REFUSE-DERIVED FUEL IN INDONESIA

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NEXUS3 FOUNDATION

IPEN for a toxics-free future

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Authors

Yuyun Ismawati, Nindhita Proboretno, Mochamad Adi Septiono, Krishna Zaki

Contact: nexus3@nexus3foundation.org

IPEN is a network of over 600 non-governmental organizations working in more than 120 countries to reduce and eliminate the harm to human health and the environment from toxic chemicals.

www.ipen.org

Nexus3 or Nexus for Health, Environment, and Development (formerly known as BaliFokus Foundation) is an organization in Indonesia that works to safeguard the public, especially vulnerable populations, from the impact of development to health and the environment, towards a just, toxics-free, and sustainable future.

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CONTENTS

LIST OF ABBREVIATIONS

AMDAL	*Analisis Mengenai Dampak Lingkungan*/Environmental Impact Assessment
CFB	Circulating Fluidized Bed
EBT	Energi Baru dan Terbarukan/New Energy Sources and Renewable Sources
ESDM	Energi dan Sumber Daya Alam/Energy and Mineral Resources
PC	Pulverized Coal
PEF	Processed Engineered Fuel
PLN	Perusahaan Listrik Negara/State-Owned Electricity Company
PLTSa	Pembangkit Listrik Tenaga Sampah/Electricity from Waste facility
PLTU	Pembangkit Listrik Tenaga Uap/Coal-fired power plant
PT SBI	PT Solusi Bangun Indonesia
PT SIG	PT Semen Indonesia Group (SIG) or PT Semen Indonesia
RDF	Refuse-Derived Fuel
SRF	Solid Recovered Fuel
STRL	*Sertifikat Teknologi Ramah Lingkungan* or STRL
TSR	Thermal Substitution Rate
TRL	Technology Readiness Level
TKT	Tingkat Kesiapterapan Teknology
WTE	Waste-to-Energy

CONVERSION

1 kcal/kg	0.0042 mega Joule/kg
1 mega Joule	239.006 kcal/kg
1 tonne	1 metric ton

1. INTRODUCTION

Since the early 1990s, the production of alternative fuels has become a quite popular waste management option in different countries. Solid Recovered Fuel (SRF) is considered a complementary intervention to preparing the residual waste stream for material recovery or disposal in landfills. The treatment processes that produce waste-derived fuels have been widely implemented in some countries.

SRF is a subset of the larger family of Refuse-Derived Fuels (RDFs), produced from non-hazardous waste streams, and differing from a "generic" RDF in that it is a type of fuel that meets specific requirements (i.e., classification and specification) defined by a national or international standard.

These treatment processes often involve some sort of mechanical treatment (MT) or mechanical-biological treatment (MBT). It is important to highlight that SRFs put on the market never equals one, univocal kind of fuel, but alternative fuels of which the properties might differ from each other.

India and China, which have to manage high annual amounts of wastes and satisfy their internal demand for energy, recently started developing

Figure 1. Transboundary shipments of RDF (red line) and SRF (blue line) in Asia. Source: Ishigaki Tomonari, 2017

domestic pre-treatment systems for SRF. They have also become a rather consistent importer of SRF/RDF from neighbouring producing countries.

The transboundary shipment of SRF and RDF is significant, also in Europe. For example, the United Kingdom exports significant amounts to countries like Germany, the Netherlands, and Sweden. Different factors drive the trade, but policy, waste treatment capacities, and current market prices are some of the main reasons.

In Asia, RDF and SRF have been traded between Cambodia, China, India, Indonesia, Thailand, Malaysia, Myanmar, and Vietnam for many years [1].

As an international reference, a classification of waste fuels introduced by the American Standards for Testing of Materials (ASTM) is now considered as main reference in many countries. Table 1 shows the seven types of RDF based on pre-sorted municipal solid waste (MSW) [1].

TABLE 1. SEVEN TYPES OF RDF BASED ON PRE-SORTED MUNICIPAL SOLID WASTES (MSW)

RDF-1	Waste used as fuel in as-discarded form
RDF-2	Waste processed to coarse particle size, with or without ferrous metal separation.
RDF-3	Shredded fuel derived from MSW that has been processed to remove metals, glass, and other inorganic materials (95%wt., passes 50mm^2 10 mesh)
RDF-4	Combustible waste processed into powder form (95%wt., passes 50mm 10 mesh)
RDF-5	Combustible waste densified (compressed) into a form of pellets, slugs, briquettes, or briquettes (d-RDF)
RDF-6	Combustible waste processed into liquid fuel
RDF-7	Combustible waste processed into liquid, gaseous fuel

Source: The American Standards for Testing of Materials (ASTM)

As a big nation with more than 270 million citizens, to Indonesia, solid waste management is a massive challenge. In 2020, the country's waste generation reached 67.8 million metric tonnes (Mt), which is estimated to grow at a significant rate for the foreseeable future [2]. In addition, the increased rate of solid waste management infrastructure and its financing cannot keep up with waste generation. As a result, a vast amount of unmanaged waste pollutes Indonesian land and rivers, as well as the ocean.

The Solid Waste Management Act No. 18/2008 was issued to improve solid waste management in Indonesia, including the cessation of all open dump waste disposal by 2013. The ambitious target was not achieved, as the Ministry of Environment and Forestry recently recorded that 198 open dump waste disposal facilities remain in operation.[1]

In 2020, at least 20 landfills were almost full and will need to be closed, extended, or replaced with a new site. The rate of managed waste in Indonesia remains low at 56.57%.

In the last five years, there has been increasing global concern about plastic pollution. Researchers identified Indonesia as the second-largest ocean plastic polluter [3, 4]. Furthermore, Indonesian researchers have estimated that 0.27–0.59Mt of plastic waste has been discharged into the Indonesian ocean [5]. Meanwhile, waste recycling in Indonesia, which largely relies on the informal sector and amounts to less than 5% of waste generated [6], has a plastic recycling rate of only 7% [7].

The situation is worsened by the fact that plastic and plastic recycling industries are primarily only available on Indonesia's major islands, namely Java and Sumatra. Further, a survey conducted by the Ministry of Environment and Forestry in 2020 revealed that about 17.6% of total waste generation nationwide is plastic waste and about 38.2% of wastes is generated by households.[2] However, waste generation in Indonesia differs between big cities and small cities. The World Bank estimates that the waste generation rate is 3.57 liter/capita/day, equivalent to 0.87 kg/capita/day [8]. Meanwhile, plastic waste generated per capita is 0.07 kg of plastic waste/capita/day or about 8% of the total waste generation rate [9].

The National Plastic Action Partnership (NPAP) report has revealed that Indonesia's plastic recycling rate in 2020 was approximately 10% of the total plastic waste generation, or 6.8 million tonnes [10]. The study also identified that around 4.2 million tonnes, or 61%, of post-consumer plastic wastes are not collected by waste collectors or management systems but leaked to the environment. The rest is ending up in landfills.

1.1. POLICY AND REGULATION ON WASTE MANAGEMENT

Law No. 18 concerning Solid Waste Management, issued in 2008, is the umbrella policy for waste management in Indonesia. The law is supported by several Government Regulations (Peraturan Pemerintah), mainly issued by The Ministry of Environment and Forestry (KLHK). The law stipulates that waste management in Indonesia should prioritise waste minimisation.

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1 Sistem Informasi Pengelolaan Sampah Nasional, https://sipsn.menlhk.go.id/sipsn/ accessed by 10 June 2021

2 Ibid.

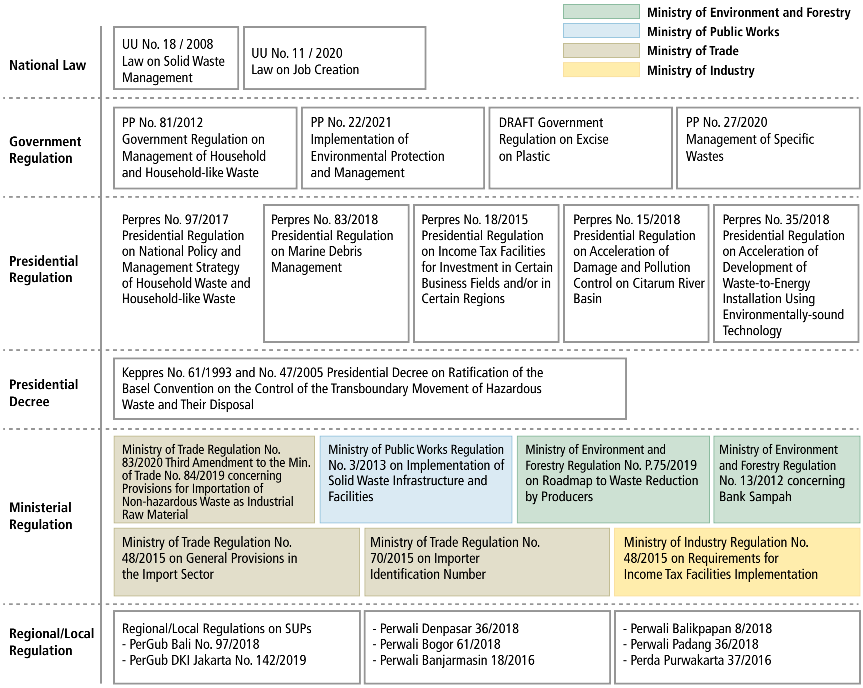


Figure 2. Summary of Indonesia's national waste management regulations (as of July 2021). Source: KLHK-SWI (2019), Nexus3-ICEL-AZWI (2021)

KLHK stated that the local government had improved the quality of waste management through the preparation of the Regional Waste Management Strategy Policy (Jakstrada), which is a mandate from Presidential Regulation No. 97 year 2017 on National Policy and Management Strategy on Household Waste and Household-like Waste.[3]

This policy provides a direction towards balanced waste management based on the amount of waste generated in 2025, and the phase-out and prohibition of several types of single-use plastics such as plastic shopping bags, plastic straws, and styrofoam containers.

Figure 2 provides a summary of Indonesia's national waste management regulations (as of July 2021). Due to the pandemic, several draft regulations are still in the pipeline and might be released in 2022. By the end of June 2021, two provinces and 58 regencies/cities have issued regional

3 Perpres No. 97/2017 tentang Kebijakan dan Strategi Nasional Pengelolaan Sampah Rumah Tangga dan Sampah Sejenis Sampah Rumah Tangga https://peraturan.bpk.go.id/Home/Details/73225/perpres-no-97-tahun-2017

policies related to waste reduction through the prohibition and restriction of single-use plastics. To promote plastic waste reduction at the upstream level, the Ministry of Environment and Forestry had issued a regulation stipulating the mandates for producers to develop a roadmap to reducing 30% of their plastic packaging by 2030.[4]

For RDF application and implementation, several regulations have been issued to support producers and offtakers.

1.2. WASTE GENERATION AND PLASTICS WASTES

The World Bank observed approximately three million people engaged in waste recycling in Indonesia, including informal collection, waste picking, collection, processing, and trade. An informal collection of recyclables in Java is estimated at 10%, and less on other islands due to transport costs and lack of local capacity for trade and treatment. Most of the items collected by waste pickers are plastic, metals, and cardboard with varying price per kilogram, depending on the product type, source, and collection level (from the source, from waste pickers, from collector/middleman, etc.), ranging from US$0.04 - US$1.19/kg [8].

Proper recycling, around 2%, is happening through waste banks/Bank Sampah through the voluntary segregated collection at the community level, and around 8% from sorting of mixed waste in the form of self-reported, including household composting.

The Ministry of Environment and Forestry has established a national action plan to reduce waste up to 30% and manage properly up to 70% by 2025.[5] The national action plan is also targeting the reduction of plastic waste leakage to the ocean up to 0.075 - 0.18 million tonnes per year. Further, the national policy and strategy (*Kebijakan dan Strategi Nasional* or *Jakstranas*) is that by 2025, the recycling rate target will be 50%, waste-to-energy plants will be available in 12 cities, RDF plants will be built in 34 cities/regencies, and restrictions or regulations to limit single-use plastics will be established in 257 cities/ regencies in 17 provinces.

Based on the national policy and strategy stipulated in Law No. 18/2008 concerning waste management, and the Presidential Decree No. 97/2017, there are three main approaches to tackle waste in Indonesia:

4 Peraturan Menteri Lingkungan Hidup dan Kehutanan Republik Indonesia No. P.75/MENLHK/SETJEN/KUM.1/10/2019 tentang Peta Jalan Pengurangan Sampah oleh Produsen http://jdih.menlhk.co.id/uploads/files/P_75_2019_PETA_JALAN_SAMPAH_menlhk_12162019142914.pdf

5 The National Policy and Strategy (Jakstranas) refers to Presidential Regulation No. 97 year 2017 concerning National Policies and Strategies for the Management of Household Waste and Types of Household Waste https://peraturan.bpk.go.id/Home/Details/73225/perpres-no-97-tahun-2017

- waste minimisation incorporated into an eco-living lifestyle;
- circular economy; and
- services and technology.

Basic objectives for waste minimisation are behavioural changes and minimisation, prevention, or restriction/limitation of waste generation. The main target stipulated in the Presidential Decree No. 97/2017 is to phase down 1) single-use plastic bags, (2) plastic cutlery, including plastic straws, and (3) styrofoam packaging by 30% by 2029.

The waste minimisation approach, which is widely adopted by sub-national and local governments, is reflected in the prohibition of the production and use of single-use plastics (SUPs). Before the COVID-19 pandemic, more than 20 cities and provincial governments had already issued local regulations to prohibit the single-use plastics, as well as implemented regulations supporting Zero Waste Cities.[6,7] By the end of 2021, two provinces (Bali and Jakarta), and 75 cities and regencies had issued local regulations prohibiting SUPs [11].

For 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) applied the approach of behavioural change through providing enabling systems to support the redesign, reuse, and recycling in certain sectors. To support this goal, the MoEF has created the Circular Economy ecosystem and its support systems, such as the end users of recycled products, the recycling industry, Garbage Bank communities, 3R MRF, recycling centres (*Pusat Daur Ulang*/PDU, Material Recovery Facilities/MRF, Intermediate Treatment Facilities/ITF), involvement of the informal sector players (scavengers), and social enterpreneurs [9].

Complementing the MoEF, the Ministry of Public Works issued technical guidance to establish the 3R MRF [12] based on a regulation issued in 2013[8], and Bappenas released a circular economy policy with five priority sectors [13]. The environmental factors to support a circular economy include fiscal incentives for the recycling industry, sourcing scraps for

6 Jakarta Post, News Desk. 25 December 2018. Bali enacts plastics ban, targeting 70 percent reduced use in 2019. https:// www.thejakartapost.com/news/2018/12/25/bali-enacts-plastics-ban-targeting-70-percent-reduced-use-in-2019.html.

7 Jakarta Post, Ni Komang Erviani. 15 July 2019. Bali wins plastic-ban battle in Court, steps closer to being plastic-free island. https:// www.thejakartapost.com/news/2019/07/15/bali-wins-plastic-ban-battle-in-court-steps-closer-to-being-plastic-free-island.html

8 Peraturan Menteri Pekerjaan Umum No. 03/PRT/M/2013 tentang Penyelenggaraan Prasarana dan Sarana Persampahan Dalam Penanganan Sampah Rumah Tangga Dan Sampah Sejenis Sampah Rumah Tangga http://ciptakarya.pu.go.id/plp/upload/peraturan/ Permen_PU_No_3_Tahun_2013_-_Penyelenggaraan_PS_Persampahan.pdf

industrial materials, imported as well as from domestic sources, and recycling content in packaging or products, etc. By mid 2020, data shows that only 9-11% of post-consumer plastic had been recycled [9, 10].

