisation of waste including RDF production.

European Committee for Standardisation (CEN): CEN has developed a set of standards for RDF under the EN 15359 series. These standards define the specifications for RDF in terms of its physical and chemical properties, as well as its environmental performance.

International Solid Waste Association (ISWA): ISWA provides guidance and best practices for RDF production and utilisation. While ISWA doesn't set official standards, it offers technical reports and information on RDF quality and its various applications.

United Kingdom (UK): The UK's Environment Agency has established guidance documents and standards for RDF production and quality. These guidelines outline the requirements for RDF production facilities, sampling procedures, and quality criteria.

Japan: Japan's Ministry of the Environment has set quality standards for waste-derived fuels, including RDF, under the Waste Management and Public Cleansing Law. These standards include specifications for various properties of RDF, such as moisture content, calorific value, and heavy metal concentrations.

United States (US): While the US doesn't have a national standard for RDF, some states have established their own guidelines. For example, California's Department of Resources Recycling and Recovery (CalRecycle) has provided recommendations for alternative daily cover materials, which can include RDF.

Germany: Germany's waste management regulations include quality standards for RDF, specifying parameters such as calorific value, moisture content, and heavy metal limits.

Singapore: Singapore's National Environment Agency (NEA) has set guidelines for waste-to-energy facilities, including those using RDF. These guidelines outline requirements for emissions, energy recovery, and waste quality.

Netherlands: The Dutch organisation NEN has developed standards for solid recovered fuels, including RDF, under the NEN 5905 series. These standards cover specifications, testing methods, and quality parameters.

6.1 RDF Production Lines Characterisation

An RDF production line consists of several ‘‘stations’’ arranged in series as a train and performing unit operations aimed at separating unwanted components and conditioning the combustible matter to obtain an RDF of predetermined characteristics. This is accomplished through successive treatment stages of screening, shredding, size reduction, classification, separation, drying and densification, although the actual line composition will depend from specific site conditions. In fact, the type, number, and position of process equipment along the production line heavily affect the mass balance and the quality of the end product.

The number of possible trains developed from a given number of unit operations (usually trains of four to six operations are adopted) becomes very large. However, to discern the practicality and feasibility of different trains, some rules of thumbs may be defined. Such guidelines will be briefly discussed here and successively adopted when defining the actual lines investigated.

As a general rule, the MSW treatment line should start with a shredding or screening stage; otherwise, the following equipment would suffer from low efficiency. However, if a line starts with a shredder it would suffer from frequent jams because of hard-to-shred components which had not been previously separated by screens, hand sorting, magnetic separation, or air classifiers. This would cause the entire line to go down.

To place more than twice the same equipment on a line is not advisable as the added cost would not be justified by the low efficiency increment. Screens are an exception as they perfect and supplement the action of shredders and mills and always need to be placed after such unit operations. It is also useless to repeat the same operation consecutively unless an intermediate size reduction is present.

The simultaneous presence of a shredder and a mill is not a redundancy as the mill improves the rough size reduction process carried out by the shredder. However, if the refuse has not been previously shredded the mill throughput is reduced and its energy consumption increased. In any case a mill should be always preceded by a magnetic separation or air classification to avoid excessive wear due to presence of metal scrap.

If a parallel composting line is employed, precautions must be taken that the separated inorganic components from the RDF line (glass, metals) do not pollute the compost. Therefore, it is necessary to start the RDF line with a screen to avoid shredded glass or metal entering the composting process. Moreover, the first shredder should be installed following a hand sorting/ magnetic separation or eddy current/hand sorting system to preliminarily separate the glass. To this end the eddy current/magnetic separation combination would be unsuitable. Finally, a hand sorting stage cannot operate on already shredded refuse.

6.2 Material Recovery Facilities (MRFs)

Material Recovery Facilities (MRFs) are RDF/SRF processing facilities that use mechanical treatment, such as sorting, size reduction, and filtering. They consist of a large shed or industrial buildings where recyclable waste is sorted, bulked up, and made ready for transport and sale. MRFs utilise conveyor belts and a mix of manual and automatic procedures to separate materials and remove unwanted items.

Mechanical and Biological Treatment (MBT) is a further processing of MRFs products by using drying, composting, and anaerobic digestion. MBT Biodrying is a variation of MBT that uses heat from anaerobic digestion for the drying process.

Investment costs (CAPEX) and processing costs (OPEX) of converting MSW into RDF or SRF vary by country due to differences in quality and emission requirements, processes and facilities, tipping fees, land prices, MSW composition, climate, plant capacity, transportation costs, and labour and energy costs as well as recovered material prices.

7. The Off Taking Sector for RDF in Indonesia

Refuse Derived Fuels (RDF) can be used as a source of energy in various economic sectors as a means to reduce fossil fuel consumption and manage waste. So far, the number of RDF off takers or buyers in Indonesia are still limited, namely the cement industry and several coal-fired power plants (the industry has it is own RDF regulation prohibiting using municipal waste as a source of raw material, and thus excluded from the analysis).

The potential sectors of off-taking industries in Indonesia for the different types of Refuse-derived fuels (RDF) will depend on the characteristics of the RDF and the local demand for energy and fuel, the regulatory environment, and energy and fuel prices, Additionally, the specific sectors of off-taking industries may vary depending on the characteristics of the RDF and the local demand for energy and fuel.

Cement industry: The cement production process requires significant amounts of energy, and many cement kilns use RDF as a supplementary or alternative fuel source. RDF can replace traditional fuels like coal, or natural gas, reducing greenhouse gas emissions and lowering fuel costs.

Fertilizer industry: . RDF can replace traditional fuels in the production processes.

Steel industry: Steel manufacturing processes, particularly in blast furnaces, can use RDF as a supplemental fuel. The high temperatures in these furnaces can break down RDF, reducing waste volume and generating energy.

Textile sector: RDF used in the textile sector should have a consistent and suitable calorific value to provide efficient heat for industrial processes, such as drying, dyeing, and finishing. However, textile industry is considered to be a p

Metal casting: Moderate potential - RDF used in metal casting should possess a high calorific value to provide the intense heat required for melting metals and alloys.

Pulp and paper industry: The pulp and paper industry requires significant amounts of energy for various processes, and RDF can be used as a fuel source to replace or supplement traditional fuels. This can help reduce greenhouse gas emissions and manage waste. However, pulp and paper industry could become supplier of RDF raw materials from a non-recyclable part.

7.1 The Potential of Economic Sectors as Off-Takers for RDF

To estimate the potential of each economic sector as off-takers for Refuse Derived Fuels (RDF), factors such as energy consumption, production processes, environmental regulations, and potential for RDF substitution have to be taken into account:

Cement industry: High potential - The cement industry has a high potential for RDF utilisation due to its energy-intensive production process and the ability to use RDF as a supplementary or alternative fuel source. Many cement kilns have already adopted RDF to replace traditional fuels like coal and natural gas, reducing greenhouse gas emissions and lowering fuel costs.

Steel industry: Moderate potential - The steel industry has a moderate potential for RDF utilisation, particularly in blast furnaces. However, the overall use of RDF in steel production is relatively limited compared to other fuels, and the energy demand of the sector might not be fully met by RDF alone.

Textile sector: Low to moderate potential - The textile sector has a low to moderate potential for RDF utilisation, as energy demand in this sector is typically lower compared to other heavy industries. However, the use of RDF in textile production can still contribute to environmental sustainability and waste management. Factors such as the scale of textile production, local waste management policies, and availability of RDF will influence the potential for RDF use in this sector. Sector is considered as a potential raw material supplier.

Metal casting: Moderate potential - The metal casting industry has a moderate potential for RDF utilisation, as the high temperatures used in the casting process can accommodate the use of alternative fuels like RDF. The potential for RDF uses in this sector will depend on the scale of production, energy requirements, and the willingness of the industry to adopt alternative fuels. The environmental benefits and cost savings from using RDF may drive its adoption in this sector.

Pulp and Paper Industry: Moderate to high potential - The pulp and paper industry has a moderate to high potential for RDF utilisation due to its significant energy requirements for various processes. RDF can be used as a fuel source to replace or supplement traditional fuels like coal, oil, or natural gas. Sector is considered as a potential raw material supplier.

7.2 Correlating RDF Off Taking Industries with Types of RDF

Potential sectors of off-taking industries for each type of RDF are for:

Low-grade RDF: Cement industry: Low-grade RDF can be used as a fuel in cement kilns, which require high temperatures to produce cement clinker. The cement industry is already a major consumer of RDF in Indonesia. Some of the largest cement producers in the country, such as PT Holcim Indonesia Tbk and PT Semen Indonesia Tbk, use RDF as a fuel in their kilns to reduce their dependence on fossil fuels.

Medium-grade RDF: Medium-grade RDF can be used as a fuel for industrial process heating, such as in the production of cement, steel, and, and processing. However, the adoption of RDF for this purpose is so far relatively limited in Indonesia.

High-grade RDF: Industrial process heating: High-grade RDF can be used as a fuel for industrial process heating, such as in the production of cement, steel, and other materials.

Transportation fuel: High-grade RDF can be converted into liquid or gaseous fuels for usage as transportation fuel. While there is currently no significant production of transportation fuel from RDF in Indonesia, there is potential for the development of this sector in the future, and not considered in the analysis.

In terms of location, the potential off-taking industries for RDF are distributed throughout Indonesia, with some concentration in areas with high population density and industrial activity. For example, Jakarta and the surrounding province of Banten and West Java are home to several large RDF off-takers, including the Bantargebang WTE plant and several cement producers. Similarly, East Java has a number of large cement industry that could potentially use RDF as a fuel.

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7.3 The Potential of RDFs in Major Off Taking Sectors

The degree to which Refuse Derived Fuels (RDF) can replace traditional sources of energy in various economic sectors depends on the specific energy requirements, production processes, and the quality of RDF, and applicable policies.:

Cement industry: RDF can replace a significant portion of traditional energy sources in the cement industry, ranging from 30% to 40% in 2050 based on Cement Association, depending on the quality of RDF and the plant's configuration. The 40% percentage includes various alternative fuel mixtures which cannot be achieved entirely from RDF which has a relatively low calorific value.

The global cement industry has a well-established tradition of utilizing RDF as an alternative fuel source. Cement plants in Austria lead the way with a 65.3% RDF substitution rate, followed by Germany at 61.1%, the European Union at 27%, and North America, Japan, and Australia each at 11% (Lusy Widowati, 2023). However, Indonesia lags significantly behind with a substitution rate of less than 1% (Lusy Widowati, 2023).

In 2022, Indonesian cement plants were estimated to necessitate around 240 Mio. GJ of energy for cement production and 235 Mio. GJ for clinker production (Lusy Widowati, 2023). These plants utilize a diverse range of fuel types, including B3 and non-B3 fossil fuels, waste, used tires, and other sources, to meet their energy requirements.

In Indonesian cement plants, RDF is advocated as an alternative fuel primarily because of its numerous environmental advantages. These include decreasing reliance on non-renewable fossil fuels like coal, which in turn reduces the environmental footprint associated with extracting natural resources. Additionally, utilizing RDF helps mitigate emissions, including greenhouse gases, by substituting fossil fuels with materials that generate fewer emissions and residues during combustion.

Acknowledging the distinct combustion characteristics and physical and chemical properties of alternative fuels such as RDF compared to coal is crucial. RDF may contain undesirable compounds like phosphates, chlorine, heavy metals, and other minor elements that can affect the clinkerisation process in the kiln. Therefore, using RDF requires adjustments to the design of supporting equipment in cement kilns and modifications to plant operating conditions to ensure the quality of the produced clinker is maintained.

In Indonesia, 16 cement companies with more than 20 plant locations and 48 kiln lines can potentially use RDF as a partial substitute for coal and are considered in the study as a major off taker.

Co-processing in cement kilns

The Indonesian Government, through Law No. 3 of 2014 concerning Industry, promotes the development of a Green Industry. This law encourages sustainable resource use, aiming to balance industrial growth with environmental preservation, benefiting communities.

The cement industry is considered ready to adopt the Green Industry concept. One such strategy is implementing Refuse-Derived Fuel (RDF) technology. By using this technology, the cement industry can utilise the energy from domestic and industrial solid waste, conserve natural resources such as fuels, reduce CO2 emissions, and address waste issues.

