WHITE PAPER

MARCH 2021

OPPORTUNITIES FOR WASTE FATS AND OILS AS FEEDSTOCKS FOR BIODIESEL AND RENEWABLE DIESEL IN INDONESIA

Yuanrong Zhou, Stephanie Searle, and Tenny Kristiana

www.theicct.org

communications@theicct.org

twitter @theicct

BEIJING | BERLIN | SAN FRANCISCO | SÃO PAULO | WASHINGTON

THE INTERNATIONAL COUNCIL ON CLEAN TRANSPORTATION

ACKNOWLEDGMENTS

This work was generously supported by the David and Lucile Packard Foundation and the Norwegian Agency for Development Cooperation. Thanks to Chelsea Baldino for reviewing this paper.

International Council on Clean Transportation
1500 K Street NW, Suite 650,
Washington, DC 20005

communications@theicct.org | www.theicct.org | @TheICCT

EXECUTIVE SUMMARY

Indonesia is one of the largest biodiesel producing countries in the world. It already has the world's highest biodiesel blending target at 30%, or B30, and is aiming to further increase that blending ratio. To meet these ambitions, Indonesia has devoted significant resources to scaling up the palm biodiesel industry, and today, virtually all biodiesel in Indonesia is produced from a single feedstock—palm oil. But this alone might not be adequate to support bigger blending targets in the years ahead. At the same time, Indonesia is actively seeking opportunities in renewable diesel, a more advanced biofuel that can be produced from the same oil and fat feedstocks as biodiesel, but which possesses superior compatibility properties as a drop-in fuel. As Indonesia would need to deploy an even greater amount of oil and fat feedstocks to meet an increasing blending target and establish a new renewable diesel market, we propose that Indonesia diversify its biofuel industry by including waste feedstocks.

In this study, we assess the current production levels and either disposal of or use of four different waste biodiesel and renewable diesel feedstocks in Indonesia: (1) inedible animal fats, which are by-products of livestock slaughtering; (2) waste fish oil, which can be extracted from fish processing solid wastes, fish processing wastewater, and waste fish; (3) sludge palm oil (SPO), the residual oil floating on the palm oil mill effluent (POME); and (4) tall oil, a by-product of the wood pulp and paper industry. While other countries have been using these feedstocks in biodiesel and renewable diesel production, Indonesia is generally throwing away inedible animal fats and fish wastes and not collecting SPO. Tall oil is not extracted to its full technical potential and most of what is produced is exported. By leveraging its extensive experience in palm biodiesel and with devoted efforts toward establishing a renewable diesel market, it is technologically feasible for Indonesia to utilize these waste feedstocks to make biodiesel and renewable diesel domestically.

We estimate that approximately 1.4 billion liters of biodiesel or 1.35 billion liters of renewable diesel can be produced from these four waste oil and fat feedstocks annually. This would be in addition to the 3.2 billion (biodiesel) or 3 billion (renewable diesel) liters from used cooking oil that is technically available, as estimated in a previous ICCT study (Kharina et al., 2018). Therefore, in total, 4.6 billion liters of biodiesel or 4.35 billion liters of renewable diesel could be produced from waste oils and fats each year. This amount can narrow the trade deficit by reducing fossil diesel import demand by 65% based on 2018 import value. As shown in Figure ES1, waste biodiesel can provide almost 60% of the B30 volumetric target.