Policies to support the importation of scraps, especially for paper, plastic, metals, rubber, glass and fabric/rugs, have been issued and revised several times to meet the Basel Convention provisions and the new amendments for the plastics waste trade. Various stakeholders have already discussed a roadmap to phase down the importation of scraps, including enabling infrastructures to increase the recycling rate in Indonesia.

The MoEF has issued another policy stipulating the extended producer responsibility, or EPR, mandating corporations, retailers, and packaging producers to develop strategies to reduce the plastic content of their products and packaging by 30% by 2030, in the Ministry of Environment & Forestry Regulation No. P75/2019.[9]

As for recycled products, a standard for food-contact recycled PET plastics has been issued by the Indonesian Food and Drugs Administration (BPOM) to guide PET recyclers and ensure the safety of the products for consumers [14].

In 2019, Indonesia generated an estimated 57.4 million metric tons of waste and approximately 6.8 million metric tons of plastic wastes [9, 10]. The Indonesian Institute of Science released a baseline number of 0.27-0.59 million tonnes of ocean plastic per year [5]. A study has shown that about 3.2 million metric tons of plastic waste was mismanaged and ended up in marine environments [15]. In the last five years, many studies have been conducted on microplastics in Indonesia's waters, oceans, and coastal regions, in the atmosphere, as well as in food chains [16-23].

The National Plastic Action Partnership (NPAP) developed a system model based on LIPI's calculations, which estimates that approximately 620,000 tonnes of plastic entered Indonesia's waters in 2017 [5, 10]. Research shows that 4.2 million tonnes of plastic are not collected into a managed waste system after use (which equals about 61% of plastic waste). Due to the lack of a collection system, households and small businesses have no other option than to dispose of them in an environmentally harmful way. Recent reports have found that households burn 78% of uncollected plastic waste, often close to their homes, while 12% is discarded the garbage into the water bodies, and 10% is dumped on land or buried [10].

9 Peraturan Menteri Lingkungan Hidup dan Kehutanan No. P75/MENLHK/SETJEN/KUM.1/10/2019 tentang Peta Jalan Pengurangan Sampah Oleh Produsen http://jdih.menlhk.co.id/uploads/files/P_75_2019_PETA_JALAN_SAMPAH_menlhk_12162019142914.pdf

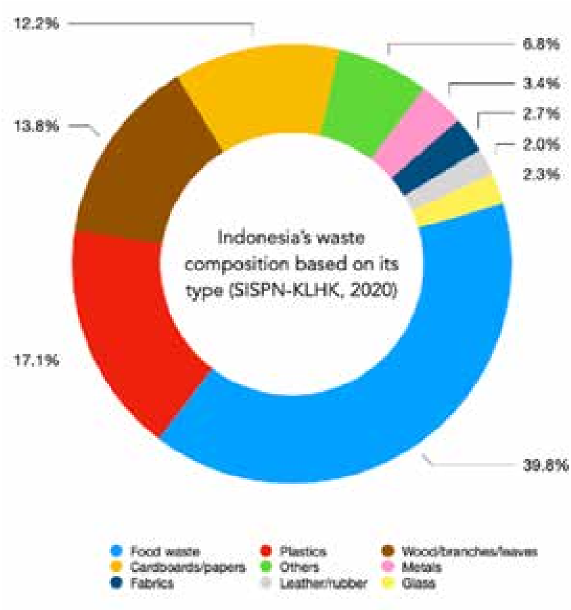


Fig. 3. Waste composition in Indonesia (2020). Source: SISPN - KLHK, 2020

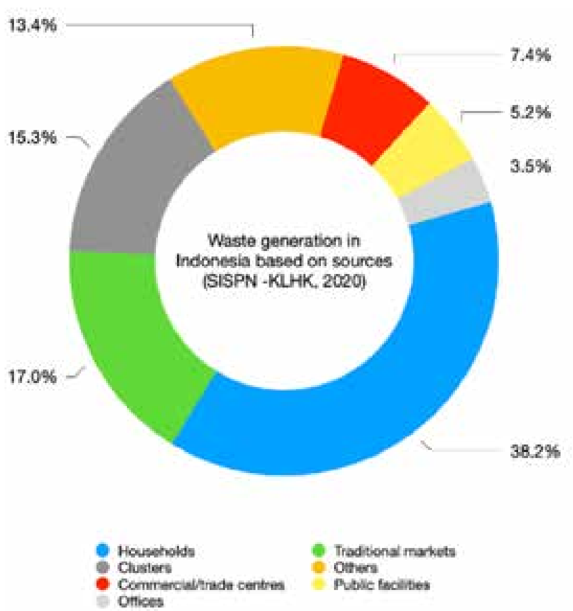


Fig. 4. Waste generation in Indonesia based on sources (2020).
Source: SISPN - KLHK, 2020

There is a notable difference among different types of plastic. Rigid plastics, such as polyethylene terephthalate (PET) bottles, have a higher value for recyclers and cause less pollution. However, some flexible plastics, particularly multi-layered plastics or sachets, cannot be recycled economically. About three-quarters of the plastic waste leaking into the environment are these multi-layers plastics and sachets [10].

1.3. PUBLIC PRIVATE PARTNERSHIP AND SUPPORT SCHEME

The primary concept of the waste management system is collecting, transferring, and sending waste to the disposal sites. Technology interventions have been promoted intensively to support local authorities, especially in dealing with municipal waste management. The technology backed by the relevant agencies is sanitary landfills, landfill gas capture and utilisation, landfill mining, thermal treatment, RDF, recycling, and various composting techniques.

In the last ten years, the Indonesian government has launched various incentives to support private investments in the waste sector through several relevant agencies. The Ministry of Finance and the Ministry of Environment and Forestry supported government agencies cooperating with private entities to build 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 recognised that the provision of infrastructures to meet the needs of the public has many challenges, mainly the limited development budget, including the cost of preparation, development costs, maintenance, and operational mechanisms. This challenge ensures that the required infrastructure can be prepared, built, maintained, and managed to meet the public's needs to the maximum extent possible.

By definition, a PPP is a cooperation between the Government and Business Entities providing infrastructure or services for the public interests.[10] PPP refers to specifications that the government agencies have predetermined which partially or wholly use the resources of the business entity by taking into account the risk-sharing between the parties.

10 Peraturan Menteri Keuangan No. 180/PMK.08/2020 tentang Fasilitas untuk Penyiapan dan Pelaksanaan Transaksi Proyek Kerja Sama Pemerintah dengan Badan Usaha dalam Penyediaan Infrastruktur https://peraturan.bpk.go.id/Home/Details/152732/pmk-no-180pmk082020

To support the implementation of PPP in Indonesia, the Ministry of Finance[11] developed infrastructure financing incentives by providing various facilities and government support, as follow:

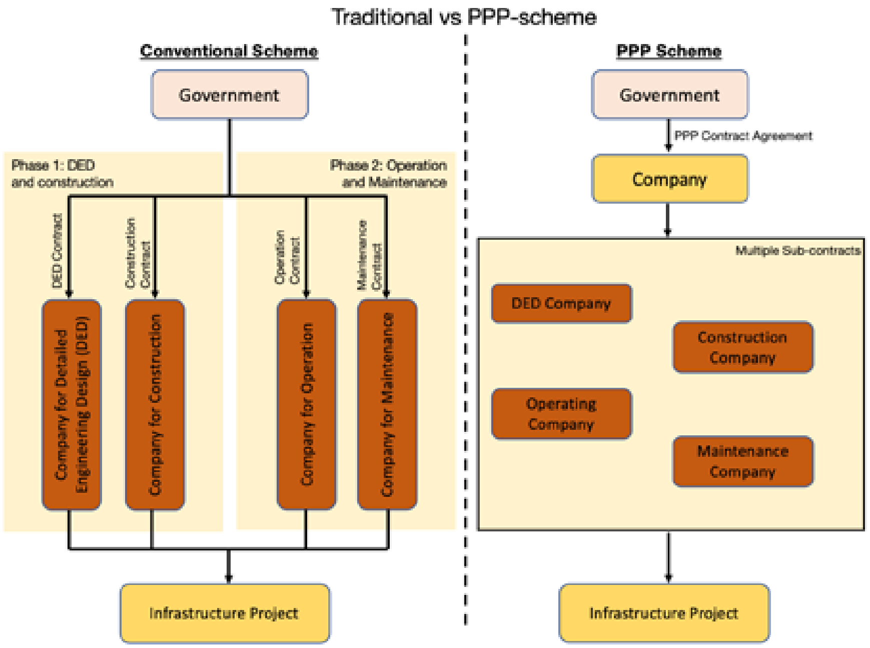
- **Project Preparation Facility**, also known as Project Development Facility (PDF), is a facility provided to assist the responsible person in PPP (*Penanggung Jawab Proyek Kerjasama*/PJPK). The person in charge will receive assistance in preparing the final feasibility study and tender documents. The facility also accompanies the responsible person in PPP project transactions to obtain financing from financial institutions (or achieve financial close).
- **Feasibility Support** or Viability Gap Fund (VGF) is a government support in the form of a partial contribution of construction costs given in cash to PPP projects that already have economic viability but have not have financial feasibility. The Ministry of Finance can provide feasibility support when no other alternatives are available to make the Cooperation Project financially feasible. Local governments also can provide this support after obtaining approval from the Regional House of Representatives for infrastructure guarantees.
- **Infrastructure guarantee** is the provision of guarantees for the person in charge of PPP with financial obligations to pay compensation to business entities in the event of infrastructure risk – following the allocation agreed in the PPP agreement – which is the person in charge's responsibility. Infrastructure guarantees are carried out by *PT Penjaminan Infrastruktur Indonesia* (PT PII) as a single-window policy. If the coverage of underwriting needs exceeds the capital capacity of PT PII, the Ministry of Finance and PT PII will provide a joint guarantee.

In addition to the form of support from the Ministry of Finance above, waste management infrastructure projects with a PPP scheme also receive government support in the form of the tipping fees[12] subsidies for waste management or *Bantuan Langsung Penanganan Sampah*/BLPS, and a feed-in-tariff to sell energy to the grid especially produced by the thermal treatment plants.[13]

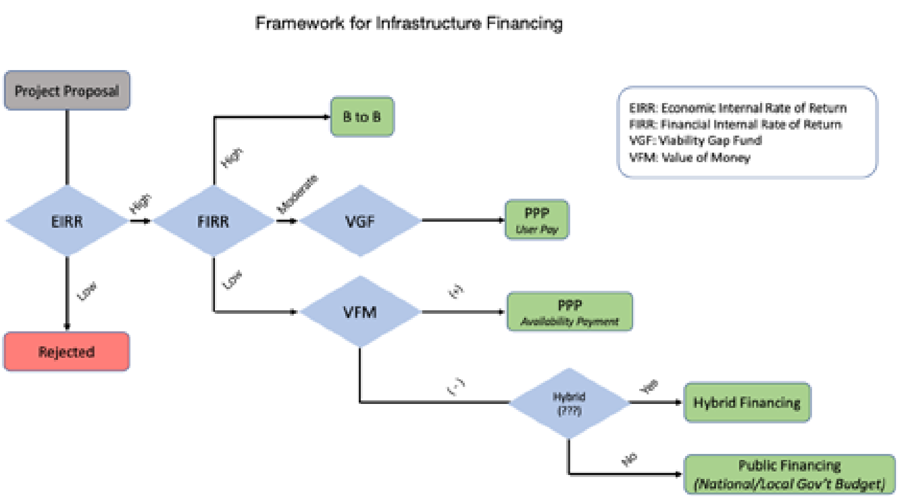
11 Ministry of Finance website, Government Support for PPP. https://kpbu.kemenkeu.go.id/read/19-37/gca/implementation-of-the-ppp/government- support-for-ppp

12 Peraturan Menteri Lingkungan Hidup dan Kehutanan No. P.24/MENLHK/SETJEN/KUM.1/5/2019 tentang Bantuan Biaya Layanan Pengolahan Sampah Dalam Rangka Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan https://peraturan.go.id/common/dokumen/bn/2019/bn796-2019.pdf

13 Peraturan Menteri Lingkungan Hidup dan Kehutanan No. P.24/MENLHK/SETJEN/KUM.1/5/2019 tentang Bantuan Biaya Layanan Pengolahan Sampah Dalam Rangka Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan https://peraturan.go.id/common/dokumen/bn/2019/bn796-2019.pdf



Traditional vs PPP-scheme financing in Indonesia.
Source: Suhendra, Maman et al. 2017



As part of the infrastructure project financing framework in Indonesia, the Ministry of Finance provides Viability Gap Fund or VGF, for projects that are financially not feasible.
Source: Indonesian Ministry of Finance, 2019

The Presidential Regulation No. 35 of 2018 targets a total power generation production of 234 MW by utilizing around 5.8 million tonnes per year of municipal waste, or about 9% of the total waste production (64 million tonnes per year).[14] Investments in the construction of waste-to-energy (WTE) facilities offered by investors in Indonesia range from US$54 million to US$340 million.[15] 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 approximately US$5.3 million per MW. Hence, a significant investment of US$1.16 billion will be needed to build WTE facilities in 12 cities to generate electricity of 219.5 MW of electricity.

The Indonesia's Corruption Eradication Committee or KPK (*Komisi Pemberantasan Korupsi*) has recommended the national agencies to stop the idea of developing waste-to-energy operations in 12 cities because the projects will become a financial burden for the national as well as local governments for the next 25 years.[16]

Referring to the existing regulations, the Presidential Regulation No. 35 year 2018,[17] the feed-in tariff of electricity generated from a waste-to-energy facility with thermal technology is 13.35 cents per kWh. This price is relatively higher than the feed-in tariff for electricity generated from the coal-fired power plants (9.9 cents per kWh).

As an alternative, KPK recommended cities to process municipal waste into other forms of products - not necessarily to produce electricity - to prevent a huge loss of subsidies. RDF was mentioned as a potential form of product that can be sold to the offtakers, such as the cement kilns or coal-fired power plants, as coal substitute. With the development of RDF, the State Electricity Company (PLN) will not need to bear the burden to purchase electricity. However, the risk and the carbon emission from the utilisation of RDF will be shifted to the offtakers.

14 Presidential Regulation No. 35 year 2018 https://peraturan.bpk.go.id/Home/Details/73958/perpres-no-35-tahun-2018

15 https://metro.tempo.co/read/1477352/project-itf-sunter-jalan-di-place-fortum-finnish-backward/full&view=ok

16 Kontan. 4 November 2020. KPK: Proyek PLTSa di 12 daerah bakal bebani anggaran pemda dan PLN selama 25 tahun
https://industri.kontan.co.id/news/kpk-proyek-pltsa-di-12-daerah-bakal-bebani-anggaran-pemda-dan-pln-selama-25-tahun

17 Peraturan Presiden No. 35 tahun 2018 tentang Percepatan Pembangunan Instalasi Pengolah Sampah Menjadi Energi Listrik Berbasis Teknologi Ramah Lingkungan. https://peraturan.bpk.go.id/Home/Details/73958/perpres-no-35-tahun-2018

2. RDF AS ALTERNATIVE FUELS FOR COFIRING AND CO-PROCESSING

2.1. COFIRING IN COAL-FIRED POWER PLANTS

Indonesia's electricity supply mainly comes from coal-fired power plants (37.15%), oil (33.58%), natural gas (23.12%), and renewable energy sources (9.15%). To reduce carbon emission from the energy sector, the Ministry of Energy and Mineral Resources (MoEMR) developed several interventions, among others to:

- increase the efficiency of final energy consumption;
- implement clean coal technology in coal-fired power plants;
- extend the gas network;
- implement a mandatory B30 program (30% palm oil-based fuel);
- promote and increase the renewable and new energy sources up to 23% by 2025 including energy from wastes; and
- increase the number of gas fuel stations (Bahan Bakar Gas/BBG).