Indonesia currently has 16 cement companies with an installed capacity in 2022 of 118.9 million (119.2 in 2023) tons/year. The cement kilns from these 16 companies total 48 kilns and all of them are kilns with dry technology, some kilns have a combustion system with a pre-heater, pre-heater with pre-calciner (ILC and/or SLC) consisting of 4 (four) or 5 (five) stages. The two largest companies are Semen Indonesia Group, PT Indocement Tunggal Prakarsa Tbk.

The substitution of fossil fuels with alternative fuels (AF) has become a prominent topic in the cement industry worldwide. The discussions surrounding alternative fuels have intensified over the past decade, leading to a significant increase in consultancy services for the procurement, storage, handling, and dosing of AF. Cement producers have also gained extensive knowledge and experience in this area. Various machines and plants are available for producing, storing, handling, and dosing different types of RDF and SRF.

Several companies have implemented co-processing of alternative fuels in clinker production, with thermal substitution ratios of up to 10%. Alternative fuels typically used in Indonesian cement factories include agricultural waste (grain husks, palm shells, etc.) and Refuse Derived Fuel (RDF) from domestic waste. The average thermal substitution rate for alternative fuels in the global cement industry was 17%. Austria had the highest rate at 75.95%.

PT Solusi Bangun Indonesia Tbk (SBI) is an Indonesian public company with 83.27% of its majority stake owned and managed by PT Semen Indonesia Industri Bangunan (SIIB) - a part of the Semen Indonesia Group, the largest cement producer in Indonesia and Southeast Asia. PT SBI operates an integrated business of cement, ready mix concrete, and aggregate production.

The company operates four cement plants in Narogong, West Java; Cilacap, Central Java; Tuban, East Java; and Lhoknga, Aceh, with a combined production capacity of 14.8 million tonnes of cement per year.

PT SBI was the first cement company to tackle the issue of greenhouse gas (GHG) emissions. Between 2011 and 2017, SBI executed the largest project using biomass as an alternative fuel under the UNFCCC Clean Development Mechanism program, reducing CO2 emissions by a total of 1,560,837 tonnes of CO2e, with an annual average reduction of 222,977 tonnes of CO2e. The company uses rice husks and palm kernel shells as alternative fuels, which helps reduce CO2 emissions that would otherwise result from these waste materials decomposing.

The maximum achievable TSR is restricted by the kiln system's capacity to burn the fed AF without causing operational or quality issues. The cement industry is advised that it is impossible to define the best injection positions and operating practices in general terms due to plant and fuel-specific properties. Each plant can be optimized for the highest possible substitution rate for different alternative fuels.

The Stockholm Convention on POPs, ratified by 185 parties, identifies cement kilns co-processing hazardous waste as a source category with the potential for high formation and release of PCDD/PCDFs.

The Air Emission Quality Standards used as a reference are in accordance with the Emission Quality Standards stipulated in the environmental documents of each cement factory. The cement industry that uses RDF must have the internal capacity to measure and monitor levels of conventional pollutants such as particulates, CO, NOx and SO2 using reliable and continuous emissions analysis equipment. Monitoring of non-conventional emissions, including heavy metals, must be carried out in accordance with the period specified in the utilization permit.

This statement from Minister of Environment and Forestry Regulation No.19 of 2017’s attachment only applies to cement plants that use 100% RDF and based on the meeting of the Indonesian Cement Association with the Ministry of Environment and Forestry in 2023, it was agreed that this Regulation cannot be implemented because it is impossible for cement plant to use 100% RDF.

For cement plant that use fuel mixtures, the applicable Emission Quality Standards are in accordance with the Environmental Permit for each plant.

Steel industry: The overall use of RDF in steel production is relatively limited compared to other fuels, and the energy demand of the sector might not be fully met by RDF alone.

Energy Demand: The steel sector is energy-intensive, requiring significant heat energy for processes such as smelting and metal casting. RDF, with its high calorific value, can serve as an alternative fuel source to meet these energy demands.

Reduction of Fossil Fuel Dependence: By using RDF as an alternative to fossil fuels (such as coal or coke) in steel manufacturing processes, the sector can reduce its dependence on non-renewable resources and contribute to environmental sustainability.

Emission Reduction: RDF combustion typically results in lower greenhouse gas emissions compared to fossil fuels. Utilizing RDF in the steel sector can help reduce carbon dioxide emissions associated with traditional fuel sources.

Waste Diversion: The steel sector's demand for RDF provides an opportunity to divert a significant portion of municipal solid waste from landfills, contributing to improved waste management practices and reduced environmental impact.

Technological Feasibility: Technological process may not allow for quick conversion to utilisation of RDD. The characteristics of RDF, such as its particle size, moisture content, and combustion behaviour, need to align with the requirements of steel production.

Economic Considerations may not be feasible due to low potential in savings in energy expenses, and investment in additional infrastructure.

Fertilizer Industry: The fertilizer industry is characterized by energy-intensive processes, particularly in the production of nitrogen-based fertilizers and phosphate compounds.

RDF, with its notable calorific value, presents a potential alternative fuel source to fulfil the substantial energy demands required for various chemical processes involved in fertilizer manufacturing.

Reduction of Fossil Fuel Dependence: This transition contributes to a reduction in the industry's reliance on non-renewable resources, aligning with environmental sustainability goals and promoting eco-friendly practices.

Technological Feasibility: Fertilizer sector may face some challenges in swiftly transitioning to RDF utilisation due to specific technological processes, however, the sector is considered as one of the most potential candidates for RDF offtake after cement industry.

Textile sector: The potential for RDF to replace traditional energy sources in the textile sector is relatively low compared to other heavy industries, with substitution rates usually below 30%. However, the use of RDF in textile production can still contribute to environmental sustainability and waste management. Factors such as the scale of textile production, local waste management policies, and availability of RDF will influence the potential for RDF use in this sector. The Sector can become a supplier of RDF raw materials.

Metal casting: The high temperatures used in the casting process can accommodate alternative fuels like RDF, which can be used in furnaces or other heating systems. The potential for RDF uses in this sector will depend on the scale of production, energy supply requirements, and the willingness of the industry to adopt alternative fuels.

Pulp and Paper industry: The pulp and paper industry is known for its high energy intensity. The technological characteristics of this industry depend on raw materials, pulping processes, and the final products. Energy input from coal, gas, petroleum, black liquor, and biomass is required at each stage of pulp and paper manufacturing to produce steam or electricity, which is mostly used in the manufacturing process.

The installed capacities of various pulp and paper companies totals 10,057,000 tons. With a 2017 production rate of 76% and an expected rate of around 80% of installed capacity in 2020, there are 85 integrated pulp and paper companies (IPKs) distributed primarily across Sumatra and Java, with 15 of them not in operation. These IPKs are classified into pulp, integrated pulp and paper, integrated pulp and paper HTI, and paper industries, and they produce pulp and various paper types.

Based on 2020 data from the Ministry of Industry, the annual thermal energy requirement of the integrated pulp and paper industry, based on installed capacity, stands at approximately 465 Mio. GJ (Lusy Widowati, 2023). Of this total, approximately 37% (172 Mio- GJ) is derived from fossil fuels, predominantly coal (76.5% or 6 Mio tons per year) and natural gas (20% or 32 Mio. MMBtu) (Lusy Widowati, 2023). The remaining 63% (293,00,400 GJ) is sourced from biomass, with the majority (82.5%) of this biomass energy originating from black liquor, a byproduct of the wood cooking process in the digester (Lusy Widowati, 2023).. External biomass sources, including bark, empty bunches, palm kernel shells, and palm fibers, contribute to around 17.5% of the biomass energy requirements (Lusy Widowati, 2023). The industry being an unlikely a potential off taker in the short run, could assume a role of a potential supplier of raw materials.

7.4 RDF Technology Modifications Suggested for Major Off Taking Sectors

The use of Refuse Derived Fuels (RDF) in various economic sectors may require modifications or upgrades to existing equipment to ensure efficient combustion, emissions control, and safety.

Cement industry:

- Upgrading fuel feed systems to handle RDF.
- Installing new storage and handling facilities for RDF
- Modifying the combustion system, such as adapting the burner or adjusting the air supply
- Updating emissions control systems, like electrostatic precipitators, bag filters, or scrubbers

Fertilizer industry

- Combustion systems would need modification to accommodate the use of RDF (burners and combustion chambers to ensure efficient energy generation).
- Feeding Systems to control the introduction of RDF, considering factors like particle size and moisture content.
- Storage and handling infrastructure for RDF needs to be installed.

Steel industry:

- Adapting fuel feeding systems for RDF.
- Installing RDF storage and handling facilities.
- Modifying the combustion system, such as adjusting burners and air supply.
- Upgrading emissions control systems, if necessary.

Metal casting:

- Adapting fuel feeding systems for RDF.
- Installing RDF storage and handling facilities.
- Modifying the combustion system, such as adjusting burners, air supply, or furnace design to accommodate RDF.
- Upgrading emissions control systems, if necessary, to handle potential changes in flue gas composition.

7.4.1. Cofiring

Cofiring entails the simultaneous combustion of multiple fuel types derived from various materials within a single combustion system. This practice is applicable across three boiler types: PC Boiler, CFB Boiler, and Stoker Boiler, utilizing three distinct methods: (1) Direct Cofiring, acknowledged for its cost-effectiveness and widespread adoption, (2) Indirect Cofiring, involving the conversion of biomass into fuel gas prior to combustion, and (3) Parallel Cofiring, a method popular in the pulp and paper industry where biomass is combusted separately (Lusy Widowati, 2023). Theoretically, CFB technology enables higher substitution rates and imposes less stringent requirements on heating value, particle size, and ash content.

In direct cofiring, refuse-derived fuel (RDF) and coal are blended before combustion in the same boiler, a method prevalent in pulverized coal boilers. Indirect cofiring requires an RDF gasifier to convert RDF into syngas prior to introduction into the coal boiler, offering pollution mitigation benefits through syngas purification. Parallel cofiring necessitates a separate RDF-fired boiler, with steam produced feeding into the coal-fired boiler's system, often utilized for by-products in paper mills to maximize RDF utilization. Each method presents distinct advantages and applications within the realm of boiler technology and resource utilization.

In 2009, ENEL's Fusina-Venice coal plant successfully cofired RDF with coal (95% coal, 5% waste pellets), achieving low emissions and up to 35% thermal efficiency (Lusy Widowati, 2023). Key issues include tube corrosion, fly ash quality, and emissions.

High chlorine content in RDF during cofiring can corrode boilers, cause slagging, and increase hydrochloric acid emissions. It can also lead to the formation of polychlorinated dibenzodioxins and polychlorinated dibenzofurans. Incinerating chlorine-rich waste produces hydrochloric acid and releases dioxins. Additionally, combustion may release mercury due to its high volatility.

Slag and fouling are influenced by factors like ash composition, slag viscosity, and particle size. RDF particle size is crucial, as larger particles can promote slag formation. Variations in the non-combustible part of RDF particles compared to coal affect fouling and slagging. Corrosion is a concern due to high temperatures triggering corrosive reactions.

The effect of RDF parameters on coal cofiring in coal power plant can be seen in table below:

Table 2: RDF Parameter and its effects on coal fired power plant cofiring process

RDF Parameter	Technical Impact	Environmental Impact	Economic Impact
Higher moisture content	Lowering NCV can cause ignition and complete □dak combustion problems. Causes emission of unburned pollutants such as CO, soot and PAHs.	Soot can cause environmental degradation due to haze formation and acid rain. PAHs are highly toxic, mutagenic and/or carcinogenic to microorganisms.	Higher investment cost due to boiler retrofit to address combustion issues. Higher investment cost for separate plant and burner to handle incomplete combustion.
Bulk Density	Fuel feeding problem		Additional investment costs for storage, transport, handling and separate feeders from existing facilities
Particle Size	Lowers ignition temperature. Increases CO2 production. Reduced fuel injection stability due to RDF particle agglomeration.	Improved CO2 emissions due to lower fuel injection stability and reduced burnout fraction.	Higher costs for pre-treatment and particle size reduction. Higher utility costs.
Ash content	Fly ash utilisation issues due to higher alkali metal content (K and Na).	Particulate emissions	Additional costs for fly ash handling
Cl content	Induces corrosion on boiler surfaces; Lowers fly ash quality; Reduces boiler efficiency	Aerosol formation Land degradation due to fly ash disposal	Higher operational and maintenance costs due to corrosion;

			Additional costs for fly ash disposal
Alkali and alkaline earth metals (e.g. K, Na, Ca, Mg)	Slagging and fouling of boiler equipment Corrosion of heat exchangers and superheaters Poisoning of SCR catalyst system lowers NOx emission reduction efficiency Ca favours the formation of calcium sulphate retains more sulphur in the ash	Aerosol formation	Higher operational and maintenance costs due to increased fouling and corrosion, and SCR catalyst poisoning Additional costs for fly ash disposal
Silica	Favours ash formation and its deposition leading to erosion of heat transfer tubes		
Potentially toxic elements (PTEs) and fine particles.	Increased potential for heavy metals to be trapped in ash Ash utilisation and disposal issues Increased formation of submicron particles (<0.2 lm)	Emission of highly volatile elements such as Hg, Cd and Talium (Tl) Aerosol formation	Higher operational and maintenance costs due to prolonged erosion

(Source: Lusy Widowati, 2023)

7.5 Technical specifications for Refuse Derived Fuels for off taking sectors.

RDF consists of a heterogeneous mix of materials. Therefore, the quality and specifications of RDF are crucial for its users. Consequently, facilities using RDF should adhere to related regulations, such as waste handling requirements, emission standards, and occupational safety and health, while considering the risks of using RDF on process and equipment stability.