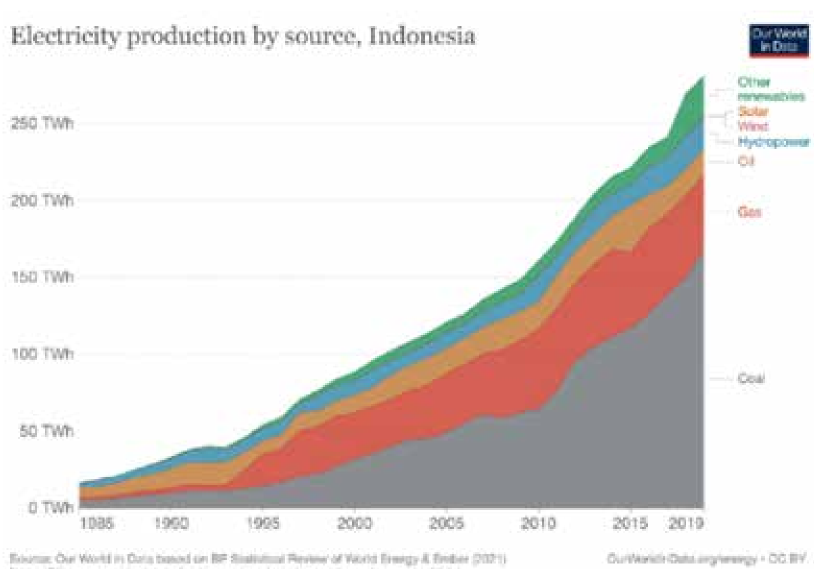


Figure 5. Electricity production by source in Indonesia from 1995 to 2019.
Source: Our World in Data

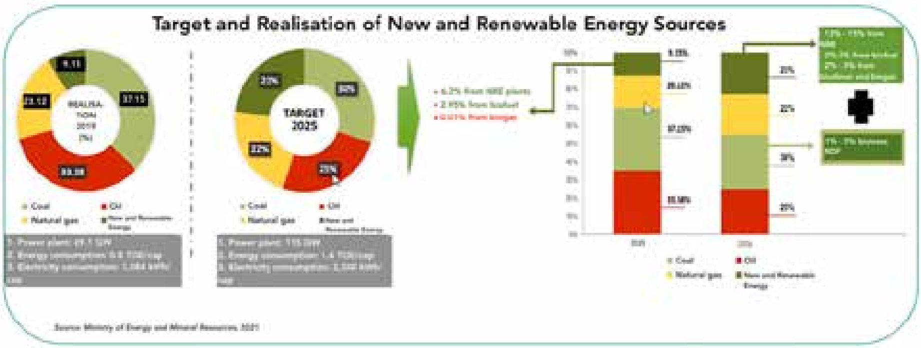


Figure. 6. Target and realisation of new and renewable energy sources in Indonesia 2019 - 2025. Source: Ministry of Energy and Mineral Resources, 2021

The Indonesian government has developed plans to extend the life of PT Perusahaan Listrik Negara's (PLN's) coal-fired power fleet by switching to biomass cofiring, leveraging PLN's existing 18 gigawatts (GW) of coal-fired power plants. The planners claimed that they could slowly increase the biomass power generation by cofiring and under-utilized coal units, while at the same time claiming credit for increasing the renewable energy mix [24]. However, many parties share the view that cofiring is actually supporting the extension of the life of coal-fired power plants and reducing the opportunity for new renewable energy power plants to grow.

The government has prepared a Ministerial Regulation related to the biomass and cofiring program in coal-fired power plants (PLTU) by utilizing biomass as a coal substitute. This program is carried out to achieve the New Renewable Energy (NRE) target of 15% by 2025 [25]. Figure 6 shows the target mix of energy supply by 2025.

PLN's cofiring roadmap set out plans to migrate 114 existing coal-fired power plants, with a total capacity of 18,154 MW, by 2024 and includes feedstock management improvement between 2021 and 2023. The cofiring plan will require large-scale biomass production to secure stable alternative fuel supplies of between 4 to 9 million tonnes annually [24].

Cofiring can be done by burning two or more types of fuel from different materials in the same combustion system. This can be done in three boiler types — PC Boiler, CFB Boiler and Stoker Boiler — by implementing these three methods:

- **Direct cofiring:** the cheapest and most commonly used option;
- **Indirect cofiring:** biomass is first gasified into fuel gas and then used as fuel; and
- **Parallel cofiring:** biomass is burned separately, popularly used in the pulp and paper industry.

Figure 7. Distribution of 52 coal-fired power plants in Indonesia with RDF co-firing. Source: PT PLN Persero, 2021

Figure 8. PT Indonesia Power launched the waste-to-energy co-firing program at the Lontar Coal-fired Power Plant (PLTU) in Tangerang, Banten. Photo: Petrominer, 2020

Figure 9. PT PLN Persero has successfully implemented co-firing on 17 PLTUs until June 2021. Photo: Sindonews, 2021

By the end of 2021, PT. PLN through its subsidiaries has conducted cofiring trials at 21 PLTUs with different technologies (Circulating Fluidized Bed/CFB, stoker and Pulverized Coal/PC) using wood chip biomass as raw materials — wood pellets, palm oil kernel shells, and waste pellets/SRF, at percentages ranging from 1- 30%.

To maintain the quality of the RDF, pre-treatment is required before it can be used in the WTE system, with preliminary treatment needed in the form of natural, bio-drying or mechanical drying. The pre-treatment is done by preheating the RDF materials to evaporate water that is carried

TABLE 4. WASTES USED FOR ALTERNATIVE FUEL SOURCES AND THEIR ENERGY CONTENT

Wastes	Energy (MJ/kg)[a]	Energy (kcal/kg) (Petcode ~ 7 500)[b]
Used tire	23.03	5 500
Husk	19.93	4 760
Industrial plastic	18.21	4 350
Waste oil	14.65	3 500
Scrap paper	14.23	3 400
Contaminated waste	14.23	3 400
RDF plastic	11.72	2 800
Sewage sludge	8.37	2 000

Source: [a]Akcansa (2010) and [b]Ekincioglu et al. (2012)

along with the waste, and to facilitate combustion. RDF pellets are also claimed by PLN to contain less sulfur compared to coal and are seen by the Ministry of Energy and Mineral Resources as having the potential to reduce CO_2, NO_x and SO_x emissions from the energy sector.

Assuming the percentage of biomass pellet mixing is 5% for PC and CFB boilers and 30% for stoker boilers, about 4 million tonnes/year of biomass pellets will be needed for cofiring in the 114 PLTU units owned by PLN spread over 52 locations throughout Indonesia. Additionally, 749,000 tonnes of pellets per year will be needed, assuming the percentage of waste pellet mixing is 1% in the three types of PLTU boilers. More study is needed to assess the risks of the offtakers to prevent the failure of nation-wide RDF investments.

TABLE 3. RDF CHARACTERISTICS STANDARD FOR USE IN COAL-FIRED POWER PLANT (PLTU) AS COAL SUBSTITUTE.

No.	Parameter tested	Unit min/max	Class 1	Class 2	Class 3	Test Methology
1	Organic materials[a]	%, min	95	95	95	-
2	Sizing					
	Fluff					
		Min. mesh number	200	200	200	
		mm, min.	0.074	0.074	0.074	
		Max. mesh number	50	50	50	
		mm, max.	0.297	0.297	0.297	
	Pellets					
	Diameter	mm, min.	6 ± 1.0	6 ± 1.0	6 ± 1.0	
		mm, max.	10 ± 1.0	12 ± 1.0	12 ± 1.0	
	Length	mm	$3.15 \leq P \leq 40$	$3.15 \leq P \leq 40$	$3.15 \leq P \leq 40$	
	Briquettes					
	Diameter	mm, min.	50	50	50	
		mm, max.	70	70	70	
	Length, thickness	mm, min.	20	20	20	
		mm, max.	70	70	70	
3	Density					
	Fluff	gram/cm^3, min.	0.4	0.4	0.4	SNI 8021
	Pellets	gram/cm^3, min.	0.8	0.7	0.6	SNI 8021
	Briquettes	gram/cm^3, min.	0.9	0.9	0.9	SNI 8021
4	Water content[b]	%-weight	< 15	< 20	< 25	SNI 01-1506
5	Ash content[b]	%-weight	< 15	< 20	< 25	SNI 06-3730
6	Volatile matter[b]	%-berat, maks	65	70	75	SNI 06-3730
7	Fix carbon value[b]	%-weight	> 15	> 10	> 5	SNI 06-3730
8	Net calorific value[b]	MJ/kg, mean[d]	≥ 20	≥ 15	≥ 10	SNI 01-6235
9	Sulfur total content[b]	%-weight	≤ 1.5	≤ 1.5	≤ 1.5	

No.	Parameter tested	Unit min/max	Class 1	Class 2	Class 3	Test Methology
10	Chlorine content[b]	%-weight, mean[d]	$\leq$ 0.2	$\leq$ 0.6	$\leq$ 1	
11	Mercury content (Hg)[b]	mg/MJ, median[d]	$\leq$ 0.02	$\leq$ 0.03	$\leq$ 0.08	
		mg/MJ, 80th percentile[d]	$\leq$ 0.04	$\leq$ 0.06	$\leq$ 0.16	
12	Potassium content (in K_2O)	%-weight, max	5	10	15	
13	Natrium content (in Na_2O)	%-weight, max	2.5	2.5	2.5	
14	Hardgrove Grindability Index (HGI)[c]	HGI, min	35	35	35	
15	Melting point of ash (Initial Deformation Temperature /IDT)	°C, min	1200	1180	1180	

Source: Ministry of Energy and Mineral Resources, 2021

2.2. CO-PROCESSING IN CEMENT KILNS

The Government of Indonesia, through Law No. 3 of 2014 concerning Industry, encourages the development of a Green Industry.[18] The law supports prioritizing efforts to increase the efficiency and effectiveness using of resources in a sustainable manner. This way, the industry will harmonize its industrial development with the preservation of environmental functions that could provide benefits to the community.

The cement industry is one of the industrial sub-sectors that is considered ready to apply the Green Industry concept. One strategy that was taken is the implementation of Refuse-Derived Fuel (RDF) technology. Through the application of this technology, the cement industry can utilize the energy content of domestic waste and industrial solid waste, support efforts to conserve natural resources such as fuels, reduce CO_2 emissions, and contribute to tackling the waste problem.

Figure 10 shows the distribution of cement kilns in Indonesia. The cement production capacity in Indonesia in 2017 was 107.9 million tonnes. According to the Indonesian Cement Association (ASI), in 2016, there were 13 cement companies with a total production of 61.6 million tonnes of cement and 51.69 million tons of clinker. The three largest companies are

18 https://peraturan.bpk.go.id/Home/Details/38572/uu-no-3-tahun-2014

Semen Indonesia Group, PT Indocement Tunggal Prakarsa Tbk., and PT Solusi Bangun Indonesia Tbk (SBI) [26].

For every 1% the clinker ratio decreases in cement kilns, CO_2 emissions are reduced by 8.75 kg CO_2 emissions per ton cement. Thus, for the total production (2017) of 70.7 million tonnes:

- Ordinary Portland Cement (OPC) proportion: 27%, clinker ratio 90%
- Non-OPC proportion: 73%, clinker ratio 70%
- CO_2 emission reduction potential if OPC is replaced with non-OPC: 3.34 million tonnes of CO_2

The substitution of fossil fuels by alternative fuels (AF) has become the hottest issue of the cement industry in many regions of the world [27]. A study in Turkey set with three scenarios (S1, S2, and S3) was built, including different coal substitution rates (15% and 30%). Two alternative fuels were applied, using refuse-derived fuel [RDF] and thermally dried sludge [DS]. The study results indicate that RDF as an alternative fuel released less CO_2 emission than DS in cement production. The use of RDF to replace coal reduced CO_2 emission by 27% and 12%, with 30% and 15% substitution rates for all cement types. On the contrary, a substitution rate of 15% with Dried Sludge (DS) increased CO_2 emission by 0.5% compared with the current situation [28].

Due to the intensity of AF discourses in the last 10 years, consultancies for the procurement, storage, handling, and dosing of AF have increased significantly. The cement producers have also built comprehensive know-how and experience in the field of AF. Various machines and plants for the production, storage, handling and dosing of different types of RDF and SRF are abundant.

Table 5 shows the potential sources of RDF/SRF in Indonesia's major islands identified by the Ministry of Energy and Mineral Resources.

TABLE 5. POTENTIAL OF MATERIALS FOR RDF/SRF IN INDONESIA

No.	Potential	Sumatera	Kalimantan	Jawal-Madura-Bali	Nusa Tenggara	Sulawesi	Maluku	Papua	Total (MWE)
1	Palm oil kernal peels	8812	3384	60	0	323	0	75	12654
2	Sugar cane	339	0	853	0	42	0	0	1235
3	Rubber	1918	862	0	0	0	0	0	2780
4	Coconuts	53	10	37	7	38	19	14	178
5	Rice husks	2255	642	5353	405	1111	22	20	9808
6	Maize/corns	408	30	954	85	251	4	1	1733
7	Cassava	110	7	120	18	12	2	1	270
8	Woods	1212	44	14	19	21	4	21	1335
9	Cow dung	96	16	296	53	65	5	4	535
10	Municipal wastes	326	66	1527	48	74	11	14	2066
	TOTAL	**15529**	**5061**	**9215**	**635**	**1937**	**67**	**150**	**32594**

Source: Ministry of Energy and Mineral Resources, 2021

Figure 10. Distribution of cement plants in Indonesia. Source: Asosiasi Semen Indonesia (ASI)

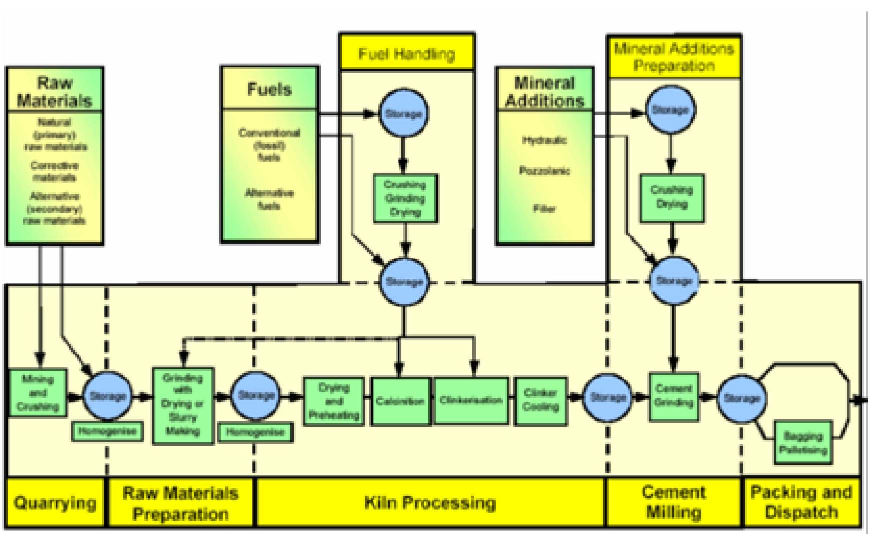


Figure 11. Processes identification and system boundaries of cement production (Environment Agency, 2001). Source: Kartensen, WBCSD (2006)

Figure 11 shows the system boundaries of cement production and where the fuel feeding station is located in the kiln processing stage. The technology used in all cement plants in Indonesia is a dry process with preheating, either with or without calciner. Heat consumption in clinker production in Indonesia in 2016 ranged between 3 000 and 4 000 MJ/ton of clinker (data from ASI).

Several companies have implemented co-processing of alternative fuels in clinker production, which can equal an up to 10% thermal substitution ratio (data from ASI, 2015, processed by consultants). Alternative fuels commonly used in cement factories in Indonesia are agricultural waste (grain husks, palm shells, etc.) and Refuse Derived Fuel (RDF) from domestic waste. The average thermal substitution rate for the use of alternative fuels the in cement industry worldwide (2016) was 17%. Austria has the highest thermal substitution rate of 75.95% [29]. The government of Indonesia has set the target rate of thermal substitution to 15% by 2025, as stipulated in the Presidential Regulation No. 22/2017.[19]

PT Solusi Bangun Indonesia Tbk (SBI) is an Indonesian public company whose majority stake, 83.27%, is owned and managed by PT Semen Indonesia Industri Bangunan (SIIB) – part of the Semen Indonesia Group – the largest cement producer in Indonesia and Southeast Asia. PT SBI runs 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 total production capacity of 14.8 million tonnes of cement per year.[20]

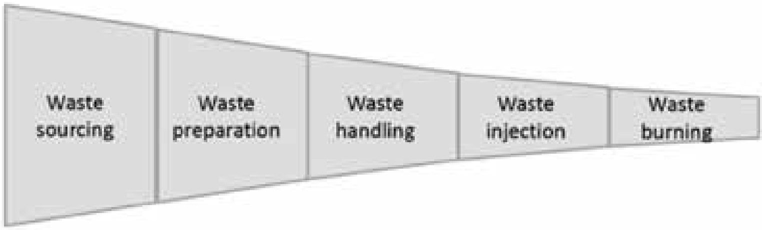
PT SBI was the first cement company to address the problem of greenhouse gas (GHG) emissions. SBI runs the largest project to use biomass as an alternative fuel in the UNFCCC Clean Development Mechanism program for the period of 2011 to 2017 and reduced CO_2 emissions by in total 1 560 837 tonnes of CO_2e, with annual average emission reductions of 222 977 tonnes of CO_2e.[21,22] As a substitute for coal, PT SBI utilizes unused rice husks and palm kernel peels as fuel. This intervention helps to reduce and avoid the release of CO_2 emissions that usually arise if the two types of waste are left to decompose.

19 Peraturan Preslden Republlk Indonesia Nomor 22 Tahun 2017 Tentang Rencana Umum Energi Nasional. Available at https://www.esdm.go.id/ assets/media/content/content-rencana-umum-energi-nasional-ruen.pdf

20 PT Solusi Bangun Indonesia https://solusibangunindonesia.com/

21 CDM Project 3726 : Partial substitution of fossil fuels with biomass at Semen Gresik cement plant in Tuban. Available at https://cdm.unfccc.int/ Projects/DB/ERM-CVS1274361514.11/view

22 Project Design Document (PDD) CDM Project 3726 : Partial substitution of fossil fuels with biomass at Semen Gresik cement plant in Tuban. Available at https://cdm.unfccc.int/filestorage/6/0/D/60DNJOKLGWBT4P1VS8IXF3EAYHM9Q5/SCC%20Semen%20Gresik%20%20PDD.pdf?t=UER8cjdwYWN4fDD_AloiKDwVhWJu9cgdxuRB



option	buy more	install more	install more	install more	?
limit	availability	CAPEX	CAPEX	CAPEX	Burnout!

Figure 12. Sufficient permits to burn AF assumed - increasing the mass flow. Source: Mersmann (2019)

Figure 13. Example of RDF fluff for co-firing in cement kiln. Photo: Holcim, 2015

Figure 14. Example of RDF in form of Compost Like Output (CLO). Photo: Holcim, 2015

Alternative fuel and raw materials (AFR) derived from industrial wastes such as tyres, waste oil, plastics, solvents and many more, are commonly used by the cement industry as substitute fuels. AFR used in cement industries can be both solid or liquid [30]. Hazardous organic wastes have also been used as a co-fuel since the early 1970s [31]. RDF used as an alternative fuel in cement kilns is generally prepared by cutting, sorting, and separating metals and other materials that cannot be used as fuel to make fluffy solid fuels or other forms such as pellets of uniform size.

The calorific value of RDF is around 2,500 – 4,000 kcal/kg and comes mainly from plastic, paper, or cardboard. The properties of RDF vary compared to that of coal, generally having a lower calorific value and sulfur content but a higher chlorine content. RDF with low sulfur content is more desirable because combustion sulfur dioxide emissions must meet regulatory limits.

Genon and Berzio (2007) summarized information from various databases and found in one simulation that replacing 50% of the coal heat rate with RDF showed a decrease in heavy metal emissions of Cd and Hg. However, subsequent simulations using a different set of RDF characteristics showed that Cd and Hg heavy metal emissions actually increased [32].

The maximum achievable TSR is limited by the ability of the kiln system to actually burn out the fed AF without generating operational or quality problems. Mersmann (2019) reminds the cement industry that due to the many plant and fuel-specific properties, it is not possible to define best injection positions and best operating practices in general terms. Every plant can be optimized for the highest possible substitution rate for different alternative fuels [27].

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

For emissions monitoring in cement kilns that used only RDF as alternative fuel, the technical guidance referred to the Ministry of Environment and Forestry Regulation No. 19 year 2017 concerning emission standard for the cement industry.[23] The regulation stipulates the emission standard of dioxins and furans (PCDD/F) to 0.1 ng TEQ/Nm^3 and that it only needs to be measured/monitored every four years after the plant started

23 PEraturan Menteri Lingkungan Hidup Dan Kehutanan Republik Indonesia Nomor P.19/MENLHK/SETJEN/KUM.1/2/2017 tentang Baku Mutu Emisi Bagi Usaha Dan/Atau Kegiatan Industri Semen. Available at https://jdihn.go.id/files/146/P.19%20(1).pdf

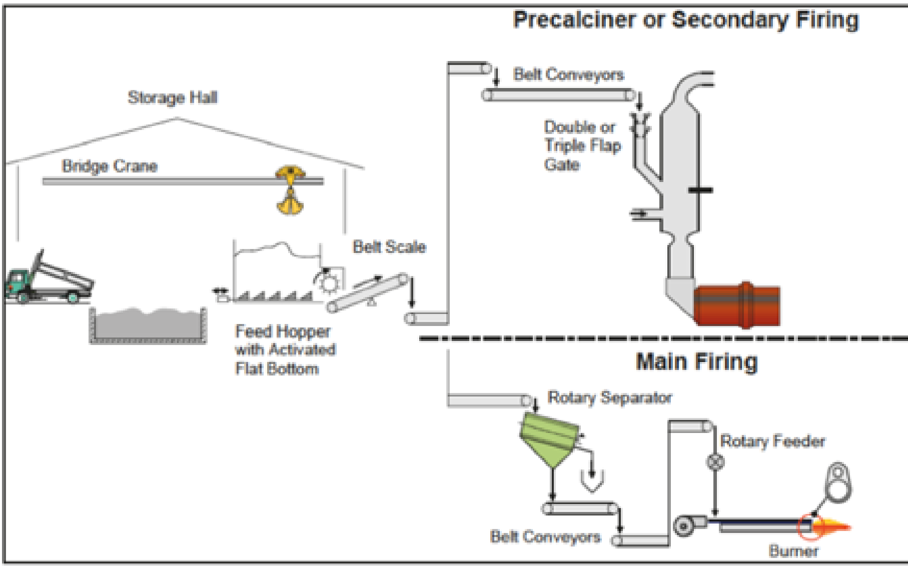


Figure 15. Flow diagram of alternative fuels use in cement industry for cofiring. Photo: GIZ, 2006

its operation.[24] Meanwhile, when the cement kilns used hazardous wastes for cofiring, the monitoring of PCDD/F should be conducted at least once a year and based on the permit to utilise hazardous wastes as alternative fuels [26].

24 Widowati, et al. 2017. Pedoman Spesifikasi Teknis Refuse Derived Fuel (RDF) sebagai Alternatif Bahan Bakar di Industri Semen. Kementerian Perindustrian - Asosiasi Semen Indonesia, Jakarta.

3. BIOPELLETS AND BRIQUETTES

Refused-Derived Fuel (RDF) and Solid Recovered Fuel (SRF) gained popularity after KPK recommended the relevant ministries not to continue the national priority program to build waste-to-energy plants. Biopellets and briquettes/brickets are the most common shape of RDF used by the industry. Any waste generators can produce RDF following certain guidelines and complying with the national standards.

The Badan Standar Nasional already issued four Standar Nasional Indonesia (SNI) for biopellets and two SNIs for briquettes. Three more SNIs are in the pipeline to be approved and issued in 2022. Most SNIs in Indonesia are voluntary unless it was enforced by a Ministerial Regulation. Some SNIs are voluntary for a period of time, usually for four years, before they become mandatory. Furthermore, to obtain a certified SNI, a company must follow the process of registration, laboratory analysis, and verification by an assigned/approved institution, and then be certified. The process might take about eight to nine months depending on the availability of the assessors.

However, for small-scale users in informal setting, such as using fluff to feed furnaces in a tofu factory or a small boiler in a small- to medium-sized factory, are not affected by the industrial standards. Even worse, unlike for the cement industry and other thermal treatment plants, there are no standards for the emissions and bottom ash resulting from these small-medium enterpreneurial operations.

Table 6 shows the national standards for biopellets and briquettes.

TABLE 6. NATIONAL STANDARDS FOR BIOPELLETS AND BRIQUETTES

SNI number	Concerning	Technical committee	Scope
Biopellets			
SNI 8675:2018	Biomass pellets for energy (*Pelet biomassa untuk energi*)	27-10, solid bioenergy and gas	This standard stipulates the requirements for biomass pellets used as energy for domestic and/or industrial purposes
SNI 8021:2020	Wood pellets (*Pelet kayu*)	79-01, wood forest products	This standard specifies the classification, quality requirements, sampling, test methods, packaging and labeling of wood pellets
SNI 8951:2020	Biomass pellets for electricity generation (*Pelet biomassa untuk pembangkit listrik*)	27-10, solid bioenergy and gas	This standard stipulates the requirements and specific test methods for biomass pellets used as fuel in Coal-fired Power Plants (PLTU) using Pulverizer Coal (PC) or Circulating Fluidized Bed (CFB) or Stoker boilers and PLTBm (Biomass Power Plants).
SNI 8966:2021	Refuse Derived Fuel/ Solid Recovered Fuel for electricity generation (*Bahan bakar jumputan padat untuk pembangkit listrik*)	27-10, solid bioenergy and gas	This standard establishes quality requirements and test methods for the use of solid jump fuel in power plants for co-firing purposes, and as a standard guideline in establishing specifications, sampling, test methods, shipping and storage.
RSNI1 XXXX:2021 (in review process)	Woodchips for cofiring in electricity generation plant (*Potongan kayu untuk cofiring pada pembangkit listrik*)	27-10, solid bioenergy and gas	This standard stipulates the requirements and test methods for specification of wood chips used as fuel for cofiring in Coal-fired Power Plants (PLTU).
RSNI1 XXXX:2021 (in review process)	Palm oil shells for cofiring in power plants (*Cangkang sawit untuk cofiring pada pembangkit listrik*)	27-10, solid bioenergy and gas	This standard stipulates the requirements and test methods for the specification of palm shells used as cofiring fuel in Coal-fired Power Plants (PLTU).
RSNI1 XXXX:2021 (in review process)	Sawdust for cofiring in power plants (*Serbuk gergaji untuk cofiring pada pembangkit listrik*)	27-10, solid bioenergy and gas	This standard stipulates the requirements and test methods for the specification of sawdust used as fuel for cofiring in Coal-fired Power Plants (PLTU).
Briquettes			
SNI 19-4791-1998	Coconut coir powder briquettes	27-10, solid bioenergy and gas	This standard includes references, definitions, quality requirements, sampling methods, test methods, marking requirements, and packaging methods
SNI 01-6235-2000	Wood charcoal briquettes	27-10, solid bioenergy and gas	This standard includes scope, reference, definition, quality requirements, sampling, test method, test pass requirements, marking and packaging requirements for wood charcoal briquettes.

Source: Badan Standarisasi Nasional Indonesia, 2021

Current discussions about RDF and SRF in Indonesia are largely focused on national standards (SNIs) and industrial standards. At the time of this study, there is no assurance that the coal-fired power plants will apply the requirement of SNI certificates to their suppliers. Moreover, many RDF producers or suppliers are small to medium-sized business units operated by community groups, cooperatives, or small companies.

The national agencies seem eager to push for the RDF projects and use SNIs as quality assurance for project development. However, emissions and releases from coal-fired power plants that use alternative fuels consisting of coal mixed with RDF mixed waste doesn not exist. For the cement industry, the emissions standard for AF with hazardous waste and RDF are available, although laboratories to analyse dioxins (PCDDs/PCDFs) are not available in the country.

The Indonesian government should review the health and environmental risks of siting the RDF projects and the potential toxic emissions and ash generated from power plants or boilers with RDF in many cities and rural areas.

3.1 RDF TECHNOLOGY AND TECHNOLOGY READINESS LEVEL

To produce RDF pellets and briquettes many vendors offer their technologies. Some machinery is imported from China and some is manufactured in Indonesia. Several companies and projects have applied different kinds of technology to produce RDF pellets and briquettes.

The cost to build a whole unit of one RDF plant with the capacity to process 100 tonnes of wastes and produce 60 tonnes of RDF fluff was approximately US$6 million. Another project to process 50 tons of wastes and produce 20-30 tons of pellets costs about US$350 000. All projects using RDF technologies claimed that their machineries already had obtained environmentally friendly certificates (*Sertifikat Teknologi Ramah Lingkungan* or STRL) from the Ministry of Environment and Forestry. However, the Environmental Impact Assessment study has very often been corrupted and has not addressed the real potential risks of the activities to the environment and people. Some projects have failed during the pilot stage and were protested against by the communities.

The concept of Technology Readiness Levels (TRL) was first developed in the USA by NASA.[25] Now it is widely taken as the basis philosophy for the new technology graduation development stages by many agencies and organizations worldwide. The classification reflects the state of development

25 NASA, 28 October 2012. Technology Readiness Level (TRL). https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

results for wide production and/or application. Assessment of TRL and current TRL assignment indicates to the markets and consumer readiness of the process/technology for wide market implementation. Knowledge of TRL makes it easier for developers and customers to monitor the progress of research and the choice of technologies that are most ready for industrial application.