Three main parameters typically assess the quality of RDF as an alternative fuel:

- NCV or net heating value (correlated to combustion performance),
- Chlorine (correlated to technical behaviour), and
- Mercury (correlated to environmental impact). Mercury is a significant global environmental pollutant due to its medium and long-term negative health effects.

7.5.1. RDF Specifications per sector

Each economic sector has specific requirements for Refuse Derived Fuels (RDF), based on their processes and equipment.

Cement Industry:

- Calorific value: 14-20 MJ/kg
- Moisture content: < 20%
- Ash content: < 25%
- Chlorine content: < 1%
- Particle size: 20-50 mm

Fertilizer Industry:

- Calorific value: 16-22 MJ/kg
- Moisture content: < 15%
- Ash content: < 20%
- Sulfur content: < 1%
- Chlorine content: < 0.7%
- Particle size: 10-40 mm

Steel Industry:

- Calorific value: 18-22 MJ/kg
- Moisture content: < 10%
- Ash content: < 15%
- Sulfur content: < 0.8%
- Chlorine content: < 0.5%
- Particle size: 10-30 mm

Metal Casting:

- Calorific value: 18-22 MJ/kg
- Moisture content: < 10%
- Ash content: < 15%
- Sulfur content: < 0.8%
- Chlorine content: < 0.5%
- Particle size: 5-30 mm

7.6 Optimizing the use of RDFs in off taking sectors

Optimizing the use of Refuse Derived Fuels (RDF) in various economic sectors involves adapting production processes, improving fuel quality, and investing in supportive infrastructure. Here are some suggestions for each sector:

Cement industry:

- Invest in pre-processing facilities to improve RDF quality, such as sorting and shredding
- Optimise the fuel feeding system to ensure consistent and efficient combustion.
- Monitor and adjust the air supply and combustion conditions to reduce emissions and improve energy efficiency.
- Implement regular maintenance and inspection of equipment to maintain optimal performance.

Fertilizer Industry

- Combustion Systems Optimisation including burners and combustion chambers, to accommodate the specific characteristics of RDF.
- Implement advanced combustion technologies to ensure efficient energy generation from RDF, taking into account the calorific value and combustion behavior.
- Develop and implement precise feeding systems capable of controlling the introduction of RDF into the production process.
- Customise feeding mechanisms to manage variations in particle size and moisture content of RDF, ensuring a consistent and controlled supply to the combustion systems.
- Install dedicated storage facilities for RDF to accommodate the particle size range and prevent degradation or contamination.
- Develop efficient handling infrastructure for transporting RDF within the facility, including conveyor systems and automated processes to streamline the integration of RDF into the fertilizer production line.
- Establish robust quality control measures to monitor RDF characteristics, including particle size, moisture content, and chemical composition.

Steel industry:

- Invest in RDF pre-processing facilities to improve fuel quality and compatibility with steel production processes.
- Optimise fuel feeding and combustion systems to ensure efficient use of RDF.
- Monitor and adjust the air supply and combustion conditions to reduce emissions and improve energy efficiency.
- Implement regular maintenance and inspection of equipment to maintain optimal performance.

Metal casting:

- Adapt fuel feeding systems and combustion equipment to handle RDF effectively.

- Invest in RDF pre-processing facilities to improve fuel quality and compatibility with metal casting processes.
- Optimise combustion control and air supply to ensure efficient RDF use and minimise emissions.
- Implement regular maintenance and inspection of equipment to maintain optimal performance.

8. The Supply Side of RDFs

To ensure that the provision of Refuse Derived Fuels (RDF) meets the needs of the industry in terms of technical specifications, volume, and continuity, it is essential to establish a comprehensive and well-planned strategy. The following elements must be considered:

- Develop clear technical specifications: Establish industry-wide technical specifications for RDF, including calorific value, moisture content, ash content, and particle size. These specifications should be based on the requirements of end-users and should be aligned with relevant regulations and environmental standards.
- Promote waste segregation and collection: Encourage proper waste segregation and collection at the source to ensure a steady supply of suitable waste material for RDF production. This may involve public awareness campaigns, incentives, and penalties for non-compliance.
- Invest in infrastructure and technology: Develop state-of-the-art RDF production facilities with advanced technologies to ensure consistent quality and high processing efficiency. Regular maintenance and upgrades should be planned to keep the facilities up to date.
- Establish long-term contracts: Encourage long-term contracts between RDF producers and end-users to guarantee a continuous demand for RDF. This will also provide a stable market for RDF producers and encourage further investment in the sector.
- Diversify feedstock sources: RDF producers should aim to diversify their feedstock sources to reduce the risk of supply disruptions. This may include exploring alternative waste streams or securing waste materials from multiple suppliers.
- Implement quality control and assurance systems: Establish rigorous quality control and assurance systems to monitor and maintain RDF quality. Regular testing and certification should be conducted to ensure that RDF products meet the required technical specifications.
- Regulatory support: Governments should provide a supportive regulatory environment, including incentives, subsidies, or tax breaks, to encourage the growth of the RDF industry. Clear and consistent regulations will also help to minimise risks and uncertainties for investors and stakeholders.
- Build partnerships and collaborations: Establish partnerships and collaborations between RDF producers, end-users, waste management companies, and government agencies. These collaborations can help to identify new opportunities, share best practices, and address any challenges that arise.

- Monitor and forecast demand: Regularly assess and forecast the demand for RDF in the market to ensure that production levels are aligned with industry needs. This can help to prevent supply shortages or surpluses.
- Public awareness and education: Increase public awareness about the benefits of RDF and its role in sustainable waste management. This can help to drive demand for RDF products and support the growth of the industry.

8.1 Requirements for Ensuring a Sustainable Supply of RDFs to the Off Taking Sectors

As indicated above, to ensure a sustainable supply of Refuse Derived Fuels (RDF) for various economic sectors, it is essential to establish a reliable waste management infrastructure, enhance cooperation between stakeholders, and support technological advancements. The following is required to improve partnership and help match RDF demand and supply.

- Collaborate with waste management companies and municipalities to secure a consistent RDF supply.
- Encourage investments in waste sorting, recycling, and RDF production facilities.
- Promote partnerships between the industry and waste management sector to facilitate RDF use and knowledge sharing.
- Promote industry-wide adoption of RDF through knowledge sharing and collaboration between the steel and waste management sectors.
- Encourage investments in waste sorting, recycling, and RDF production facilities tailored to the industry's energy needs.
- Support the development of waste-to-energy projects in the pulp and paper industry to boost demand and promote RDF use.

8.2 Regulatory adjustments to support Off Taking Sectors in the Utilisation of RDF

To support and facilitate the industrial sectors in the utilisation of Refuse Derived Fuels (RDF) in Indonesia, the following potential regulatory adjustments could be considered - by implementing these regulatory adjustments, Indonesia can create a supportive environment for the growth of the RDF industry and promote its utilisation across various industrial sectors.

- Develop clear RDF standards and guidelines: Establish national standards and guidelines for RDF quality, including calorific value, moisture content, ash content, and other relevant parameters. This will ensure consistency in RDF production and provide a clear understanding of the expectations for both producers and users.
- Incentivise RDF production and usage: Introduce financial incentives, such as subsidies, tax breaks, or low-interest loans, to encourage investment in RDF production facilities and the adoption of RDF as a viable alternative fuel in industrial sectors.
- Encourage waste segregation and collection: Implement regulations to promote proper waste segregation and collection at the source. This could include mandatory recycling programs, public awareness campaigns, and penalties for non-compliance.

- Streamline permitting and approval processes: Simplify and expedite the permitting and approval processes for RDF production facilities and projects, making it easier for investors and developers to establish and operate such facilities.
- Strengthen environmental regulations: Ensure that environmental regulations related to air emissions, water discharge, and solid waste management are up-to-date and in line with international best practices. This will help minimise the potential negative impacts of RDF utilisation and encourage the adoption of cleaner technologies.
- Enhance monitoring and enforcement: Improve monitoring and enforcement of existing waste management and environmental regulations to ensure compliance by RDF producers and industrial users.
- Develop public-private partnerships: Encourage public-private partnerships between RDF producers, waste management companies, and government agencies to support the growth of the RDF industry and facilitate collaboration.
- Incorporate RDF in national energy and waste management policies: Integrate RDF as a priority area within Indonesia's national energy and waste management policies, highlighting its potential to contribute to sustainable development and greenhouse gas emissions reduction.
- Support research and development: Allocate resources and funding for research and development in RDF production technologies, waste management strategies, and alternative applications to encourage innovation and improvements in the sector.
- Establish pilot projects: Support pilot projects that demonstrate the feasibility and effectiveness of RDF utilisation in various industrial sectors. This can help build confidence in the technology and showcase its potential benefits.

Example: The potential for the cement industry of creating circularity through RDFs

Cement and concrete are crucial to the built environment, but their production contributes significantly to global carbon dioxide emissions and solid waste. With industries moving towards net-zero emissions, around €210 billion is at risk by 2050 worldwide due to carbon dioxide and landfill costs. Traditional cement production methods won't create additional value, so alternative options are needed to decrease costs and emissions. Circular technologies like alternative fuels such as RDFs could help decarbonise cement and concrete emissions. Implementing these circular strategies could add billion of annual net value gain to the built environment, mitigating a proposition of the stated value at risk.

The cement value chain can create closed loops for carbon dioxide, materials and minerals, and energy through circular economies, which aim to eliminate waste and pollution, circulate products and materials, and regenerate nature. Circularity can work in tandem with reducing carbon emissions in cement production by following three key decarbonisation strategies: redesign, reduce, and repurpose. Shifting from fossil to alternative fuels such as RDFs can help reduce emissions, focussing on using alternative fuels from waste material and recovering energy and waste heat throughout cement and concrete production. The global average share of alternative fuels is expected to reach 43% by 2050.

Circularity in cement can create additional value - adopting circularity is necessary to mitigate at least 50% of the value at risk, while emerging technologies and business models will create additional value to address the remaining value at risk.

The annual net impact of recirculating carbon is estimated to be €6 billion globally by 2050 (at 2022 prices, without considering inflation). This is mainly driven by the expanding global carbon markets and the expected rise in carbon dioxide prices, which could offset or surpass the costs of technology. There's significant potential for carbon dioxide abatement through circular technologies in cement over the next 20 years, with around two billion metric tons of emissions potentially avoided or mitigated by 2050. The uptake of these technologies will vary by region due to external factors like carbon dioxide prices, decarbonisation subsidies, and landfill costs. In Europe, rapid evolution in circular technology adoption is expected, driven by higher carbon dioxide and landfill disposal prices.

Regional cost differences highlight the importance of regulatory frameworks, which can facilitate circularity through financial incentives and standardisation. Indonesia might consider financial incentives like carbon dioxide pricing schemes, carbon credit systems, and landfill taxation which could encourage players to lower emissions and make recycling waste materials more attractive. Standardisation would also positively affects the amount of waste material to be used in cement production. The Indonesian concrete industry (and off takers in general) could use circular technologies by:

Building a cost-benefit position with existing carbon dioxide prices, landfill costs, and regulatory frameworks. Individually assess externalities and select the most beneficial technologies based on region and plant location.

Determining the availability and accessibility of waste material for recirculation. Accelerate the transition to circularity by planning to locate facilities together in industrial hubs and

Ensuring offtake agreements for circular products. Offtake agreements for low-carbon building materials are becoming increasingly available, driven by initiatives like the Race to Zero campaign.

9. The Economics of Producing and Using RDFs

So far investing in MSW to RDF conversion facilities in Indonesia is not economically feasible, as the production cost is slightly higher than the RDF selling price. However, the current facilities continue to exist because they are owned and financed by governments, extern grants and / or subsidized local governments. Thus, the primary goal of these facilities is to reduce municipal waste for environmental health rather than profit from recycling, reusing, and reducing waste. The cost of processing RDF is considered the cost for maintaining environmental health by reducing MSW volume. Therefore, investment in MSW to RDF facilities cannot be solely financed by the private sector seeking profits; instead, they should be partially or fully financed by governments or local governments.

However, investment in RDF facilities indicated that private sector participation is possible in the case of external grants and or from government/local government budgets or other international grants. This limitation implies that RDF facilities cannot be fully financed by private funds or through Public-Private Partnership (PPP) financing schemes due to low value for money.

9.1 Elements of a Value Chain for Generating RDFs

The value chain for RDF generation involves several key elements, including waste collection, sorting, processing, transportation, and marketing.

Waste Collection

The first step in the RDF value chain is waste collection. In Indonesia, MSW is typically collected by local governments or private contractors and transported to a central location for sorting and processing. The quality and quantity of waste collected are critical factors in the RDF value chain, as they determine the amount and quality of fuel to be produced.

Sorting

The second step in the RDF value chain is sorting. The waste is sorted to remove any non-combustible materials, such as metals, glass, and plastics, that may interfere with the combustion process. Non-combustible materials are typically removed using a combination of mechanical and manual sorting techniques.

Processing

The third step in the RDF value chain is processing. The remaining combustible materials are shredded and dried to create a high-density fuel. The exact process used for processing depends on the type and quality of the waste being processed. In Indonesia, RDFs are typically produced using a combination of mechanical and manual processing techniques.

Transportation

The fourth step in the RDF value chain is transportation. Once the RDF is produced, it must be transported to its destination. Depending on the intended use of the fuel, transportation may involve the use of trucks, trains, or ships. The cost and efficiency of transportation are critical factors in the overall economics of the RDF value chain.

Marketing

The final step in the RDF value chain is marketing. RDFs are typically sold to energy producers, such as cement kilns, power plants, and industrial boilers, who use the fuel to generate energy. The price and demand for RDFs depend on a variety of factors, including the availability of other fuel sources, government policies, and the cost of production.

Pollution considerations:

However, throughout the RDF generation process and the waste handling stages, pollution subjects must be addressed to ensure environmental sustainability and public health. In waste collection vehicles using fossil fuel emit pollutants that contribute to air contamination. In addition, management of collection sites should included measure that lead to prevention of leakage, and contaminating soil and water.

MSW sorting is also posing pollution risks. Manual and mechanical sorting techniques release dust and particulate matter into the air, especially without proper dust control measures. During processing, shredding and drying, volatile organic compounds and other pollutants can be emitted too. Wastewater from RDF production also requires treatment to prevent water pollution.

Similar to the collection stage, transporting RDF from production facilities to end users raises further pollution concerns. Vehicles used for transport can emit pollutants along the transport routes if they are not maintained or operated efficiently. Spills or leaks during transport can also result in environmental contamination if proper handling practices are not followed.

The final use of RDF, typically in industrial processes such as cement kilns, involves combustion, which produces air pollutants such as particulate matter, nitrogen oxides (NOx) and sulphur dioxide (SO2). Without appropriate emission control technologies, these pollutants can affect air quality and public health. The disposal of residual ash from RDF combustion also requires careful management to prevent soil and water pollution.

Opportunities

The generation of RDFs from MSW in Indonesia also presents several opportunities. One opportunity is the potential for energy production and cost savings. By using RDFs as a fuel source, energy producers can reduce their reliance on more expensive fossil fuels, such as coal and oil. This can result in significant cost savings for energy producers and help to reduce greenhouse gas emissions.

Another opportunity is the potential for job creation and economic development. The RDF value chain requires a significant amount of labour and expertise, including waste collectors, sorters, processors, and transporters. This can create job opportunities and stimulate economic growth in local communities.

Studies and data reveal that the total investment cost of an MSW to RDF conversion facility tends to increase with the facility's capacity in TPD. A higher capacity demands a higher investment cost. However, the investment cost increase per TPD is not linear, as a larger capacity results in a lower cost per TPD.

RDF production cost includes the total expenses required to convert MSW into RDF at the desired quality for buyers. This cost encompasses electricity, labour, transportation, consumables, equipment maintenance, and spare parts. These costs are represented by the operating expense (OPEX). The RDF production cost per ton should be lower than its selling price. Data analysis shows that the production cost slightly increases as the capacity of the MSW to RDF conversion facility grows.

Also, MSW to RDF conversion facility projects in Europe are not economically viable because the production costs in these facilities exceed the RDF selling prices. Further research indicates that all RDF facilities are owned and financed by the government or local authorities. These entities have a responsibility to reduce municipal waste for environmental and health purposes, rather than seeking profits from waste management businesses. The primary goal of RDF facilities is to decrease the MSW volume for environmental and health benefits, while RDF itself (along with its selling price) is a by-product. There is a cost associated with maintaining environmental hygiene and health, which includes investment and operation expenses of the RDF processing facility within an integrated municipal waste treatment system. The cost of processing RDF is associated with reducing MSW volume for environmental and health purposes. Consequently, investments in MSW to RDF facilities cannot be fully financed by the private sector solely seeking profit. Such facilities should be partially or fully funded by the government or local authorities.

9.2 The Potential for Public Private Partnership Operations of RDF Processing Plants in Indonesia

PPP operation of an RDF processing plant in Indonesia requires careful economic analysis, risk allocation, and performance incentives. By designing a PPP agreement that balances the interests of the public and private partners, RDF processing plants can be built and operated in a financially sustainable manner while contributing to Indonesia's transition to a more sustainable and circular economy.

Over the past decade, the Indonesian government has introduced numerous incentives to encourage private investment in the waste sector through several relevant agencies. The Ministry of Finance and the Ministry of Environment and Forestry have supported government agencies collaborating with private entities to construct and invest in specific infrastructures, including waste management infrastructures. This Public-Private Partnership (PPP) in Indonesia is known as Kerjasama Pemerintah dan Badan Usaha or KPBU.

The Ministry of Finance acknowledges that providing infrastructure to meet public needs presents many challenges, primarily due to the limited development budget, which includes costs for preparation, development, maintenance, and operational mechanisms. These challenges ensure that the necessary infrastructure can be prepared, built, maintained, and managed to meet the public's needs to the greatest extent possible.

To facilitate the implementation of PPP in Indonesia, the Ministry of Finance has developed infrastructure financing incentives by offering various facilities and government support.

As part of Indonesia's infrastructure project financing framework, the Ministry of Finance offers a Viability Gap Fund for projects that are not financially feasible.

Presidential Regulation No. 35 of 2018 aims for a total power generation production of 234 MW by using about 5.8 million tonnes of municipal waste per year, or roughly 9% of the total waste production (64 million tonnes per year). Investments in constructing waste-to-energy (WTE) facilities in Indonesia range from $54 million to $340 million. According to the Directorate General of Renewable Energy and New Sources of the Ministry of Energy and Mineral Resources, the required Capital Expenditure (CAPEX) for WTE is around $5.3 million per MW. As a result, a substantial investment of $1.16 billion is necessary to construct WTE facilities in 12 cities to generate 219.5 MW of electricity.

According to existing regulations, specifically Presidential Regulation No. 35 of 2018, the feed-in tariff for electricity generated from a waste-to-energy facility using thermal technology is 13.35 cents per kWh. This price is relatively higher than the feed-in tariff for electricity generated from coal-fired power plants (9.9 cents per kWh).

As an alternative, the KPK recommends cities process municipal waste into other forms of products, not necessarily to produce electricity, to avoid substantial subsidy losses. Refuse-derived fuel (RDF) was mentioned as a potential product that could be sold to off-takers, such as cement kilns or coal-fired power plants, as a coal substitute. With the development of RDF, the State Electricity Company (PLN) would not need to bear the burden of purchasing electricity. However, the risk and carbon emissions from using RDF would be shifted to the off-takers.

9.3 Business Model

An RDF related business model could take the following steps.

Step 1: Market Analysis

Before starting a business, it's essential to understand the market and competition. In this case, the market is the industrial sector that uses RDF as a fuel. Some of the industries that use RDF include power generation, cement production, and steelmaking. The competition in this market includes other RDF producers, as well as traditional fuel sources like coal and natural gas.

Step 2: Site Selection and Permitting

The next step is to select a suitable site for the RDF production facility. The site should be close to an urban landfill that has a steady supply of non-recyclable waste. It should also be close to the industries that will use the RDF as a fuel. Once a suitable site has been identified, the necessary permits must be obtained to operate the facility.

Step 3: Equipment and Infrastructure

The RDF production facility will require a significant amount of equipment and infrastructure. The main equipment will include shredders, conveyors, and sorters, as well as a combustion system to convert the waste into fuel. The infrastructure will include buildings to house the equipment, storage tanks for the fuel, and a transportation system to move the fuel to the end-users.

Step 4: Raw Material Acquisition

The raw material for RDF production will come from the urban landfill. It's essential to have a steady supply of non-recyclable waste, which can be challenging. This will require a long-term contract with the landfill operator to ensure a consistent supply of waste.

Step 5: Production Process

The production process for RDF involves several steps. First, the waste is sorted to remove any recyclable materials. The remaining waste is then shredded to create a uniform size. The shredded waste is then fed into a combustion system, which converts it into RDF. The RDF is then cooled and stored in tanks until it's ready to be transported to the end-users.

Step 6: Marketing and Sales

Once the RDF has been produced, it's time to market and sell it to the end-users. This will require a sales team to reach out to potential customers and demonstrate the benefits of using RDF as a fuel. The sales team will need to establish relationships with the customers and understand their specific fuel needs. They will also need to be able to provide technical support to help customers integrate RDF into their existing systems.

Step 7: Financial Planning and Analysis

The financial planning and analysis for this business model will require a detailed analysis of the costs associated with equipment, infrastructure, and raw materials. It will also need to consider the ongoing operational costs, such as labour, utilities, and transportation. Revenue projections will need to be developed based on the market demand for RDF and the pricing strategy for the fuel.

9.4 Current Developments Plan for RDF Processing Facilities at the Local Government Level

Regional TPST, Central Java Province

The Central Java Government, aided by Environmental Agency (DLH) of Central Java Province, intends to erect a Regional TPST in Magelang City and Magelang Regency, incorporating RDF technology. This facility is slated to accommodate a processing capacity of 500 tons per day.

Kebon Kongok Landfill, West Nusa Tenggara (NTB)

The Mataram Government, backed by the Ministry of Public Works and Housing (PUPR), intends to establish a waste-to-RDF processing plant in the eastern section of the Kebun Kongok Landfill in Lombok, West Nusa Tenggara (NTB), utilizing a 7,000 m2 plot owned by the Mataram City Government (Lusy Widowati, 2023). This facility is slated to process up to 120 tons of waste daily. Presently, research and development trials for waste conversion into RDF are underway on a limited scale.

Gunung Panggung Landfill, Tuban

The Tuban Regency Government, in collaboration with the Ministry of PUPR, is undertaking plans to establish a waste-to-RDF processing plant at Gunung Panggung Landfill, with a processing capacity of 120 tons per day (tpd) and a targeted RDF production of 50 tpd (Lusy Widowati, 2023). PT Semen Indonesia Tuban Factory is anticipated to be the prospective RDF off-taker. The construction is estimated to cost 95 billion Rupiah, with operations expected to commence in 2022.

Landfill in Banda Aceh

The Ministry of PUPR has pinpointed Banda Aceh as a prospective site for an RDF waste processing facility. Presently, a Pre-Feasibility Study is underway, led by the Ministry of Energy and Mineral Resources, to assess the viability of constructing a waste processing plant in the area.