Based on the Minister of Research, Technology and Higher Education Regulation No. 42 year 2016[26] concerning the measurement and determination of the level of technology readiness, every result of research and technology development activities must be measured. The level of a particular technology research and development result is measured systematically to be adopted by users, either by the government, industry, or society. The measuring instrument used to measure technology readiness is the technology readiness level (TRL) or *Tingkat Kesiapterapan Teknologi* (TKT).

TRL or TKT shows the stages of technological readiness and is divided into a scale of 1 to 9, where stage 1 shows the basic principles of the technology being researched and reported; stage 2 shows the formulation of the concept and/or application of the formulation; 3 shows proof of concept functions and/or essential characteristics analytically and experimentally; 4 shows the validation of components/subsystems in a laboratory environment; and stage 5 shows the validation of components/subsystems in an appropriate setting.

Stage 6 shows a demonstration model or prototype system/subsystem in a suitable environment; 7 shows a demonstration of the prototype system in a real environment; 8 indicates the system is complete and reliable through testing and demonstration in a real environment; and 9 indicates the system is genuinely tested/proven through a successful operation.

Currently, there is no mechanism to control whether the technology sold and used in the market to produce RDF already reached its maturity (Technology Readiness Level 8-9). Moreover, there is lack of communication between the committee or board of TRL evaluation (under *Badan Riset dan Inovasi Nasional* or BRIN) and the committee that validates and issues the Certificate of Environmentally Sound Technology (under MoEF).

Many machines and tools claimed to be RDF pellet production machines are available in various e-commerce platforms in Indonesia, as well as through direct sales to the local government agencies. Some of the com-

26 Peraturan Menteri Riset, Teknologi, dan Pendidikan Tinggi No. 42 tahun 2016. Available at https://peraturan.bpk.go.id/Home/Details/141280/permen-ristekdikti-no-42-tahun-2016

panies or proponents of RDF have claimed that they have obtained the Certificate of Environmentally Sound Technology from the Ministry of Environment but the technology is still at TRL 4-5 level. The agreement between the RDF company with the local governments is sometimes only as a pilot project but is promoted as a final or formal project.

3.2. RDF PROJECTS IN INDONESIA

In this section, several RDF projects are discussed. Some projects are highlighted due to the nature of their development or the dynamics in the implementation.

3.2.1. TPST Jeruk Legi Cilacap

After KPK made the announcement in November 2020, they communicated with the Coordinating Ministry of Maritime and Investments and a state-owned company, PT Sarana Multi Infrastruktur Tbk (PT SMI)[27] to break the barrier to potential investments in RDF plants in many cities.

KPK projected that for a medium-sized RDF plant, the city administrator or investor will need at least IDR 400 billion (approx. US$28 million). This investment will be paid off when the RDF pellets (fluff) are pur-

TABLE 7. RDF PROJECTS BIDDING 2021-2022

				Bid Values	
Year	**Bidding Package**	**Agency in Charge**	**Stage**	**in IDR**	**in USD**
2021	Development of MRF for RDF in Bandung City and Bandung Regency	Min. of Public Works and Settlements	Finished	19,100,000,000.	1,335,664.
2021	Development of MRF for RDF in Karawang and Purwakarta Regencies	Min. of Public Works and Settlements	Finished	24,000,000,000.	1,678,322.
2021	Development of MRF for RDF in Bandung City	Min. of Public Works and Settlements	Cancelled	6,300,000,000.	440,559.
2021	Development of MRF for RDF in Tuban Regency, East Java	Min. of Public Works and Settlements	Cancelled	122,600,000,000.	8,573,427.
2022	Development of MRF for RDF in West Lombok Regency	Min. of Public Works and Settlements	Technical evaluation	37,900,000,000.	2,650,350.

Source: https://lpse.pu.go.id/eproc4/lelang?kategoriId=2&tahun=2021&instansiId=&rekanan=

27 PT Sarana Multi Infrastruktur Tbk at a glance. https://ptsmi.co.id/pt-smi-at-glance

TABLE 8. COMPARISON OF TECHNOLOGY READINESS LEVEL (TRL)

TRL	NASA[1]	European Union[2]	Indonesia[3]	
1	Basic principles observed and reported	Basic principles observed	Basic principles of technology observed and reported	Basic research
2	Technology concept and/or application formulated	Technology concept formulated	Concept formulation and/or technology application	
3	Analytical and experimental critical function and/or characteristic proof-of concept	Experimental proof of concept	Analytical and experimental function and/or critical characteristics proof of concept	
4	Component and/or breadboard validation in laboratory environment	Technology validated in laboratory	Codes validation, component and/or breadboard validation in laboratory environment	Applied research
5	Component and/or breadboard validation in relevant environment	Technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)	Codes validation, components and/or breadboard validation in a simulation environment	
6	System/subsystem model or prototype demonstration in a relevant environment (ground or space)	Technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)	System/subsystem model or prototype demonstration in a relevant environment	
7	System prototype demonstration in a space environment	System prototype demonstration in operational environment	Prototype demonstration conducted in the real environment/application	Development research
8	Actual system completed and "flight qualified" through test and demonstration (ground or space)	System complete and qualified	System complete and qualified through testing and demonstration in the real environment/application	
9	Actual system "flight proven" through successful mission operations	Actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)	Actual system proven/tested through successful operation	

1 NASA. https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf
2 Technology readiness levels (TRL); Extract from Part 19 - Commission Decision C(2014)4995. 2014. https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf
3 Peraturan Menteri Riset, Teknologi dan Pendidikan Tinggi No. 42 tahun 2016 tentang Pengukuran Dan Penetapan Tingkat Kesiapterapan Teknologi. https://peraturan.bpk.go.id/Home/Details/141280/permen-ristekdikti-no-42-tahun-2016

Figure 16. Officers show the type of waste that is converted into refuse-derived fuel (RDF) at the TPST Tritih Lor Village (Jeruklegi), Cilacap, Central Java. Photo: PT SBI/Mongabay Indonesia

Figure 17. Coordinating Minister for Maritime Affairs and Investment Luhut B Pandjaitan (third from left) inaugurated the operation of the RDF plant Tritih Lor TPST in Cilacap, Central Java (21/7/2020). Photo: PT SBI/Mongabay Indonesia

TABLE 9. MULTI-STAKEHOLDERS FINANCING OF RDF JERUK LEGI CILACAP PROJECT

Party	Type of CAPEX	Amount of CAPEX (IDR)	Amount of CAPEX (USD)	%
Ministry of Public Works	Civil works	27,862,198,000	1,948,405	33%
	Excavators and equipments	1,500,000,000	104,895	2%
Central Java Province	Supporting infra-structures	9,200,000,000	643,357	11%
Cilacap Regency government	Vehicles/trucks	3,000,000,000	209,790	4%
Danida ESP3 (Denmark)	Mechanical and elec-trical equipments	43,000,000,000	3,006,993	51%
Total		**84,562,198,000**	**5,913,440**	**100%**

Source: Bastian et al. (2021)

chased by cement kilns or coal-fired power plants as an alternative fuel to replace coal.[28]

Processing municipal waste into RDF requires buyers or offtakers who will guarantee the purchase of RDF products in power generation facilities or cement plants as a substitute for coal. The officials regarded the RDF plants as a milestone in Indonesia's waste management and see the potential of 34 cement factories and 50 more coal-fired power plants as the offtakers of RDF products.[29] Moreover, an official from the Ministry of Environment and Forestry was hopeful that RDF could be one of the solutions to tackle the country's waste management crisis because in one day about 28,000 tons of waste could be processed into RDF.

The RDF facility in Jeruk Legi, Cilacap, built with funds from several parties including a Danish government fund (ESP3 Project) and Holcim/ Semen Indonesia Group, cost around Rp80 billion - Rp90 billion (about US$5 to 6.5 million). The 3 hectare plant was designed to process 120 tonnes of municipal waste per day and produces 40-55 tonnes of RDF fluff per day [33, 34]. The offtaker of the RDF fluff is PT Solusi Bangun Indonesia, a subsidiary of Semen Indonesia Group (SIG).

28 Kontan. 27 June 2021. Perpres PSEL berpotensi direvisi, daerah bisa kembangkan pellet RDF. https://industri.kontan.co.id/news/perpres-psel- berpotensi-direvisi-daerah-bisa-kembangkan-pellet-rdf

29 L Darmawan, 27 July 2020. Pertama di Indonesia, Sampah RDF Jadi Pengganti Batu Bara. Mongabay, Energy. Cilacap-Jateng. https://www.mongabay.co.id/2020/07/27/pertama-di-indonesia-sampah-rdf-jadi-pengganti-batu-bara/

Figure 18. About 70-90 scavengers sorted 120 ton of waste per day and collected 3% of recyclables from the piles dropped at the RDF reception facility. The remaining wastes are the RDF feedstock. Photo: WALHI

Figure 19. The RDF materials treated for 21 days at the Biodrying bays to reduce 35% of humidity in the RDF materials. Photo: WALHI

Figure 20. About 40-60 tons of RDF fluff products produced daily to be used at the cement kilns. Photo: WALHI

Figure 21. The tank to hold water produced from the Biodrying process without chemicals or biological process. Photo: WALHI

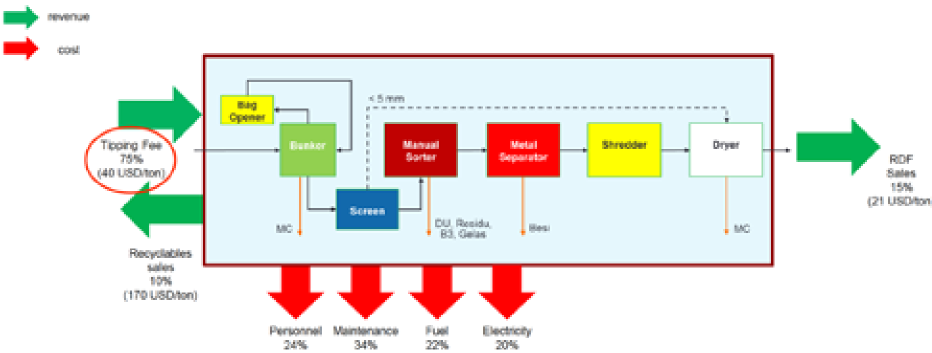


Figure 22. Financial scheme based on 1000 tons per day MSW feedstock. Source: Prawisudha presentation (2022)

Table 9 shows the contributions of several parties to build the RDF plant in Cilacap. The Danida ESP3 project contributed more than 50% of the project's capital expenditure in the form of a grant, the rest was funded by the Indonesian government budget, as well as by Holcim (by land sold to the Cilacap Regency), SBI, and Unilever (no detailed information available). This kind of scheme might not be easy to be replicated in other places and there are issues of assets and technical challenges in the future if the institutional setting is not clear.

Several high-ranking officials attended the inauguration of the RDF Cilacap plant, including the Coordinating Minister of Maritime Affairs and Investment, the Minister of Energy and Mineral Resources, the Minister of Maritime Affairs and Fisheries, and the Directorate General for Solid Waste, Hazardous Substances and Hazardous Wastes of the Ministry of Environment and Forestry.[30,31]

RDF fluff from Jeruklegi was processed entirely from plastic and residuals of municipal waste. After sorting by scavengers, feedstocks are treated using a bio-drying method, then the dried mixed waste is cut into smaller pieces with irregular dimensions. The offtaker of RDF, PT. Solusi Bangun Indonesia, then uses this RDF fluff as feedstock for their cement kilns in Cilacap along with additional inert materials. The addition of dirt as inert

30 Mongabay. 27 Juli 2020. Pertama di Indonesia, Sampah RDF Jadi Pengganti Batu Bara. https://www-mongabay-co-id.translate.goog/2020/07/27/pertama-di-indonesia-sampah-rdf-jadi-pengganti-batu-bara/?_x_tr_sl=id&_x_tr_tl=en&_x_tr_hl=en-GB&_x_tr_pto=wapp

31 https://www.unilever.co.id/news/press-releases/2021/kolaborasi-pemerintah-dan-swasta-tingkatkan-sampah-sebagai-sumber-energi-terbarukan/

materials is aimed to add weight into the mass, so the fluff is not easily blown off, either by wind or any blower, when fed into the cement kiln.

Unilever Indonesia topped up the investment to increase the production capacity of the RDF plant from 120 tonnes per day to 200 tonnes per day. As a reward for their contributions, Unilever claimed to have reduced more than 3 000 tons of plastic wastes per year and by converting it into RDF/alternative fuels used in cement kilns.[32]

For the operational costs of the facility, PT SBI has signed an agreement with the local government of Cilacap Regency to have a cost-sharing system for five years. The facility received a tipping fee of IDR500 000 or approximately US$40 per tonne waste and generates recyclables approx. 3-10% of recyclables, which is collected and sold by scavengers. The operational costs are consisting of expenses to cover personnel (24%), maintenance (34%), fuel (22%), and electricity (20%). The annual operating costs are about IDR9 billion or approx. US$640 000 [35].

32 Personal communication

Figure 23. Shredded organic waste to be processed at TOSS Centre Klungkung. Photo: Nexus3

Figure 24. Aerobic composting method to reduce the humidity of the waste using bamboo boxes. Photo: Nexus3

Figure 25. Gasification plant to generate electricity for machineries at TOSS facility in Klungkung. Photo: Nexus3

Figure 26. Example of RDF pellets produced by TOSS Centre in Klungkung. Photo: Nexus3

3.2.2 TOSS Centre Gema Santi, Klungkung Regency, Bali

Klungkung Regency is the smallest regency of Bali and located in the eastern part of the island with a population of 206,000 (2020).[33,34] TOSS is an abbreviation of "Tempat Olah Sampah Setempat" or Solid Waste Processing Technology at the Source. TOSS is a method to process organic and biomass wastes at a communal scale. The processing of organic and biomass waste material is carried out in three stages:

- Bio-drying: which utilizes the aerobic activity of microorganisms;
- Chopping, which is intended to refine the material; and
- Pelletisation to compact the material into biomass pellets.

The TOSS plant can process 80 tonnes of municipal wastes per day and convert it into 25-30 tonnes of RDF pellets with 30% residues sent to the landfill. The five billion rupiah or approximately US$350 000 project was funded by the local government of the Klungkung Regency[35] with additional support from CSR programs of some companies. Currently, there is no offtaker of TOSS Klungkung RDF pellets, instead they use the RDF pellets for their own consumption to fuel the internal/in-house gasification plant to power the machineries. The liquid composts are used in agriculture land and organic farming around the TOSS Centre.

The bio-drying process in bamboo boxes is able to reduce the water content in organic and biomass waste within 4-5 days. Sorting of non-organic materials can be done at an early stage before or after the bio-drying process. Sorting is required before the chopping and pelletising process to avoid unnecessary mechanical breakdowns.

The biomass pellet, which is the final product, has a diameter of about 10 mm with a length between 10-40 mm, a calorific value between 3 000-4 000 kcal/kg, and a moisture content of up to 15%. Compared to coal, biomass pellets tend to have higher volatile and ash content while lower ash and sulfur content.