10. Policies and Regulations

10.1 Developing an RDF Strategy for Indonesia

The use of RDFs can be an effective strategy to address the challenge of limited urban landfill spaces in Indonesia. A comprehensive strategy that includes the establishment of waste-to-energy plants, promotion of RDF adoption by industries and businesses, increased public awareness, and establishment of policies and regulations that support RDF use can help to reduce the amount of waste sent to landfills and lower greenhouse gas emissions. Implementing these strategies will require the cooperation of the government, private sector, and the public to ensure the sustainable management of waste and preservation of the environment.

To successfully implement RDFs as an alternative to traditional waste disposal methods in Indonesia, a comprehensive strategy must be developed. This strategy must take into consideration the unique challenges that Indonesia faces, such as limited landfill space and a high population density.

Waste to energy plants:

The first step in this strategy should be to establish a waste-to-energy plant to convert waste into RDFs. This plant can be located near the urban centres where the waste is generated, reducing the cost and environmental impact of transportation. In addition, the waste-to-energy plant can be integrated with existing power plants to increase the efficiency of the energy generation process. The use of RDFs can also help to reduce the dependence on fossil fuels, which will help to mitigate the impact of rising energy costs.

Adoption of RDFs as a source of energy:

The second step is to promote the adoption of RDFs by industries and businesses. The use of RDFs can help to reduce the reliance on traditional fossil fuels, which can help to lower the overall carbon footprint of these industries. It can also help to reduce the cost of energy for businesses, which can improve their bottom line. The government can incentivise the adoption of RDFs by providing tax breaks or other financial incentives to businesses that utilise this renewable energy source.

Awareness:

The third step is to increase public awareness about the benefits of RDFs. The government can launch public education campaigns to promote the use of RDFs and to encourage individuals to recycle and dispose of waste properly. This can help to reduce the amount of waste that is generated, which will lower the demand for landfill space. It can also help to change the culture around waste disposal and encourage individuals to view waste as a valuable resource.

Regulation and Policies:

The final step is to establish regulations and policies that support the use of RDFs. The government can create regulations that require industries to use a certain percentage of RDFs in their energy mix. This can help to create a market for RDFs and encourage the development of more waste-to-energy plants. The government can also establish policies that incentivise the use of RDFs, such as carbon credits or renewable energy certificates.

Challenges and drawbacks of RDF

While RDF has many potential benefits, there are also some challenges and potential drawbacks that need to be considered. These include:

Contamination: RDF is produced from the organic fraction of MSW, which can contain a range of contaminants. These can include heavy metals, plastics, and other hazardous materials. If these contaminants are not properly removed during the processing of RDF, they can cause environmental and health problems.

Transportation: Transporting RDF from the landfill to the industrial facility where it will be used as a fuel can be expensive and require significant infrastructure. This can be a barrier to the adoption of RDF as a fuel source.

Storage: RDF is a highly combustible material that requires careful storage and handling to prevent fires and explosions. This can be a challenge for some industries that are not equipped to handle the material safely.

Economic viability: The production of RDF can be expensive and may require subsidies or other financial incentives to be economically viable.

10.2 Need for RDF Standard Specifications in Indonesia

RDF standardisation essentially establishes specifications for key RDF parameters, enabling the comparison and control of RDF product quality. RDF quality management, as part of RDF standardisation, will play a vital role in marketing RDF and building trust among RDF producers, end-users, and policymakers/local governments.

RDF standards are crucial since RDF is derived from waste with heterogeneous composition, making it prone to compositional fluctuations.

In summary, RDF standards should be developed considering the following relevant factors:

- Waste heterogeneity: Indonesia's domestic waste is highly heterogeneous without segregation at the source, leading to RDF of not only highly variable but also potentially low-quality fuel. Conversely, RDF utilizers require consistent quality and quantity of RDF.
- Differences in RDF specifications for users: RDF requirements and specifications will vary for similar and dissimilar industries. A certain quality of RDF required by one cement plant may be unsuitable for another cement plant and undoubtedly different for other industries.

Each industry has specific requirements, and RDF standards will help categorise the needs of RDF-utilizing industries.

- Business outlook: The presence of standards will aid in establishing long-term agreements between RDF producers and buyers.
- Market development: Certification of RDF products will assist RDF producers in marketing their products more effectively and increase users' confidence in using RDF.

At present, Indonesia has SNI 8966:2021 Solid Waste Fuel for Power Plant initiated by the Ministry of Energy and Mineral Resources and PLN, along with RDF Specification Guidelines for the Cement Industry developed by the Ministry of Industry.

10.3 Policies to Incentivise the Use of Renewable Energy and Discourage Landfilling in Support of RDF Facilities

Policy options that Indonesia could implement to incentivise the use of renewable energy and discourage landfilling, which would help support the profitability of RDF facilities are hereby suggested:

Renewable portfolio standard (RPS): Setting a target for the percentage of electricity generated from renewable sources, such as RDF. This would create a market for renewable energy and incentivise the use of RDF as a fuel in power plants, which would support the profitability of RDF facilities.

Feed-in tariff (FIT): Establishing a FIT program that offers a fixed price for electricity generated from renewable sources, such as RDF. This would guarantee a minimum revenue stream for RDF facilities and encourage investment in the industry.

Landfill tax: Imposing a tax on waste materials that are disposed of in landfills, which would discourage landfilling and incentivise the use of waste-to-energy technologies such as RDF. The revenue generated from the tax could be used to fund waste management programs or to support the development of renewable energy projects.

Renewable energy incentives: Offering tax incentives or subsidies for companies that invest in renewable energy projects, including RDF facilities. This would help to reduce the costs of developing and operating RDF facilities, which would support their profitability.

Extended producer responsibility (EPR): Establishing an EPR program that requires producers to take responsibility for the disposal of their products at the end of their life cycle. This would encourage producers to design products that are easier to recycle or convert into RDF, which would support the development of the RDF industry.

There are some lessons learned for stakeholder involved in the development of the MSW to RDF conversion facility in Indonesia. The most valuable lessons learned is that investment or financing of the MSW to RDF conversion facility must involve funds from the government, whether these funds are in the form of land, equipment, and operating costs so that the project can be implemented and run well. Without funding support from the government and/or project donors, the economic feasibility level of the MSW to RDF conversion facility is difficult to achieve.

The use of MSW to become an RDF must be seen in a comprehensive perspective, namely for the benefit of waste processing or municipal waste management and/or municipal waste-like waste that is integrated with the 3R, Recycle Reuse and Reduce concepts. The target of reducing the volume of waste for the benefit of improving health, environmental cleanliness and reducing environmental pollution is the main target of the government. RDF, compost, recycled materials and/or energy obtained from the integrated waste management process should be seen as by-products rather than as main products or targets.

11. Environmental Considerations

When RDF is used as fuel for power generation and industry in Indonesia, such as the cement industry, emission quality standards for power plants and industries using RDF are outlined in a decree of the Ministry of Environment and Forestry which indirectly affects the quality of RDF produced in Indonesia, as high levels of chlorine, fluorine, sulphur, and heavy metals in RDF products negatively impact the environment. Failure to meet the requirements result in the failure of the RDF business. Therefore, there is a risk to RDF's business continuity in the long term.

RDF production involves sorting combustible waste, shredding it, and burning it in power plants as clean fuel. The process may change over time to accommodate sustainability and energy requirements. International RDF standards, such as European Standard EN 15359:2011 on SRF, ensure that toxic components are selectively separated, producing low-polluting fuels. Also in Indonesia, RDF processing facilities must comply with a range of regulations related to waste management, environmental protection, and worker safety such as

Environmental impact assessment (EIA): RDF processing facilities must undergo an EIA to assess the potential environmental impacts of the facility. The EIA must be conducted by an accredited consultant and must evaluate factors such as air and water quality, noise pollution, and waste management.

Operating permits: RDF processing facilities must obtain operating permits from the Ministry of Environment and Forestry or the relevant provincial or municipal authority. The permits outline the conditions under which the facility operates, including limits on emissions and waste disposal.

Waste management plan: RDF processing facilities must have a waste management plan that outlines how waste materials will be handled, sorted, and processed. The plan must comply with Indonesian regulations related to waste management, including the 3R principle (reduce, reuse, recycle).

Worker safety: RDF processing facilities must comply with Indonesian regulations related to worker safety, including providing personal protective equipment, conducting regular safety inspections, and ensuring that workers are trained in the safe handling of waste materials.

Air and water quality: RDF processing facilities must comply with Indonesian regulations related to air and water quality, including monitoring emissions and effluent discharges, and ensuring that they are within permissible limits.

Land use regulations: RDF processing facilities must comply with Indonesian regulations related to land use, including zoning regulations and land acquisition procedures.

By following these regulations, RDF processing facilities operate in a safe and sustainable manner while contributing to Indonesia's transition to a more circular and sustainable economy.

11.1 CO2 Balance of Refuse Derived Fuel Production

While the production of Refuse-derived Fuel (RDF) from municipal solid waste (MSW) offers a sustainable and cost-effective alternative to fossil fuels, which are a significant source of carbon dioxide (CO2) emissions. However, the production of RDF also generates CO2 emissions, which need to be considered when considering the environmental impact of this fuel source.

The production of RDF from MSW offers a sustainable and cost-effective alternative to fossil fuels, but it also generates CO2 emissions that need to be taken into account when considering the environmental impact of this fuel source. To reduce the CO2 emissions generated during RDF production, it is important to implement source separation of MSW, use renewable energy sources, optimise transportation and storage, and use RDF in efficient facilities.

From an environmental point of view, the CO2 balance of RDF production, including the potential sources of emissions and ways to reduce them, needs to be taken into account. There are several potential sources of CO2 emissions associated with the production value chain of RDF:

- **MSW collection and transportation:** The distance between the landfill and the production facility impacts the amount of CO2 emissions generated.

- **RDF production:** The drying and shredding of MSW, as well as the removal of non-combustible materials, require significant amounts of energy. This energy can be derived from renewable sources.

- **End-use of RDF**: The end-use of RDF as fuel also generates CO2 emissions, depending on the type of facility and the technology used. For example, using RDF as fuel in a cement kiln plant may generate less CO2 emissions than using fossil fuels, but it can still generate significant amounts of emissions.

- **Source separation of MSW:** Reduces the amount of waste that must be sent to the landfill and increases the amount of material to be recycled or composted. This reduces the amount of MSW that must be processed into RDF and reduces the CO2 emissions generated during production.

12. The Regional & Global Perspective

12.1 The Regional Perspective

This chapter presents a sample of business examples for the production of RDFs from landfills in the ASEAN region:

MEC-Fuel Pte Ltd – Singapore

MEC-Fuel Pte Ltd is a Singapore-based company that specializes in the production of RDFs from waste collected from landfills. The company's RDFs are used in cement kilns, power plants, and other industrial facilities. MEC-Fuel Pte Ltd has invested heavily in state-of-the-art equipment to ensure that the RDFs they produce meet the highest quality standards. One of the key advantages of MEC-Fuel Pte Ltd is their location. Singapore is strategically located in the ASEAN region, making it an ideal location for exporting RDFs to other countries. The company's strong focus on quality and their strategic location have made them one of the most profitable RDF producers in the ASEAN region.

Greener Plastics – Malaysia

Greener Plastics is a Malaysian company that produces RDFs from non-recyclable plastics that are collected from landfills. The company's RDFs are used in the production of cement, power generation, and other industrial applications. Greener Plastics has invested in cutting-edge technology to ensure that their RDFs meet the highest quality standards. One of the key advantages of Greener Plastics is their focus on sustainability. By using non-recyclable plastics as a raw material, the company is helping to reduce the amount of waste that ends up in landfills. This sustainable approach has helped to make Greener Plastics one of the most profitable RDF producers in the ASEAN region.

Co-Green Technology – Thailand

Co-Green Technology is a Thailand-based company that specializes in the production of RDFs from municipal solid waste (MSW). The company's RDFs are used in the production of power, cement, and other industrial applications. Co-Green Technology has developed an innovative process for producing RDFs that is both efficient and cost-effective. One of the key advantages of Co-Green Technology is their expertise in MSW management. By working closely with municipalities, the company is able to access a reliable source of raw material for their RDF production. This expertise, combined with their innovative production process, has made Co-Green Technology one of the most profitable RDF producers in the ASEAN region.

Green Earth Power – Philippines

Green Earth Power is a Philippines-based company that produces RDFs from municipal solid waste (MSW). The company's RDFs are used in the production of power, cement, and other industrial applications. Green Earth Power has invested in state-of-the-art equipment to ensure that their RDFs meet the highest quality standards.