RDF pellets from TOSS Gema Santi were molded into pellet form with organic waste as its main feedstock. Its feedstock consists of 95% organic materials, with an additional 2% of dried-shredded plastic and other residual waste. However, in its operation, plastic and residual waste addi-

33 https://klungkungkab.go.id/

34 https://databoks.katadata.co.id/datapublish/2021/07/22/sensus-penduduk-2020-jumlah-penduduk-bali-432-juta-jiwa

35 Peraturan Daerah Kabupaten Klungkung Nomor 2 Tahun 2019 Tentang Rencana Pembangunan Jangka Menengah Daerah Semesta Berencana Tahun 2018-2023 https://klungkungkab.go.id/bank-data/file/RPJMD_2018-2023.pdf

Figure 27. TPA Kebon Kongok was on fire several times. Photo: Suara NTB

Figure 28. The location of the landfill is near settlements. Photo: Google Earth

Figure 29. Situation of PLTU Jerenjang. Photo: Suara NTB

Figure 30. Situation of Kebon Kongok landfill.
Photo: Nexus3

IPEN

Figure 31. Bamboo boxes used to dry the organic wastes. Photo: Nexus3

Figure 32. Dried wastes will be shreded into unspecified sizes.
Photo: Nexus3

Figure 33. RDF in a form of shredded waste is now the end products of RDF Kebon Kongok. Photo: Nexus3

Figure 34. Initially this kind of RDF pellets will be used by PLTU Jeranjang. Photo: INA News

tion to the feedstock made the pellets easier to crumble due to the hardened plastic within the pellets, decreasing the ability of a pellet to bind together. Thus, at the time the samples were taken, TOSS Gema Santi no longer mixed plastic and residual waste into the feedstock.

3.2.3. RDF plant Kebon Kongok, Regional Landfill, West Lombok

West Lombok Regency is part of the West Nusa tenggara Province with a population of 730 600 people [36]. Kebon Kongok is the regional landfill for West Lombok Regency and Mataram City administrative areas and receives about 350 tonnes of waste per day. To extend the lifetime of the landfill, the local government of West Lombok Regency and PLTU Jerenjang agreed to establish a cooperation to use RDF from mixed waste as the alternative fuel to replace coal. The initial plan was to process 120 tonnes of waste into RDF pellets. The project is funded by the Ministry of Public Works for IDR37 billion or approx. US$2.5 million.

The shredded RDF from Kebon Kongok Landfill uses 95% of dried leaves and grasses along with 5% of plastic and other residual waste as its feedstock. The inorganic material ingredients were capped at 5% per the request of its offtaker, PLTU Jerenjeng, a coal-fired power plant approximately three kilometers away. This criteria was set to prevent adhesion of the melting plastics within combustion units at the coal-fired power plants. At least 45 tonnes or RDF per day will be needed to replace coal at PLTU Jeranjang.

The capacity of the pilot RDF plant is 100 kg/day of waste. The end product is shredded RDF and will be produced for the piloting phase before the upscaling process to treat 40 tonnes of waste daily and produces approx. 15 tonnes of RDF. The co-firing using RDF is estimated to substitute 2% of electricity production at the PLTU Jerenjeng.[36]

During the study, the Ministry of Public Works was still organising a bidding process to build the RDF plant with the budget of IDR37.9 billion.[37] Meanwhile, for the institutional setting to manage the RDF plant, the local goverment of West Lombok considered to establish a dedicate local government service agency or *Badan Layanan Umum Daerah* (BLUD).

36 https://www.pu.go.id/berita/tingkatkan-kualitas-pengelolaan-sampah-di-lombok-kementerian-pupr-bangun-tpst-rdf-kebun-kongok-untuk-energi-terbarukan
37 https://lpse.pu.go.id/eproc4/lelang/78199064/pengumumanlelang

3.2.4. RDF plant at TPST Samtaku Jimbaran, Badung Regency, Bali

TPST Samtaku Jimbaran is located in the southern part of Bali, within Badung Regency territory. The project is relatively new, built with the support from Danone-Aqua.[38] The facility, designed with a circular economy concept and zero waste to landfill, can manage upto 120 tonnes of waste per day, 40% of Badung Regency wastes. Currently, the facility only manages and sorts 70 tonnes of waste per day. Waste arrives at TPST Samtaku Jimbaran is sorted by 20 staff members.

Sorted recyclables are sold to middle-men, 40 tonnes of organic waste will be composted, and mixed residues are melted and converted into RDF pellets.[39]

By the time of the study, the project has no offtakers of RDF yet, but the management of PT Reciki Mantap Jaya has considered selling the RDF pellets to the local businesses for use as fuels in small-scale, industrial boilers, such as laundry contractors, tofu makers, etc.

The project attracted a lot of attention from the Indonesian officials and the public. Like the inauguration of RDF Cilacap project, the Coordinating Minister of Maritime Affairs and Investments, Luhut Panjaitan, inaugurated the project in September 2021.[40] The Ministry of Environment and Forestry (MoEF) also supported and welcomed the contribution of Danone- Aqua[41] and PT Reciki to manage municipal waste and reduce the leakage of plastic waste into the environment.

Further, in a national strategic meeting, the representative of MoEF presented TPST Samtaku Jimbaran as one of the best practitioners. The representatives of the Ministry for National Development Planning/National Planning Agency (Bappenas) also have visited the facility a couple of times together with the representative of the Ministry of Public Works and Settlements.

However, the existence of the facility is not welcomed by residents near the plant. The smell or rotten organic waste and mixed plastic burning in the production of RDF has affected some vulnerable residents. From January 2022, residents of Goa Gong have complained and protested at PT Reciki, Danone-Aqua, and the local Enironmental Agency of Badung Regency. The residents sent letters to the Minister of Bappenas and the

38 https://jakartaglobe.id/lifestyle/danoneaqua-opens-balis-largest-waste-management-facility
39 https://maritim.go.id/menko-luhut-resmikan-tpst-samtaku-bali/
40 https://maritim.go.id/menko-luhut-resmikan-tpst-samtaku-bali/
41 https://www.antaranews.com/berita/2564149/tpst-samtaku-jimbaran-wujud-tanggung-jawab-produsen-pada-kemasannya

Figure 35. The inauguration of TPST Samtaku Jimbaran by Minister Luhut in September 2021. Photo: Kemenkomarves

Figure 36. TPST Samtaku Jimbaran processes 120 tonnes per day of wastes. Photo: Kemenkomarves

Figure 37. TPST Samtaku Jimbaran separated organic waste convert into compost, recyclables sold to recyclers, and residues converted into RDF. Photo: Republika

Figure 38. RDF pellets from mixed residues produced at TPST Samtaku Jimbaran will be sold to SMEs laundry and tofu factories. Photo: Kemenkomarves

Min. of Public Works and have taken legal advise from a lawyer to challenge the procedures and administration of the plant establishment.

Danone-Aqua has also registered and sponsored the project for plastic credits to Verra.[42] An assessor, Control Union, was hired by Danone-Aqua to verify the plastic waste reduction using Verra's Plastic Waste Reduction Program.[43] The assessor visited the site in February 2022 and interviewed the manager of the plant and some members of the public. Interestingly, the assessor stated that the process at TPST Samtaku Jimbaran was in order and ticked all the boxes, paying very little attention to the voice of the residents who raised the complaints. Considering this is the first project in Indonesia that apply for Plastic Credit, it will be interesting to see the results of the assessment and how much Danone-Aqua will be able to claim their contributions.

42 Verra Plastic Waste Reduction Program and Credit https://verra.org/project/plastic-program/plastic-credits/

43 Control Union https://certifications.controlunion.com/en/news-media/news/control-union-becomes-first-approved-vvb-for-verras-plastic-waste- reduction-program

Figure 39. RDF pellet samples from TOSS Gema Santi, Klungkung Regency analysed in the lab. Photo: Nexus3

Figure 40. RDF fluffs samples from Jeruklegi Landfill, Cilacap Regency analysed in the lab. Photo: Nexus3

Figure 41. Shredded RDF samples from Kebon Kongok Landfill, West Lombok analysed in the lab. Photo: Nexus3

3.2.5. Other RDF Projects

Since 2021, several RDF projects are being discussed or negotiated. Some of the projects are government funded, and others are have been initiated by private entities and FMCGs. In 2020, after the inauguration of RDF Cilacap plant, the Indonesian government announced that until 2024 there will be 34 RDF plants/projects each with capital expenditures between IDR 70 billions to IDR 90 billions (approx. USD 4.8 million to USD 6.2 million).[44]

3.3. RDF PELLETS SAMPLES AND LABORATORY RESULTS

During the study, we collected samples from three RDF plants presented earlier, namely:

- TOSS Gema Santi, Klungkung Regency, Bali Province.
- Jeruklegi Landfill, Jeruklegi District, Cilacap Regency, Central Java Province.
- Kebon Kongok Regional Landfill, Suka Makmur Village, Gerung District, West Lombok Regency, West Nusa Tenggara Province.

These samples represented three different types of available RDF produced in Indonesia, considering there are no other active RDF plants up and running at the time this report was drafted. Samples were sent to *Laboratorium Penelitian dan Pengujian Terpadu*, *Universitas Gadjah Mada*, Yogyakarta for waste characteristics analysis: calorific value, water content, and ash content analysis. The result is shown by Table 10-12.

Calorific value is one of the most important characteristics to identify from waste feedstock, especially in thermal-based treatment. It represents the amount of heat released by complete combustion processes (in calories) from its weight materials composed of the produced oxygen and condensation, or simply, the amount of heat generated when fully burning certain mass of waste.

Its high value is needed to complete the combustion process in the thermal processes, approximately no less than 3 400 kcal/kg (approx. 14.23 MJ/kg) to achieve complete combustion to prevent unwanted by-product emission from the process. The lab results show the calorific values of the RDF samples are between 3 500 kcal/kg the lowest (TOSS Centre Klungkung) to 8 272 kcal/kg (Jeruklegi Cilacap).

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44 https://money.kompas.com/read/2020/07/21/183000626/pemerintah-akan-segera-bangun-34-rdf?page=all

TABLE 10. CALORIC VALUES OF RDF SAMPLES

Location	Code	RDF Type	Calorific Value (kcal/kg)	Calorific Value (MJ/kg)
TOSS Gema Santi, Klungkung Regency	RDF-B-01	Pellets	3,503.03	14.66
Jeruklegi Landfill, Cilacap Regency	RDF-C-01	Fluffs	8,272.91	34.61
Kebon Kongok Landfill, West Lombok Regency	RDF-L-01	Shredded	3,761.58	15.74

Water content is another important characteristic for thermal treatment since high moisture of the feedstock would hinder in achieving complete combustion of the waste. Water content (in percentage) is measured by the loss of waste mass under heating process in 105°C until a constant weight is achieved at the end of the measurement, leaving only the true, dry mass of the waste. Waste thermal treatment requires water content in waste feedstock of no more than 20%. All three samples of RDFs went through pretreatment bio-drying process considering some amount of organic waste mixed in the feedstock of RDF. Thus, the results show relatively low water content throughout.

TABLE 11. WATER CONTENT OF RDF SAMPLES

Location	Code	RDF Type	Water content (%)
TOSS Gema Santi, Klungkung Regency	RDF-B-01	Pellets	11.57
Jeruklegi Landfill, Cilacap Regency	RDF-C-01	Fluffs	1.81
Kebon Kongok Landfill, West Lombok Regency	RDF-L-01	Shredded	12.82

Ash content of RDF represents the estimated remaining ash after combustion process of the waste (or RDF) feedstock in thermal processes. The ash content should be useful for ash treatment planning for ash treatments in waste management processes. The true dry mass of waste (after analysis of water content) is comprised of volatile fraction (loss of dry mass on constant heating at 800°C), fixed carbon content fraction (loss of dry mass on constant heating at 950°C and 600°C), and the ash fraction (or the 'residuals') [37]. The result shows ash content of 9% at the lowest (Kebon Kongok Landfill) and 19% at the highest (TOSS Gema Santi).

TABLE 12. ASH CONTENT IN RDF SAMPLES

Location	Code	RDF Type	Ash content (%)
TOSS Gema Santi, Klungkung Regency	RDF-B-01	Pellets	19.24
Jeruklegi Landfill, Cilacap Regency	RDF-C-01	Fluffs	10.90
Kebon Kongok Landfill, West Lombok Regency	RDF-L-01	Shredded	9.76

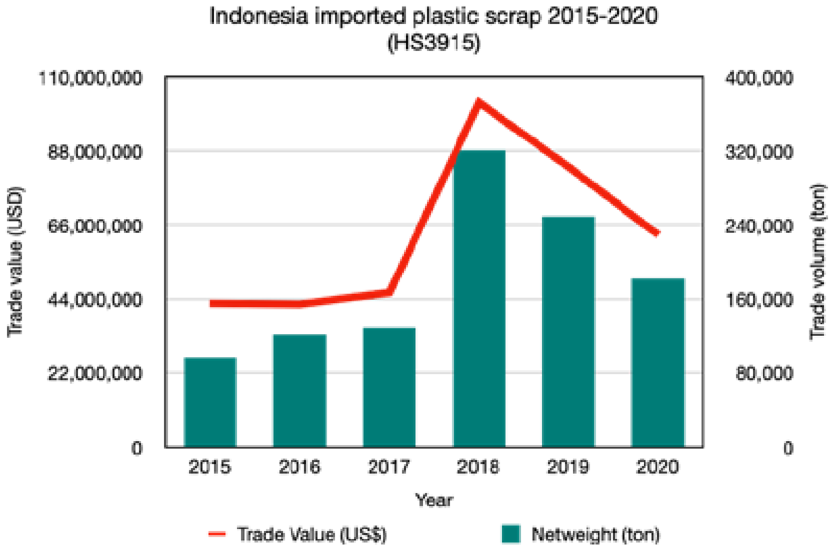

Figure 41. Indonesia imported plastic scrap 2015-2020.
Source: UN Comtrade

Figure 42. Indonesia imported paper scrap 2015-2020.
Source: UN Comtrade

4. INDONESIA WASTE TRADE AND RELATIONS TO AUSTRALIA

4.1 IMPORT OF PROCESSED ENGINEERED FUELS (PEFs)

Imports of non-B3 waste, especially paper and plastic scrap, are needed by the plastic recycling industry and the paper industry as secondary raw materials. The Indonesian plastic industry requires 1 233 000 tonnes of scrap plastic. Of this amount, only 913 000 tonnes can be supplied from domestic sources [30]. The highest imports of scrap plastic from Indonesia occurred in 2018, reaching 283 152 tonnes (see Figure 41). The latest public data in 2020 shows a decrease in scrap plastic imports compared to the previous year, only 181 718 tonnes.

For paper production, scrap paper as a secondary raw material reaches 8.6 million tonnes. Of this amount, only 40-60% can be supplied from various domestic sources [31, 32]. The highest import of scrap paper was in 2019 at 3.182 million tonnes, then in 2020 it decreased to 3 million tonnes (see Figure 42).

In the last five years, beside importing plastic and paper scraps (and other wastes commodities), Indonesia also imported 'combustible materials', classified as HS 360690 - 'Ferro-cerium and other pyrophoric alloys in all forms; articles of combustible materials n.e.c. in chapter 36'. The highest import of scrap paper was in 2016 at 148 tonnes mainly from China, and then in 2020 it decreased significantly to 88 tonnes. However, the trade value of PEF commodity under HS 360690 in 2020 doubled the value in 2019 or almost 3.5 times of value in the peak year (2016). See Figure 41-43.