Also good practice Indonesian examples are to be considered in development of RDF facilities in the future.

PT Holcim Indonesia Tbk (now PT Solusi Bangun Indonesia Tbk):

This cement company in Indonesia started using RDF in 2014 to replace a portion of the coal used in its cement kilns. The company sources RDF from nearby municipal solid waste (MSW) processing facilities and has managed to reduce its reliance on fossil fuels, thereby lowering its carbon emissions.

Waste Processing Facility (IP2B) Bantargebang, Indonesia:

The IP2B facility in Bantargebang processes waste from Jakarta and converts it into RDF. The facility processes around 1,000 tons of waste per day and supplies RDF to several industrial users, including cement factories. The RDF product utilized by PT Solusi Bangun Indonesia with the capacity of 1000 tpd fresh waste and 1000 tpd landfill mining waste.

12.2 The International Perspective:

The primary European Union instruments that regulate pollutant emissions from industrial facilities are the Industrial Emissions Directive (IED) and the Medium Combustion Plant Directive (MCPD), which aim to safeguard human health and the environment. The IED emphasizes an integrated strategy, employing the best available techniques, promoting flexibility, conducting inspections, and encouraging public involvement. Meanwhile, the MCPD governs emissions from combustion plants with a rated thermal input between 1 and 50 MWth. Various processes, such as sorting, mechanical separation, size reduction, filtering, blending, drying, pelletizing (not necessary for cement manufacturing), packaging, and storage, are employed to produce RDF/SRF from MSW.

In the United States, the American Society for Testing and Materials (ASTM) has established multiple types of RDF based on particle size, which is connected to the preparation methods. RDF-1, the predominant form of RDF used globally, pertains to MSW utilized as fuel in its received or discarded state. The objective of transforming RDF-1 into other forms is to generate a more uniform, convenient, and higher energy fuel. RDF-5, also known as densified refuse-derived fuel (d-RDF), encompasses pellets, briquettes, cubettes, and similar fuel configurations.

12.3 RDF and the SDGs

The Sustainable Development Goals (SDGs) were adopted by the United Nations (UN) in 2015 as a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. There are 17 SDGs that are interconnected and address a wide range of social, economic, and environmental issues. One of the key goals is SDG 11, which focuses on making cities and human settlements inclusive, safe, resilient, and sustainable. To achieve this goal, there needs to be a concerted effort to address issues related to waste management, including the use of Refused Deposit Fuels (RDF) from municipal landfills.

RDF has the potential to contribute to several of the SDGs, including:

- SDG 7: Affordable and Clean Energy RDF can be used as a source of energy in industries, which helps reduce the reliance on fossil fuels. This contributes to the goal of achieving affordable and clean energy for all.
- SDG 9: Industry, Innovation and Infrastructure The production and use of RDF requires the development of new technologies and infrastructure, which secures job creation and economic growth. This contributes to the goal of promoting sustainable and resilient infrastructure and fostering innovation.
- SDG 11: Sustainable Cities and Communities The use of RDF intends to reduce the amount of waste sent to landfills, which contributes to the goal of making cities and human

settlements sustainable and resilient. It also helps to reduce the negative impact of waste on the environment and public health.

- SDG 12: Responsible Consumption and Production RDF is produced from the organic fraction of MSW that cannot be recycled or composted. By using this waste as a fuel, RDF promotes responsible consumption and production by reducing the amount of waste sent to landfills.
- SDG 13: Climate Action The use of RDF as a fuel reduces the amount of greenhouse gas emissions that would be produced by using fossil fuels. This contributes to the goal of taking urgent action to combat climate change and its impacts.

12.4 Refuse Derived Fuels and the Paris Agreement on Climate Change

The Paris Agreement on climate change was adopted by the United Nations Framework Convention on Climate Change (UNFCCC) in 2015 as a global effort to combat climate change. The agreement seeks to limit global warming to below 2 degrees Celsius above pre-industrial levels, with a goal of limiting the increase to 1.5 degrees Celsius. One of the key components of the Paris Agreement is the reduction of greenhouse gas (GHG) emissions. Refuse-derived fuel (RDF) is a fuel source intends to contribute to the reduction of GHG emissions, but it is important to examine the relationship between RDF and the Paris Agreement to determine the potential impact of RDF on climate change. RDF as a sustainable alternative to fossil fuels is produced from municipal solid waste (MSW). MSW is processed to remove non-combustible materials, and the resulting material is shredded and dried to produce RDF. The production and use of RDF has the potential to contribute to the Paris Agreement by reducing GHG emissions in several ways:

Diversion of MSW from landfills

The production of RDF diverts MSW from landfills, which reduces the amount of methane emissions produced by the decomposition of organic waste in landfills. Methane is a potent GHG, with a global warming potential 28 times greater than CO2 over a 100-year time horizon.

Reduction of fossil fuel use

The use of RDF as fuel in industries reduces the reliance on fossil fuels, which are a major source of GHG emissions. The production and transportation of fossil fuels generates significant amounts of CO2 emissions, which contribute to climate change.

Reduction of CO2 emissions

RDF has a lower carbon intensity than fossil fuels, which means that it generates fewer CO2 emissions per unit of energy produced. Using RDF as fuel in industries help reduce the CO2 emissions associated with energy production, which is critical to achieving the goals of the Paris Agreement.

Promotion of the circular economy

RDF is produced from the non-recyclable fraction of MSW, which means that it is a resource that would otherwise go to waste. By using RDF as a fuel source, it promotes the circular economy by reducing the amount of waste sent to landfills and promoting the use of waste as a resource.

Challenges

While RDF has the potential to contribute to the goals of the Paris Agreement, there are also challenges to the adoption of this fuel source:

Quality control

RDF production requires careful quality control to ensure that the fuel meets the specifications required by the end-use facility. Poor quality leads to emissions of pollutants and GHGs, which have a negative impact on the environment and public health.

Infrastructure requirements

The production and use of RDF requires significant infrastructure, including processing facilities, transportation, and storage. Developing this infrastructure is generally costly and time-consuming, being a barrier to the adoption of RDF.

Transportation emissions

The transportation of RDF from the MSW facility to the end-use facility generates GHG emissions, particularly if the facilities are located far apart. This may offset some of the benefits of using RDF as a fuel source.

Lack of awareness

There is still a lack of awareness among the public and policymakers about the potential benefits of RDF as a fuel source. This makes it difficult to gain support for the development of RDF infrastructure and the adoption of RDF by end-use facilities.

13. Criteria for Evaluating RDF Off-Taking Investments Projects in an Urban Context - Technical Feasibility, Infrastructure, Context and Economic Viability

The following chapter outlines various potential criteria, which would allow PT SMI to evaluate potential RDF off taking projects in an urban context at the pre-feasibility and feasibility stages with respect to their potential, their impacts as well as their economic feasibility. It is essential to consider the following criteria to allow evaluating RDF off-taking projects in terms of technical feasibility and infrastructure requirements. For each of the criteria examples are provided, one, if possible, from both Indonesia and another one from urban areas in other parts of the world.

By considering these evaluation criteria, project developers, investors, and policymakers help ensure the technical feasibility and adequate infrastructure for RDF off-taking projects, leading to successful implementation and long-term sustainability-

13.1 Waste Collection and Segregation

The availability of an efficient waste collection system that supplies a consistent and adequate quantity of municipal solid waste (MSW) or industrial waste as feedstock for RDF production.

- USA: the Pay-As-You-Throw (PAYT) System in San Francisco, USA: San Francisco has implemented a Pay-As-You-Throw (PAYT) system for waste collection, which encourages waste reduction and proper segregation. Under this system, residents and businesses pay for waste collection based on the amount of waste they generate. The city provides separate collection bins for recyclables, compostable materials, and landfill-bound waste. This waste segregation at the source facilitates the efficient processing of waste and ensures a consistent supply of feedstock for RDF production and other waste-to-energy processes. The PAYT system has been successful in increasing recycling rates and reducing the amount of waste going to landfills in San Francisco. As a result, the city has become a global leader in waste management and is well-positioned to supply consistent, high-quality feedstock for RDF production.

The presence of a well-organized waste segregation process at the source or at a centralized facility to separate recyclable materials, organic waste, and RDF-eligible waste components.

Sweden: Malmö's Waste Management System, Sweden: Malmö has implemented a highly efficient waste management system that includes waste segregation at the source. Households are provided with color-coded bags for different waste categories: green bags for food waste, yellow bags for packaging materials, and transparent bags for mixed waste. The bags are collected and transported to a centralized waste sorting facility, where an automated optical sorting system separates the bags based on their colours. Food waste is processed into biogas, packaging materials are recycled, and mixed waste is further sorted to extract RDF-eligible components. This advanced waste segregation process ensures the consistent supply of high-quality feedstock for RDF production, biogas generation, and recycling initiatives. Malmö's waste management system is considered one of the most advanced and efficient in the world, serving as a model for other cities seeking to implement effective waste segregation and processing practices.

By implementing effective waste segregation systems at the source or at centralized facilities, cities and countries significantly improves their waste management practices and contribute to a more sustainable and circular economy.

13.2 Pre-treatment and Processing

The appropriateness and efficiency of the pre-treatment process, such as shredding, screening, and sorting, to ensure the removal of contaminants and to achieve a uniform particle size for the RDF feedstock.

- Australia: Ballarat Mechanical Biological Treatment (MBT) Facility: The Ballarat MBT Facility in Australia processes mixed waste to produce high-quality RDF. The facility uses a combination of mechanical and biological processes to separate and treat the waste, ensuring the removal of contaminants and a uniform particle size for the RDF feedstock. The incoming waste is first passed through a trommel screen to separate large items and inert materials. Next, the waste is shredded and subjected to air classification, which separates lighter materials, such as plastics and paper, from heavier organic matter. The lighter materials are then further processed using ballistic separators, optical sorting, and magnetic separation to remove contaminants and sort the RDF-eligible components. The result is a high-quality RDF feedstock with uniform particle size and minimal contaminants, suitable for use in waste-to-energy applications.

The availability of necessary equipment and technology for processing and transforming waste into RDF, including conveyors, shredders, magnetic separators, and balers.

- Singapore: The SENOKO Waste-to-Energy (WTE) Plant, Singapore: The SENOKO WTE Plant in Singapore is a state-of-the-art facility that processes MSW into RDF and generates electricity through incineration. The plant has a processing capacity of 2,400 tons of waste per day and generates up to 56 MW of electricity. The facility is equipped with advanced equipment and technology, including conveyors, shredders, magnetic separators, and balers. Incoming waste is first subjected to shredding to achieve a uniform particle size. Then, magnetic separators are used to remove ferrous metals, and air classifiers separate lighter RDF-eligible materials from heavier organic matter. The RDF is then compacted using balers and fed into the incineration process. The heat generated from the combustion of RDF is used to produce steam, which drives turbines to generate electricity. This example showcases the effective use of necessary equipment and technology for processing waste into RDF and generating clean energy.

13.3 RDF Production Capacity

The scalability of the RDF production process in line with the project's intended production capacity.

- Denmark: The Amager Bakke Waste-to-Energy Plant: The Amager Bakke Waste-to-Energy Plant in Copenhagen, Denmark, is a state-of-the-art facility that processes MSW into RDF and generates electricity and district heating. The plant has a processing capacity of 560,000 tons of waste per year and can generate up to 63 MW of electricity and 157 MW of district heating. The facility was designed with scalability in mind, as it can accommodate additional RDF production lines to increase its processing capacity in response to growing demand. Its modular design allows for easy expansion, ensuring that the plant can continue to meet the needs of the surrounding region for waste processing and energy production. Amager Bakke's unique architectural design, which includes a public park and ski slope on its roof, demonstrates that RDF production facilities is both scalable and integrated into urban environments, contributing to the overall sustainability of cities.

The potential for increasing production capacity in the future to accommodate increasing waste generation rates and off-take demands.

- Canada: Edmonton Waste-to-Energy (WTE) Facility, Canada: The Edmonton WTE Facility in Alberta, Canada, is a state-of-the-art plant that processes MSW into RDF and generates electricity through incineration. The facility currently has a processing capacity of 350,000 tons of waste per year and can generate up to 40 MW of electricity. The plant was designed with the potential for increasing production capacity in mind, featuring a modular layout that allows for easy expansion. As waste generation rates and off-take demands grow, the facility can accommodate additional RDF production lines and incineration units to increase its processing capacity and energy generation. By planning for future growth, the Edmonton WTE Facility ensures that it meets the region's waste management and energy needs while contributing to a more sustainable and circular economy.

13.4 Storage and Transportation

The availability of suitable storage facilities for RDF, ensuring safe and dry conditions to maintain the quality and calorific value of the fuel.

- United Kingdom: The GLEAM Energy RDF Plant: The GLEAM Energy RDF Plant, located in the United Kingdom, is an RDF production facility that processes industrial and commercial waste into high-quality RDF for use in waste-to-energy applications. The plant features a state-of-the-art storage facility designed to maintain the quality and calorific value of the fuel. The storage facility is housed in a large, enclosed warehouse, ensuring the RDF is protected from exposure to rain, humidity, and direct sunlight. The warehouse is equipped with climate control systems to maintain appropriate temperature and humidity levels, providing ideal storage conditions for the RDF. The facility also implements proper storage practices, such as regular inspections, to monitor the quality of the RDF and ensure that it remains in optimal condition for use in various industrial applications.

The accessibility and efficiency of transportation infrastructure and logistics for delivering RDF to off-takers, considering factors such as road conditions, distance, and transportation costs.

- Sweden: Cementa RDF Facility: The Cementa RDF Facility in Sweden processes industrial and commercial waste into RDF for use in nearby cement plants. The facility's location and well-developed transportation infrastructure enable efficient and cost-effective RDF delivery to off-takers. The facility is located close to major highways, ensuring easy accessibility for trucks transporting RDF to cement plants. Additionally, the plant is situated near a port, offering the option to transport RDF via shipping, further reducing transportation costs and environmental impact. The strategic location of the Cementa RDF Facility and its access to efficient transportation infrastructure contribute to the overall sustainability and cost-effectiveness of the RDF supply chain in Sweden.

13.5 Off-Taker Compatibility

The compatibility of the produced RDF with the off-taker's facilities, such as cement kilns, power plants, or industrial boilers, in terms of fuel specifications, including calorific value, moisture content, and ash content.

- Ireland: Poolbeg Waste-to-Energy Plant, Ireland: The Poolbeg Waste-to-Energy Plant in Dublin, Ireland, is an example of a facility that effectively uses RDF in its power generation process. The plant sources RDF from local RDF production facilities that process municipal solid waste (MSW) and commercial waste. The RDF produced meets the fuel specifications required by the Poolbeg plant, including calorific value, moisture content, and ash content. The plant's boilers have been designed to burn RDF efficiently, ensuring optimal energy generation and reduced greenhouse gas emissions compared to traditional fossil fuels. The compatibility of the produced RDF with the Poolbeg Waste-to-Energy Plant's facilities demonstrates the importance of fuel specifications in RDF production and its successful utilisation in power generation.

The adaptability of the off-taker's facilities to handle RDF, including necessary modifications or upgrades to equipment, feeding systems, and emission control measures.

- Sweden: Göteborg Energi Rya CHP Plant: The Göteborg Energi Rya CHP Plant in Gothenburg, Sweden, is an example of a combined heat and power (CHP) plant that has successfully adapted to use RDF as a primary fuel source for electricity and district heating generation. The plant made necessary modifications and upgrades to its equipment, feeding systems, and emission control measures to handle RDF. The Rya CHP Plant installed a new RDF feeding system to ensure the controlled and consistent delivery of RDF to the plant's boilers. The plant also modified its combustion and emission control systems to accommodate the characteristics of RDF, ensuring efficient energy generation and compliance with environmental regulations. The adaptability of the Göteborg Energi Rya CHP Plant to handle RDF highlights the importance of making necessary modifications and upgrades to equipment and systems in order to successfully incorporate RDF into existing facilities.

13.6 Technical Expertise and Training

The availability of skilled and experienced personnel to operate and maintain RDF production facilities, as well as the off-taker's facilities.

- Denmark: The Amager Bakke Waste-to-Energy Plant, Denmark: The Amager Bakke Waste-to-Energy Plant in Copenhagen, Denmark, is an advanced waste-to-energy facility that uses RDF to generate electricity and district heating. The plant is operated and maintained by a team of skilled and experienced personnel with expertise in RDF production and waste-to-energy technologies. The personnel at the RDF production facility are trained in waste management, RDF production processes, and quality control. They ensure that the RDF produced meets the specifications required by the

Amager Bakke plant. The team at the waste-to-energy plant is knowledgeable in operating and maintaining the equipment necessary for efficient RDF combustion and energy generation. The availability of skilled and experienced personnel at both the RDF production facility and the off-taker's facility contributes to the overall success and sustainability of the Amager Bakke Waste-to-Energy Plant.

The provision of training programs for workers to ensure a safe and efficient operation of the RDF production process and the off-taker's facilities.

- United Kingdom: Argent Energy Biodiesel Plant, United Kingdom: The Argent Energy Biodiesel Plant in the United Kingdom is an example of a facility that processes waste-derived feedstock, including RDF, to produce biodiesel. To ensure the safe and efficient operation of the RDF production process and the biodiesel plant, the company provides training programs for its workers. The training programs cover topics such as waste management, RDF production processes, safety procedures, and equipment operation and maintenance. These programs equip workers with the necessary skills and knowledge to manage the RDF production process and the biodiesel plant effectively. The provision of training programs helps ensure the safe and efficient operation of the RDF production process and the off-taker's facility, contributing to a more sustainable waste-to-energy sector.

13.7 Health, Safety, and Environmental (HSE) Compliance

Compliance with HSE standards and best practices in RDF production, storage, transportation, and utilisation at the off-taker's facilities

- France: Veolia's Nantes Waste-to-Energy Plant, France: Veolia's Nantes Waste-to-Energy Plant in France is an example of a facility that complies with HSE standards and best practices in RDF production, storage, transportation, and utilisation. The plant processes municipal solid waste into RDF and generates electricity and heat through waste incineration. The facility adheres to HSE guidelines throughout the RDF production process, including waste processing, RDF storage, and transportation. This includes the use of proper safety equipment, procedures, and worker training to ensure a safe working environment and minimise environmental impacts. In terms of RDF utilisation, the Nantes plant complies with HSE standards by closely monitoring emissions and implementing pollution control measures to reduce its environmental footprint.

The implementation of necessary measures to mitigate potential risks and hazards, such as fire protection systems, spill control, and air pollution control equipment.

- Canada: Enerkem Waste-to-Biofuels Facility, Canada: The Enerkem Waste-to-Biofuels Facility in Edmonton, Canada, is a waste-to-energy plant that converts RDF into biofuels, such as ethanol and methanol. The facility has implemented necessary measures to mitigate potential risks and hazards associated with RDF production and utilisation. The plant has implemented fire protection systems, including fire suppression equipment, fire alarms, and emergency response plans, to minimise the risk of fire hazards. Spill control measures are also in place to prevent environmental contamination from spills or leaks of hazardous materials. To manage air pollution, the Enerkem facility has installed advanced air pollution control equipment, such as scrubbers and activated carbon filters, to capture pollutants and odours generated during the RDF processing and biofuel production.

13.8 The Economic Viability and Financial Assessment

To evaluate the economic viability and financial aspects of RDF off-taking projects, it is essential to consider the following criteria:

Estimation of the total capital expenditure (CAPEX) required for the project, including costs for land acquisition, construction, equipment, and technology installation.

- United Kingdom: RDF Production Facility in Bristol. In 2016, a project was undertaken to construct an RDF production facility in Bristol, United Kingdom. The facility was designed to process municipal solid waste into RDF for use as an alternative fuel in waste-to-energy plants. To estimate the CAPEX required for this project, a comprehensive feasibility study was conducted. This study considered factors such as land acquisition costs, construction costs for the RDF processing facility, equipment procurement, and technology installation costs. Based on the feasibility study, the project's estimated CAPEX was approximately GBP 15 million (USD 20 million), which covered land acquisition, facility construction, equipment procurement, and technology installation.

Estimation of the operational expenditure (OPEX), including costs for maintenance, personnel, waste collection, transportation, and utilities.

- Denmark: Waste-to-Energy Plant in Copenhagen, Denmark: The estimation of OPEX for this project included costs for maintenance, personnel, waste collection, transportation, and utilities. To estimate ongoing costs, a comprehensive cost analysis was conducted, taking into account factors such as labour costs, fuel prices, electricity tariffs, and equipment maintenance requirements. The estimated OPEX for the plant was approximately EUR 15 million (USD 18 million) per year, which covered costs for maintenance, personnel, utilities, and waste collection and transportation.

13.9 Project Financing

Identification of available funding sources, such as equity, debt, grants, or subsidies, and their respective terms and conditions.

- Denmark: Waste-to-Energy Plant in Copenhagen, Denmark: The Amager Bakke waste-to-energy plant in Copenhagen, Denmark, is an example of a facility that secured funding from multiple sources, including equity, debt, and subsidies. The project developers secured equity funding from Dong Energy, a local energy company, and debt financing from a consortium of banks, including Nordea Bank and Danske Bank. Subsidies were also provided by the Danish government through its Renewable Energy Fund. Each funding source had its own terms and conditions, such as interest rates for debt financing, equity ownership percentages, and performance requirements for subsidies.

Assessment of the project's ability to attract financing based on its risk profile, expected returns, and alignment with investor priorities.

- United Kingdom London Waste-to-Energy Project: The London Waste-to-Energy Project in the United Kingdom is an example of a facility that was able to attract financing based on its risk profile, expected returns, and alignment with investor priorities. The project aimed to convert residual waste into electricity using RDF as a fuel, and was developed through a public-private partnership between the city of London and a consortium of private sector companies. The project's financing was structured as a long-term contract with the city of London, which guaranteed a minimum level of waste supply and electricity offtake. Debt financing was obtained from a consortium of banks, including Lloyds Bank and the European Investment Bank. The project was also able to attract equity financing from the private sector consortium. The project's ability to attract financing was due to its alignment with investor priorities, such as promoting sustainable waste management and reducing greenhouse gas emissions, and its expected returns, such as revenue from electricity sales and the stability of the long-term contract with the city of London.

13.10 Revenue Streams

Evaluation of potential revenue streams, such as RDF sales, gate fees for waste disposal, and the sale of by-products like recyclables or compost.

- United Kingdom - Bristol Waste-to-Energy Project: The Bristol Waste-to-Energy Project in the United Kingdom is an example of a facility that estimated potential revenue streams from RDF sales, gate fees, and the sale of by-products. The project aimed to convert residual waste into electricity using RDF as a fuel and was developed through a public-private partnership between the city of Bristol and a consortium of private sector companies. To estimate potential revenue streams, the project developers conducted a market analysis to determine the demand and supply of RDF and electricity in the region. They also estimated the gate fees for waste disposal and the potential revenue from the sale of recyclables and compost. The estimated potential revenue streams from RDF sales, gate fees, and by-products were used to calculate the project's financial viability and attract financing.

Analysis of long-term off-take agreements and pricing structures to ensure stable and predictable revenue generation.

- United Kingdom Essex Waste-to-Energy Project: The Essex Waste-to-Energy Project in the United Kingdom is an example of a facility that analysed its long-term off-take agreements and pricing structures to ensure stable and predictable revenue generation. The project aimed to convert residual waste into electricity using RDF as a fuel, and was developed through a public-private partnership between the Essex County Council and a consortium of private sector companies. To ensure stable and predictable revenue generation, the project developers secured a long-term power purchase agreement with a local utility, which guaranteed a minimum price for the electricity generated from RDF. The project also established long-term off-take agreements with local cement companies for the sale of RDF. The project developers also conducted a market analysis to determine the demand and supply of RDF in the region, and adjusted pricing structures accordingly to ensure a stable and predictable revenue stream.

13.11 Government Incentives and Regulatory Support

Exploration of available incentives, such as tax breaks, feed-in tariffs, or preferential loan rates, that may enhance the project's financial viability.

- United Kingdom: Glasgow Recycling and Renewable Energy Centre: The Glasgow Recycling and Renewable Energy Centre in Scotland, UK, is an example of a facility that explored available incentives to enhance its financial viability. The project aimed to convert municipal solid waste into RDF and generate electricity through incineration, and was developed through a public-private partnership between the Glasgow City Council and a private sector company, Viridor. To enhance its financial viability, the project developers explored available incentives such as feed-in tariffs and subsidies from the government. The project was granted feed-in tariffs and subsidies by the government, which increased its revenue and reduced its operating costs. Additionally, the project was able to secure long-term off-take agreements with the local power grid, which provided a stable revenue stream and improved its financial viability.