4.2. WASTE TRADE DYNAMIC WITH AUSTRALIA

In 2018-19, Australians generated approximately 67 million tonnes of waste, of which 4.4 million tonnes was exported. Around 32 per cent of the total waste export was waste plastic, paper, glass, and tyres, with a total declared value of approximately $290 million.

The Council of Australian Governments (COAG) committed to ban the waste exportation has been driven by community-level concerns about the impact of waste on the environment and a nation-wide interest in improving resource recovery [38]. Action to address domestic waste processing capacity has also been accelerated by China's announcement of restrictions on importing recyclable materials under its National Sword Policy in 2018.

The COAG has agreed to establish a timetable to ban the export of waste plastic, paper, glass, and tyres in August 2019. A phased approach to implementing the ban aims to create certainty for industry and is predicted to assist reduce further shocks to the waste and recycling sector. The plan has been set out in stages [39]:[45]

- by 1 July 2020: exports of unprocessed glass will be prohibited;
- by 1 July 2021: mixed plastics that are not a single resin/polymer type and or need further sorting, cleaning & processing are required before use in re-manufacturing;
- by 1 December 2021: whole used tyres;
- by 1 July 2022: single resin/polymer plastics that have not been reprocessed;
- by 1 July 2024: mixed and unsorted paper and cardboard; and
- by 1 July 2024: all bans in effects.

In June 2021, the Australia's plastic industry stated that they are not ready to apply the new rule by the 1 July 2021.[46] However, the Environment Minister disagreed with the sector's claim, stating a recent survey of the industry showed there was spare annual capacity for 160 000 tonnes of plastic recycling in Australia. The Minister stated that the spare capacity would allow for the processing of 75 000 tonnes of exported plastic waste by Australia to various countries in 2020.

45 Waste Trades, Department of Agriculture, Water and the Environment, Australian Government website, https://www.awe.gov.au/environment/ protection/waste/exports

46 Melissa Clarke. 2021. Recycling industry 'not ready' for ban on exporting plastic waste. ABC net. Posted Tue 29 Jun 2021 at 8:02pm, Tuesday 29 Jun 2021 at 8:02pm, updated Wed 30 Jun 2021 at 4:07am https://www.abc.net.au/news/2021-06-30/recycling-industry-not-ready-for-ban- export-plastics/100253980

Figure 43. Indonesia imported Processed Engineered Fuels (PEFs) 2015-2020 (HS 360690). Source: UN Comtrade

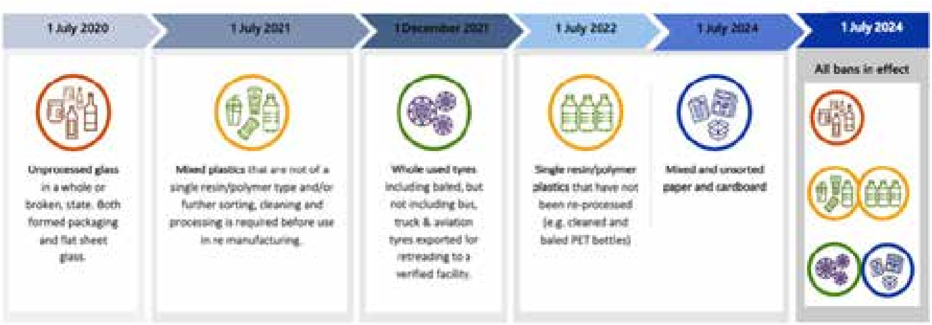

Figure 44. Australia's bans on the export of waste plastic, paper, glass, and tyres and their timetable. Source: Covington, et al. 2020

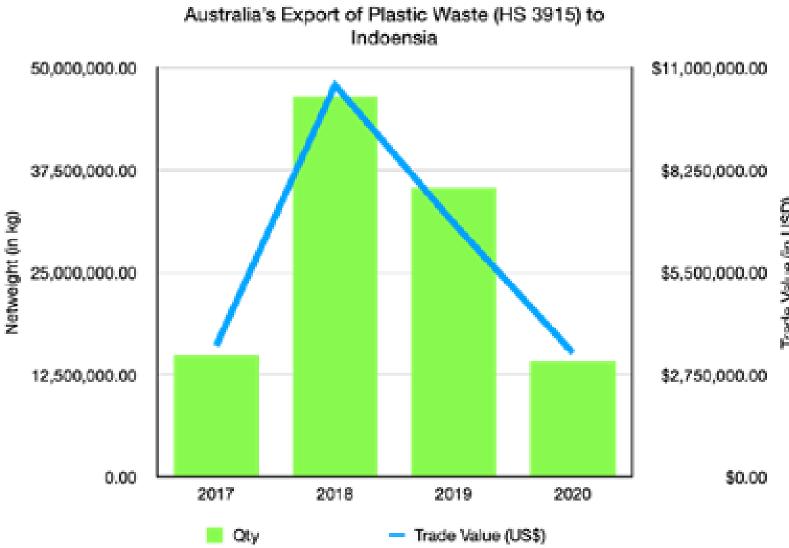

Figure 45. Source: UN Comtrade (Australia's report)

TABLE 13. EXPORT PROHIBITION DATE OF SEVERAL WASTE-DERVED PRODUCTS FROM THE AUSTRALIAN GOVERNMENT

Commodity	AHEEC Code*	Prohibition Date
Plastic	39151000 39152000 39153000	July 2022
	39159092	July 2021
Paper and cardboard	47071000 47072000 47073000 47079000	July 2024
Glass	70010000	January 2021
Whole tyres	40040000 40122000 40129000	December 2021

Note:
**Australian Harmonized Export Commodity Classification (AHEEC), which the last two digit represents Australia's supplementary information for international trade statistics*
Source: Pickin and Donovan. (2020) and Australian Department of Agriculture, Water, and Environment (2021)

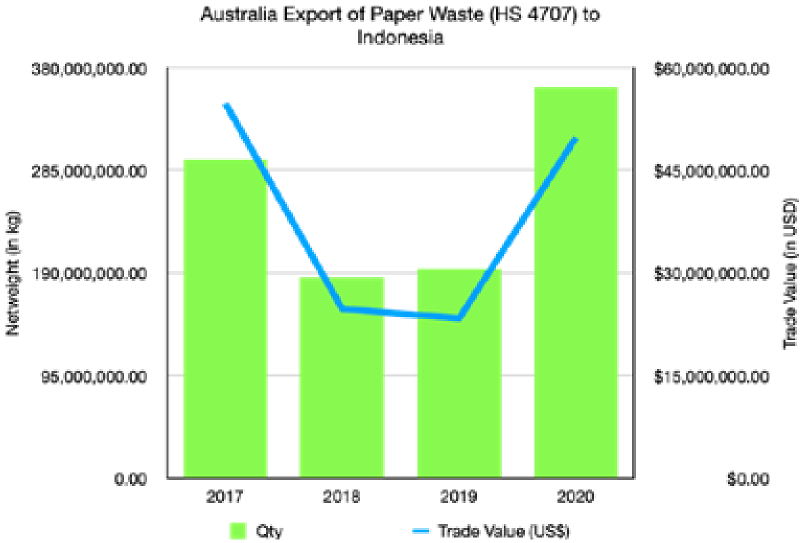

Figure 46. Source: UN Comtrade (Australia's report)

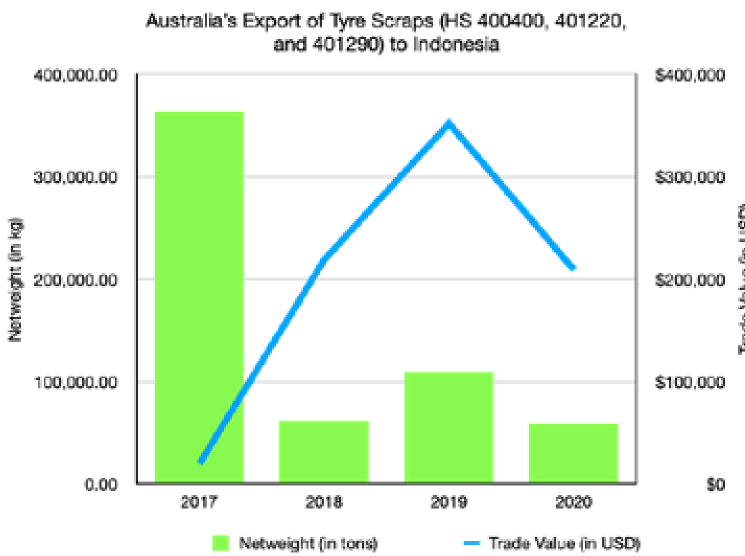

Figure 47. Source: UN Comtrade (Australia's report)

TABLE 14. AUSTRALIA'S EXPORT OF WASTE-DERIVED PRODUCTS TO INDONESIA (HS CODE 3915, 4707, 400400, 401220, 401290, 700700)

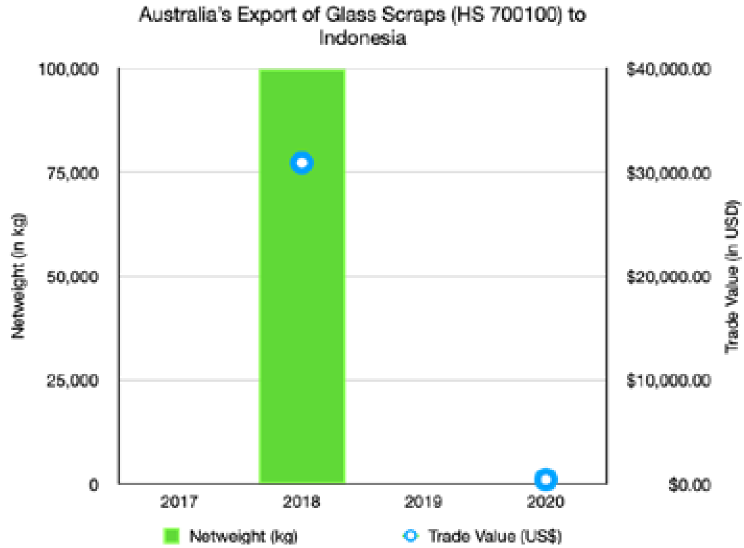

Figure 48. Source: UN Comtrade (Australia's report)

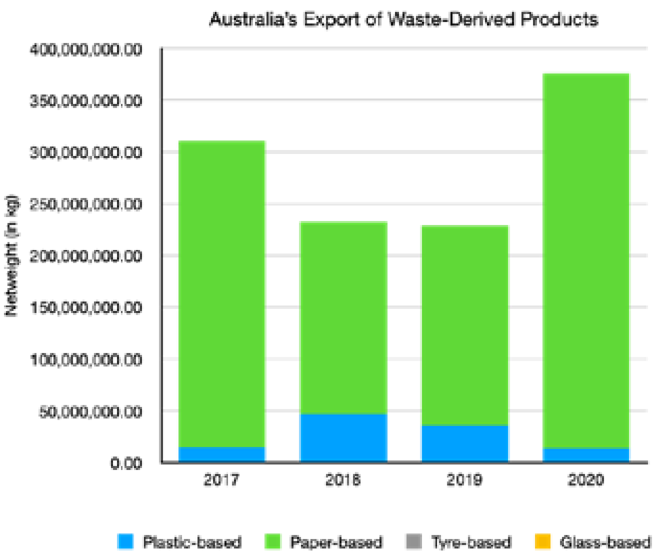

Figure 49. Australia exports of waste-derived products 2017-2020
Source: UN Comtrade, 2022

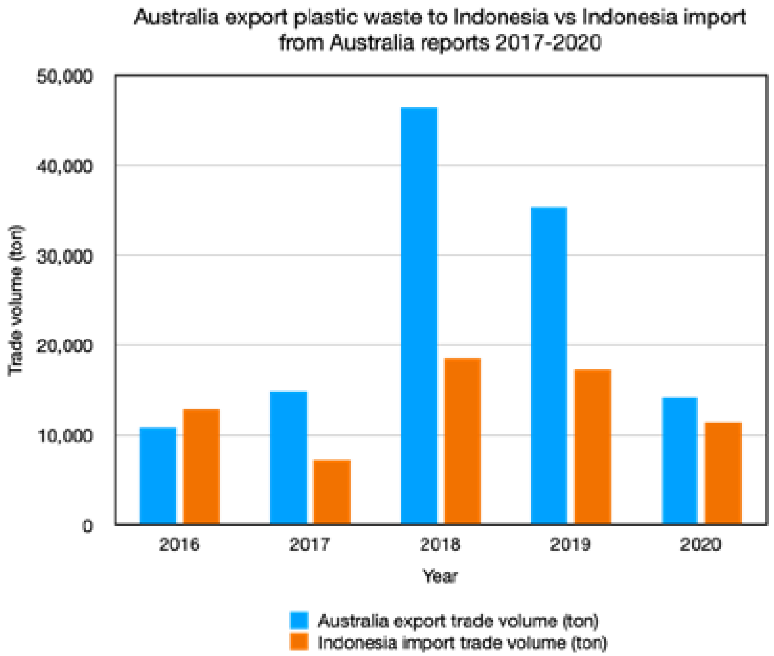

Figure 50. Australia exports of plastic scraps to Indonesia vs Indonesia imports report from Australia 2017-2020 Source: UN Comtrade, 2022

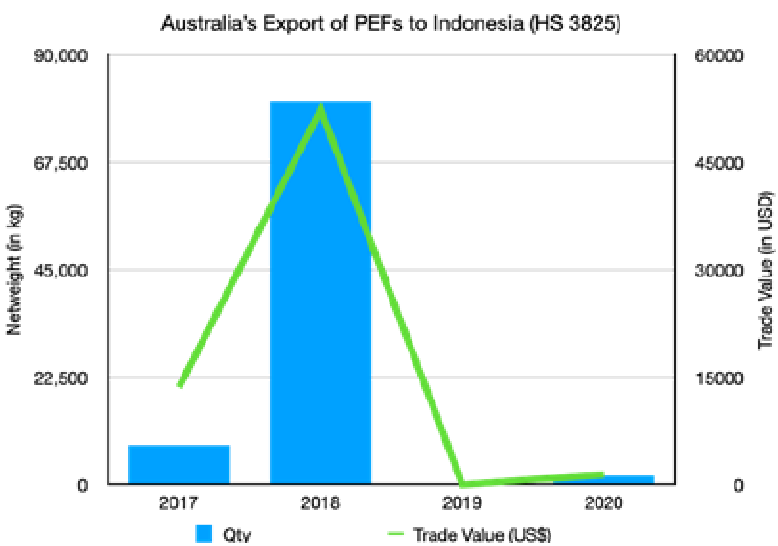

Figure 51. Australia exports of PEF (as HS 3825) to Indonesia 2017-2020 Source: UN Comtrade, 2022