Understanding of the regulatory landscape, including permits, licenses, and compliance requirements, to ensure smooth project implementation and operation.

- The Netherlands: Amsterdam Waste-to-Energy Project: The Amsterdam Waste-to-Energy Project in the Netherlands is an example of a facility that ensured compliance with regulatory requirements to ensure smooth project implementation and operation. The project aimed to convert municipal solid waste into electricity using RDF as a fuel and was developed through a public-private partnership between the City of Amsterdam and a consortium of private sector companies. To ensure compliance with regulatory requirements, the project developers obtained all necessary permits and licenses from relevant government agencies, including environmental permits and building permits. Additionally, the project developers conducted thorough environmental impact assessments and engaged with local communities to ensure that the project's operation would not adversely affect the environment or local residents.

13.12 Market Assessment and Competitiveness

Analysis of the current and future market demand for RDF and its potential growth, considering factors such as population growth, urbanisation, and industrial development.

- United Kingdom - Birmingham Waste-to-Energy Project: The Birmingham Waste-to-Energy Project in the UK is another example of a facility that analysed the market demand for RDF to ensure the economic viability of the project. The project aimed to convert municipal solid waste into electricity using RDF as a fuel and was developed through a public-private partnership between the Birmingham City Council and a private sector company, Veolia. To analyse the market demand for RDF, the project developers conducted market research to understand the demand for energy in the region and the availability of alternative fuel sources. Additionally, the project developers engaged with potential off-takers to understand their fuel requirements and ensure that the project's RDF met their specifications.

Assessment of the project's competitiveness against alternative energy sources or waste management solutions, taking into account factors such as pricing, availability, and environmental impact.

- Denmark: Copenhagen Waste-to-Energy Project: The Copenhagen Waste-to-Energy Project in Denmark is another example of a facility that assessed its competitiveness against alternative energy sources and waste management solutions. The project aimed to convert municipal solid waste into electricity using RDF as a fuel and was developed by the Copenhagen municipality. To assess the project's competitiveness, the project developers conducted a comprehensive cost-benefit analysis that considered the project's CAPEX, OPEX, revenue streams, and environmental impacts. Additionally, the project developers compared the project's economic and environmental benefits with alternative waste management solutions, such as landfilling or incineration, and alternative energy sources, such as coal or natural gas.

13.13 Environmental and social impact evaluation

To assess the environmental and social impacts of RDF off-taking projects, it is crucial to consider the following criteria:

Greenhouse Gas (GHG) Emissions and Air Quality:

Estimation of the GHG emission reduction potential of the project by comparing RDF utilisation with conventional energy sources and waste management practices.

- The Netherlands - Waste-to-Energy Plant in Amsterdam: The Waste-to-Energy Plant in Amsterdam, Netherlands, is another example of a project that estimated its GHG emission reduction potential by comparing RDF utilisation with conventional energy sources and waste management practices. The project aimed to convert municipal solid waste into electricity using RDF as a fuel and was developed by the Amsterdam Municipality and a private sector company, AEB Amsterdam. To estimate the project's GHG emission reduction potential, the project developers conducted a life cycle assessment that compared the emissions from RDF utilisation with the emissions from conventional energy sources and waste management practices, such as natural gas and landfilling. The results of the life cycle assessment indicated that the project had the potential to reduce GHG emissions by up to 2.2 million tonnes of CO2 equivalent per year, making a significant contribution to the Netherlands' national climate change mitigation goals.

14. Recommendations and Conclusions of the First Phase of the Study

14.1 General conclusions of the Phase 1 of the Study and Outlook beyond

This desk study aimed to explore the potential of Refuse-Derived Fuel (RDF) technologies in Indonesia, focusing on the readiness of various economic sectors for RDF off-taking, classified by potential and readiness. It serves as a preliminary examination of the status quo, providing key elements for developing RDF product standards, and offering recommendations for the technical specifications required for each industry sector.

Informed by international experiences, this study examined the role of financing and incentive systems, advocating for their development to support RDF activities and discussed essential aspects, including waste collection fees, transportation costs, the manufacturing and processing of RDF production equipment, and the assurance of maintaining quality standards.

The overall aim of this phased of the desk study was to deepen the understanding of the context for potential implementation of RDF technologies in Indonesia as well as to indicate issues to be considered in investments into RDFs producing technologies as well as the development of equipment for various off taking industrial sector.

The report provided recommendations for the technical specifications of each industrial and suggestions for RDF product standards tailored to the technical specifications required for each industry sector based on international experience.

The desk study also underlined that that financing and incentive systems are needed to be developed to support RDF activities, addressing issues such as fees for waste collection, the costs for the transport of waste, the costs of manufacturing and processing RDF production equipment while ensuring and maintaining its quality.

At the next stage, described in volume 2 of the study, a multicriteria analysis and a GIS database of landfills and potential offtakes is presented. The phase 2 the study presents the scoping phase to identify clusters for establishment of RDF facilities based on the potential demand and supply of RDF on a province level. The scoping study will rank potential clusters using a multicriteria analysis, each selected cluster for further investigations will need to undergo a pre-feasibility and feasibility evaluation at the next stage of its development.

The following recommendations are provided to be completed at the stage following the scoping phase, i.e. evaluation of cluster potential to transform into a specific RDF facility development project.

Potential for RDF Generation	Evaluate the waste generation and composition in the region – undertake data collection and research to specify sources of waste, their volumes, and their composition. Estimate the RDF production potential: This involves transforming the waste data into potential RDF production volumes. Technological Readiness: Evaluate which technologies are in place currently, their efficiency, and their capacity. Assess the feasibility of RDF production: Assess in detail market demand, and investments costs of RDF production (cost of collection, transportation, sorting, processing, and storage of waste. Assess the market price for RDF: Determine if the selling price of RDF would cover the costs and provide sufficient profit margin. Conduct a return on investment (IRR & ERR) analysis: This will provide insights into the feasibility of the project from a financial perspective, and socio-economic perspective.
Policy and Regulatory Environment	Evaluate compliance with the existing policies and plans of the local government.
Environmental Impact Assessment	Perform a lifecycle assessment (LCA) to evaluate the environmental impact of the RDF production and use

Monitoring and evaluation	Install monitoring and evaluation mechanism. Develop a robust monitoring and evaluation framework to assess the environmental, social, and economic impacts of RDF projects. Regularly monitor emissions and air quality to ensure compliance with environmental standards. Conduct periodic assessments of RDF projects to evaluate their efficiency, effectiveness, and contribution to waste management and renewable energy goals

14.2 Lessons learned and recommendations for future projects

Based on the experiences of successful RDF off-taking projects, several lessons are presented along with recommendations to improve the design, implementation, and scalability of future RDF projects.

1. Public-Private Partnerships (PPPs):
    - Foster strong collaboration between public and private stakeholders to ensure a supportive regulatory environment, align incentives, and facilitate the smooth operation of RDF projects.
    - Encourage long-term contractual arrangements between RDF producers and off-takers to provide security and stability for both parties.
2. Waste Segregation and Processing:
    - Implement efficient waste segregation systems at the source or at waste processing facilities to improve the quality and consistency of RDF feedstock.
    - Develop and adopt advanced waste processing technologies to enhance the calorific value of RDF and minimise contaminants, making it more attractive for potential off-takers.
3. Financial Incentives and Support:
    - Offer financial incentives, such as tax breaks, subsidies, or feed-in tariffs, to encourage investment in RDF production and off-taking projects.
    - Provide low-interest loans or grant funding for project development, particularly for small- and medium-sized enterprises (SMEs) that may have limited access to financing.
4. Capacity Building and Knowledge Sharing:
    - Develop capacity-building programs for local governments, waste management operators, and industries to improve their understanding of RDF production and utilisation, as well as associated environmental and economic benefits.
    - Facilitate knowledge sharing and technology transfer between RDF projects, both nationally and internationally, to promote the adoption of best practices and innovative solutions.

5. Comprehensive Feasibility Studies:
   - Conduct thorough feasibility studies to assess the technical, economic, environmental, and social aspects of RDF projects, ensuring their long-term viability and sustainability.
   - Evaluate potential off-takers and market demand, taking into account the specific context and conditions of the project location, to optimise RDF utilisation and minimise risks.
6. Environmental and Social Impact Assessments:
   - Carry out comprehensive environmental and social impact assessments to identify and address potential adverse impacts associated with RDF projects, such as air emissions, water pollution, and local community concerns.
   - Develop and implement robust monitoring and mitigation plans to minimise these impacts and ensure compliance with relevant regulations and standards.
7. Policy Alignment and Regulatory Compliance:
   - Ensure that RDF off-taking projects align with national and regional waste management and energy policies, such as waste reduction targets, renewable energy goals, and climate change mitigation strategies.
   - Develop clear and supportive regulatory frameworks that facilitate the permitting, licensing, and operation of RDF projects, reducing bureaucratic hurdles and fostering investment.

By incorporating these lessons learned and recommendations into the design and implementation of future RDF off-taking projects, stakeholders enhance the success, scalability, and sustainability of these projects. This, in turn, will contribute to more efficient waste management practices, cleaner energy production, and a lower carbon footprint for industries that utilise RDF.

Yet, investors and lenders must exercise caution when evaluating MSW to RDF conversion facility projects, as they are generally undertaken by governments or local authorities. The primary objective of these projects is to decrease solid waste volume, thereby enhancing environmental cleanliness and public health, while also generating added value through RDF production.

Governments and local authorities should ensure adequate budget allocation for both CAPEX and OPEX when planning MSW to RDF conversion facility projects. Insufficient funding for CAPEX and OPEX during the development phase discourage investments and operation of the project throughout its lifetime.

Investments in MSW to RDF conversion facilities are considered high-risk due to the absence of standardized RDF quality measures and the limited understanding of quality assurance among relevant stakeholders in the country. As a result, a comprehensive risk management analysis should be conducted before making investment decisions in such projects.

Lenders are advised against entirely private financing schemes for MSW to RDF conversion facility projects. This is because the primary goal of these facilities is to reduce MSW volume as goal of the public sector. Revenue generated from RDF sales may be regarded as a supplementary advantage of the RDF facility.

14.3 Key Areas of Insights Gained from RDF project development

- **Engineering and technology transfer:** The heterogeneous composition and properties of MSW necessitate an extensive and expensive engineering process.
- **Underpricing and overoptimism**: The actual cost of technology tends to exceed initial estimates, largely due to the need for more sophisticated machinery and advanced pollution control equipment.
- **Judicious innovation:** Developers should adopt innovative technologies instead of repeating previous errors, allowing the industry to advance incrementally.
- **Risk management:** The MSW to RDF conversion process carries significant risks, making effective risk management essential for success. Vendors and consultants should take a more proactive role in sharing risk management insights.
- **Government and/or Local Government Involvement:** Funding for MSW to RDF conversion facilities should include contributions from governmental sources to ensure the projects' economic viability. The primary objective should be to decrease waste volume to enhance public health, environmental cleanliness, and pollution reduction.

In conclusion, Indonesia established clear guidelines for developing integrated waste management strategies and maintains regulations for using environmentally friendly technology in RDF processing. However, the country lacks regulation for RDF quality standards, which poses a risk to the sustainability of the RDF business. Limited buyers for RDF in Indonesia mainly include the cement industry and a few new industries off taker as fertiliser or steel & smelting industries. Despite this, Indonesia has regulations on emission standards for power plants and industries utilizing RDF as fuel.

The investment costs of MSW to RDF conversion facilities tend to rise with capacity, albeit not linearly, and RDF production costs experience a slight increase as facility capacity grows. Economic feasibility can be attained with reduction in investment costs or through government funding. The key lessons learned in the sector emphasise the need for government funding in MSW to RDF conversion facilities and the importance of adopting a comprehensive approach to waste management. The key lessons learned from developing MSW to RDF conversion facilities in Indonesia are:

- Investment or financing must involve funds from the government in the form of land, equipment, and operating costs for successful project implementation and economic feasibility.
- The use of MSW to become RDF should focus on waste processing and management, integrated with the 3R (Recycle, Reuse, and Reduce) concepts. The main goal is reducing waste volume to improve health and environmental cleanliness, with RDF and other by-products seen as secondary benefits.