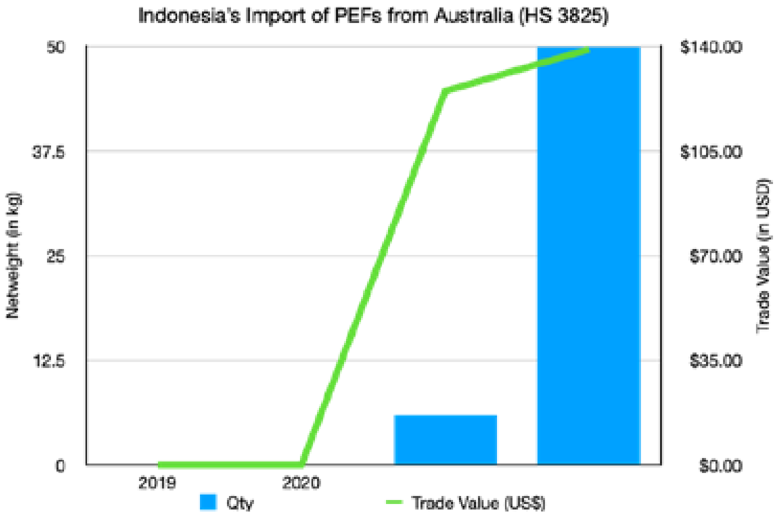

Figure 52. Indonesia imports of PEF (as HS 3825) from Australia 2017-2020 Source: UN Comtrade, 2022

	Plastic-based (kg)	Paper-based (kg)	Tyre-based (kg)	Glass-based (kg)	Total Value (USD)	PEFs (kg)	Total Value PEF (USD)
2017	14,921,730	294,947,470	363,053	0	$58,352,010	8,256	$13,611
2018	46,519,780	185,451,770	61,439	100,000	$35,553,746	80,332	$52,365
2019	35,378,430	194,117,600	109,349	0	$30,539,990	0	$0
2020	14,190,366	361,928,630	58,574	5	$53,376,622	1,887	$1,397

Source: UN Comtrade

Currently, at least two big material recovery and recycling companies in Australia have shifted to produce PEF products which is aimed to be exported to Southeast Asian and South Asian markets.[47,48,49]

Indonesia is not only a major player in the Australian plastic waste trade, i.e., 22% of Australian plastic waste exports reached Indonesia but also a

47 Metso. From waste to fuel: Success in PEF production. 2019 [cited 2022 9 February]; Available from: https://recycling.metso.com/casestudies/ recycling/from-waste-to-fuel/
48 ResourceCo. A world away from waste. 2019 [cited 2022 9 February]; Available from: https://re-sourceco.com.au/a-world-away-from-waste/
49 Australian Clean Energy Finance Corporation. Case study: Turning waste into Processed Engineered Fuel. 2020 [cited 2022 9 February]; Available from: https://www.cefc.com.au/where-we-invest/case-studies/turning-waste-into-processed-engineered-fuel/

Figure 53. Examples of paper scrap containers contaminated with high volumes of plastic wastes. Source: ABC

Figure 54. Indonesia returned eight containers of paper scrap contaminated with plastic wastes to Australia at the beginning of 2019. Source: AFP

major source of ocean plastics because 70% of the overseas ocean plastics reaching Australia is from Indonesia. Moreover, for Australia, Indonesia is the largest paper waste destination country [39].

As displayed in Figure #43, Australia's export on plastic waste peaked in 2018 (46.5 thousand tons) and continued to decline until 2020. Tyre scraps exports to Indonesia peaked in 2017 (363 tons) with decreasing trendline. Australia exports relatively small glass scraps to Indonesia compared to other waste commodities, which were in 2018 (100 tons) and 2020 (5 kg). Paper scraps dominated the export of waste commodity with more than 1 million tons in total export between 2017 - 2020.

From the latest available data during the drafting process of this report, there are relatively small PEF products being traded from Australia to Indonesia. Reports from Australia mentioned there were exports of 80 tons residual products of chemical or allied industries (HS 3825) in 2018, which happens to be the same HS Code used as PEF products.[[50]][50] Compared to Indonesia's import of the same HS Code, however, the gap was significantly higher with only the total of 56 kg during 2017-2020.

Galaiduk et al. [40] recommended that strong bilateral approaches with Indonesia are particularly important for reducing plastic pollution in Australian waters and the regional seas. Further, supporting Indonesia will not only benefit Australia's own national interests but may also induce a ripple effect by encouraging other developed countries to show their global responsibility [41].

50 Holcim Philippines statement on alternative fuels held at other ports. 28 May 2019. Available at https://www.holcim.ph/holcim-philippines- statement-alternative-fuels-held-other-ports

TABLE 15. SEVERAL RDF PROJECTS INVOLVING AUSTRALIAN COMPANIES

Company	Website	Site	Activity	Investment
PT Geo Trash Management	Info site	Lombok, West Nusa Tenggara	Waste collection, recycling, convert plastic waste into fuel using Pyrolysis technology (Dexlite, Euro 3 standard)	Unkown, still at pilot stage in collaboration with the West Nusa Tenggara Province government, pyrolysis plant to convert 1 ton of plastic wastes into 30 liters of fuel)
	Info site	Bontang, East Kalimantan	Convert 15-20 ton of plastic waste into 600 liter of fuel using Pyrolisys technology	Investment: IDR 71 billion (approx. AUD 7 million)
	Info site	Samarinda, East Kalimantan	Convert 15-20 ton of plastic waste into 600 liter of fuel using Pyrolisys technology	Investment: IDR 71 billion (approx. AUD 7 million)
	Info site	South Tangerang City	Pyrolysis, plastic to fuel	
The Minderoo Foundation	Info site	Indonesia	In partnership with Coordinating Ministry of Maritime Affairs and Investment and Ministry of Industry to promote plastic recycling as a machine for green recovery	
ResourceCo Asia	Info site	Tangerang City	In partnership with PT Oligo Infra Swarna Nusantara	RDF plant

5. CONCLUSION AND RECOMMENDATIONS

5.1. CONCLUSIONS

- RDF alone won't solve the problem of plastic pollution and residues of municipal wastes. Burning RDF means converting plastic polution to the air. Without a strong air pollution control regime, the promotion of RDF small to large scale, will increase the risk of exposures to the public health and environmental.
- RDF is one of the solutions to municipal waste problems, especiallly for organic waste. RDF made from residual of waste or mixed waste, when processed properly, could have high calorific value as alternative fuels. However, both the production of RDF, biomass and mixed waste, will need off-takers.
- In Indonesia, currently, only cement kilns and coal-fired power plants that can be considered as reliable off-takers and already regulated. Although several voluntary national standards for RDF biopellets and briquettes available for these industries, there is no guarantee that the co-firing and/coprocessing will not create another problem.
- The emissions standard for dioxins (PCDDs/PCDFs) released from cement kilns that use mixed waste as alternative fuels, only need to be monitored every four years. This regulation needs to be changed, at least once a year.
- The use of RDF for industrial boilers and SMEs is not recommended. Toxic emissions and bottom ash will create and spread new form of toxic wastes in the community. Siting criteria for MRFs combined RDF production facility is lacking.
- Technology and machineries to produce RDF need to be reviewed and its TRL need to be evaluated. Only proven technology (TRL 9) be allowed be sold in the market.
- The main objective to produce RDFs is to solve the municipal waste management. The same amount of capital expenditures for RDF investment could be alocated to improve waste management system and city landfills. Importing RDFs or PEF to Indonesia will be counter-intuitive to solving our waste management problem challenges.

5.2. RECOMMENDATIONS

- To meet the thermal substitution rate set up in the national strategy of mixed energy, restrict and limit the production of RDF only from organic waste and biomass. RDF from mixed waste residues that meet the national standard criteria only allowed to be used in cement kilns.
- To reduce the risks and increase safety in operation, there is a need to develop a mandatory SNI for RDF to be use in cement kilns and enforced by a regulation issued by the Minister of Energy and Mineral Resources.
- Prohibit the importation of waste for alternative fuels under HS codes 3825 and 360690. Implement Basel Amendments effectively and strengthen the border check.
- Increase the capacity of environmental laboratory to analyse dioxins and other POPs chemicals.
- Before the Ministry of Environment and Forestry issued the certificate of environmental friendly technology, the proponent of technology need to obtain certificate TRL-9 from the Minister of Research, Technology and Higher Education (Menristekdikti). Any technology with TRL-9 can be registered to the Minister of Trade to have a permit to sell in the market. That way consumers and the public will be protected from poor performance of RDF production plants.
- For public health safeguard, no RDF processing plant allowed to be built near residential areas.
- Roadmap of FMCGs and plastic producers to reduce plastic content by 2025 should be publicly accessible.
- National, provincial and local governments budget need to be used for waste management system improvement. The cost to build one RDF plant, IDR 90 billion (approx. USD 6 million), can be use to improve open dumping landfills, a proper waste collection system, and increase recycling rate.

ANNEX 1.

EXAMPLE OF CALCULATION OF STANDARD PRICE FOR BIOMASS FUEL BASED ON THE DIRECTOR OF PLN REGULATION NO. 001.P/DIR/2020

PLN

LAMPIRAN I
PERATURAN DIREKSI PT PLN (PERSERO)
NOMOR : 001.P/DIR/2020
TANGGAL : 5 Maret 2020

CONTOH PERHITUNGAN HARGA PATOKAN TERTINGGI BAHAN BAKAR BIOMASSA

Contoh :

- Caloric value (CV) batubara yang digunakan pada PLTU X : 4100 kcal/kg (ar).
- Harga rata-rata batubara 3 (tiga) bulan sebelumnya di PLTU X : Rp 850.000/ton (termasuk ongkos angkut)
- Contoh CV biomassa :

Jenis Industri	Bahan Baku (Feedstock) Biomassa	Nilai Kalori kcal/kg
Kelapa Sawit	Serat Sawit (Fiber)	3340
	Cangkang Sawit (Shell)	4300
	Tandan Kosong Sawit (EFB)	1900
	Pelepah Sawit (frond)	3350
	Batang Replanting Sawit (Trunk)	3500
Tebu	Ampas Tebu (Bagasse)	1850
	Daun & Pucuk Tebu (Leaf, Top Cane)	3000
Kelapa	Sabut Kelapa	3300
	Tempurung Kelapa (Coconut Shell)	4300
Karet	Batang Replanting Karet	4200
Padi	Sekam Padi (Rice husk)	3350
	Jerami Padi	2800
Jagung	Tongkol Jagung (Corn cob)	3500
	Batang & Daun Jagung	2500
Kayu	Kayu Limbah Industri (Woodwaste)	4200

- Maka harga patokan tertinggi cangkang sawit sampai tempat PLTU X (termasuk ongkos angkut) adalah sebagai berikut :

= Rp 850/kg x 0.85 x (4300/4100) kcal/kg
= Rp 758/kg

DIREKTUR UTAMA,

ZULKUIFLI ZAINI

Paraf

PLN

LAMPIRAN II
PERATURAN DIREKSI PT PLN (PERSERO)
NOMOR : 001.P/DIR/2020
TANGGAL : 5 Maret 2020

SPESIFIKASI MINIMAL BAHAN BAKAR BIOMASSA

Spesifikasi minimal pelet sampah :

- Moisture = <20%
- Caloric Value (CV) minimal 3400 kcal/kg
- Komposisi material organic minimal 95%
- Tidak mengandung material B3 dan senyawa klorida

DIREKTUR UTAMA,

ZULKIFLI ZAINI

ANNEX 2

EMISSION STANDARD FOR CEMENT INDUSTRY

Emissions standard for cement kilns that use hazardous waste as Alternative Fuels for cofiring stipulated in the Minister of Environment and Forestry No. 19/2017

LAMPIRAN III
PERATURAN MENTERI LINGKUNGAN HIDUP DAN KEHUTANAN
NOMOR P.19/MENLHK/SETJEN/KUM.1/2/2017
TENTANG
BAKU MUTU EMISI BAGI USAHA DAN/ATAU KEGIATAN
INDUSTRI SEMEN

BAKU MUTU EMISI SUMBER TIDAK BERGERAK BAGI USAHA DAN/ATAU KEGIATAN INDUSTRI SEMEN YANG MENGGUNAKAN *REFUSE DERIVED FUEL* (MENGGUNAKAN SAMPAH RUMAH TANGGA DAN/ATAU SAMPAH SEJENIS RUMAH TANGGA)

No	Parameter	Satuan	Nilai Baku Mutu Emisi
1	Partikulat*	mg/Nm^3	60
2	Sulfur Dioksida (SO2)*	mg/Nm^3	650
3	Nitrogen Oksida (NO_x)*	mg/Nm^3	800
4	Hidrogen Fluorida (HF)*	mg/Nm^3	2
5	Hidrogen Klorida (HCl)	mg/Nm^3	20
6	Karbon Monoksida (CO)*	mg/Nm^3	625
7	Cadmium (Cd)	mg/Nm^3	0,2
8	Merkuri (Hg)	mg/Nm^3	0,2
9	Lead (Pb)	mg/Nm^3	5
10	Arsenik (As)	mg/Nm^3	1
11	Nikel (Ni)	mg/Nm^3	0,5
12	PCDD/F (Dioxin dan Furan)**	ng TEQ/Nm^3	0,1

Catatan :

- kadar maksimum baku mutu diatas dikoreksi terhadap 7% Oksigen (O_2) pada kondisi 25°C, 760 mmHg.

- Pengukuran emisi dilakukan pada kondisi kering.
- Pengukuran kadar Karbon Dioksida (CO2) pada cerobong keluar.

(*) Pengukuran diwajibkan menggunakan CEMS

(**) PCDD/F diukur setiap 4 (empat) tahun sekali setelah beroperasinya unit fasilitas *Refuse Derived Fuel*.

Salinan sesuai dengan aslinya KEPALA BIRO HUKUM,	MENTERI LINGKUNGAN HIDUP DAN KEHUTANAN REPUBLIK INDONESIA,
Ttd.	Ttd.
KRISNA RYA	SITI NURBAYA

PCDD/F measured every four years after the facility started its operation

Emissions standard for cement kilns that use RDF from MSW for cofiring stipulated in the Minister of Environment and Forestry No. 19/2017

Kegiatannya (Permen KLHK no 19 tahun 2017)

No	Parameter	Satuan	Nilai Baku Mutu Emisi
1	Partikulat*	mg/Nm^3	60
2	Sulfur Dioksida (SO_2)*	mg/Nm^3	650
3	Nitrogen Oksida (NO_x)*	mg/Nm^3	800
4	Hidrogen Fluorida (HF)*	mg/Nm^3	2
5	Hidrogen Klorida (HCl)*	mg/Nm^3	20
6	Karbon Monoksida (CO)*	mg/Nm^3	625
7	Cadmium (Cd)	mg/Nm^3	0,2
8	Merkuri (Hg)	mg/Nm^3	0,2
9	Lead (Pb)	mg/Nm^3	5
10	Arsenik (As)	mg/Nm^3	1
11	Nikel (Ni)	mg/Nm^3	0,5
12	PCDD/F (Dioxin dan Furan)**	$ng\ TEQ/Nm^3$	0,1

Air emission standard for Cement Plant that use RDF as their fuel for their activities (Min. of Environment and Forestry No. 19 year 2017)

PCDD/F (Dioxin and Furan)**

Catatan:

- Kadar maksimum baku mutu diatas dikoreksi terhadap 7% Oksigen (O_2) pada kondisi 25°C, 760 mmHg.
- Pengukuran emisi dilakukan pada kondisi kering.
- Pengukuran kadar Karbon Dioksida (CO_2) pada cerobong keluar.

(*) Pengukuran diwajibkan menggunakan CEMS

(**) PCDD/F diukur setiap 4 (empat) tahun sekali setelah beroperasinya unit fasilitas *Refuse Derived Fuel*.

**PCDD/F measured/monitored EVERY 4 (FOUR) YEARS after the RDF plant in operation

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