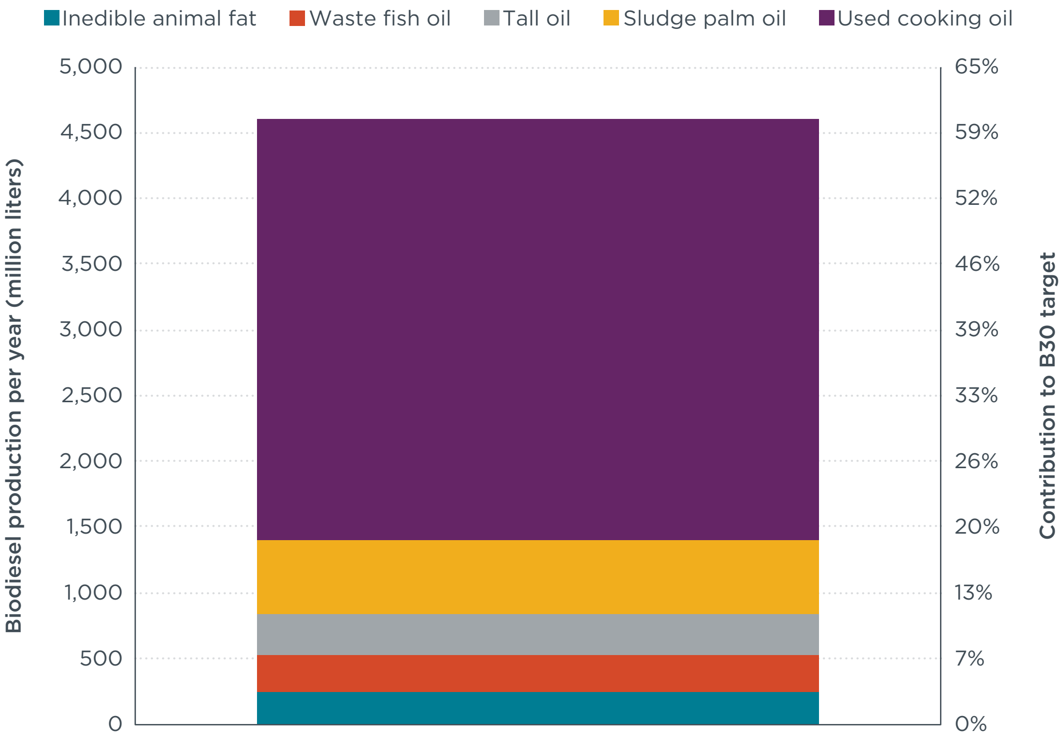

Figure ES1. Annual biodiesel production from full availability of five waste feedstocks and their contributions to Indonesia's B30 blending target.

Utilizing waste feedstocks can bring multiple benefits beyond enhancing Indonesia's energy independence. For one, it would enable biofuel producers to save money on feedstocks. Moreover, based on prior analysis from the United States, we estimate that developing a waste biofuel market has the potential to create about 28,000 jobs in Indonesia. Converting wastes into biofuels also avoids their improper disposal and helps improve air and water quality. Replacing fossil diesel with the full potential of waste biofuel could cut 12 million tonnes of carbon dioxide equivalent (CO_2e) greenhouse gas (GHG) emissions per year and contribute to Indonesia's GHG reduction targets.

Given the significant potential and various benefits of waste biofuel in Indonesia, we identify three main policy recommendations that would support a future mature biofuel market using waste feedstocks:

» Craft a regulation that makes waste feedstocks eligible for use in biofuel production and integrate them into the national biofuel program.

» Provide financial incentives to encourage the use of waste feedstocks. This could take the form of a subsidy similar to the one for palm biodiesel, which covers the price gap between biodiesel/renewable diesel and fossil diesel, or loans with preferential interest rates for small, local biofuel producers.

» Collaborate with civil society organizations to design training programs that raise awareness among feedstock suppliers regarding the value of waste-to-energy and help overcome the potential technical difficulties in waste collection and treatment.

TABLE OF CONTENTS

INTRODUCTION

For the purpose of reducing fuel imports and enhancing energy security, Indonesia has been actively promoting the domestic production and use of biodiesel. The national government has implemented two main supportive policies, a blending target and financial incentives. Indonesia has by far the highest biodiesel target in the world, a 30% blending ratio of biodiesel in fossil diesel, known as B30, and it was officially launched in 2020. Meanwhile, the Indonesian government is planning to further increase the biodiesel blending target in the next few years (Gorbiano, 2019). Regarding the financial incentives, virtually all of Indonesia's biodiesel is produced from palm oil, and in 2015, the government established a funding mechanism whereby a levy on exports of palm oil and derivatives provides a revenue stream to offset the price difference between palm biodiesel and fossil diesel.

With these policies in place, biodiesel production and consumption in Indonesia's transportation sector has increased significantly since 2015. Figure 1 illustrates domestic biodiesel production and on-road biodiesel and fossil diesel consumption between 2015 and 2020. The achieved biodiesel blending rate is also shown as the percentage values. Despite the increasing trend, the transportation sector failed to meet its B20 target between 2016 and 2018, as biodiesel accounted for less than 12% of fossil diesel consumption. The 2019 and 2020 data, as an estimate, indicates that Indonesia probably came close to its B20 and B30 targets, respectively. However, it is likely to be a different story going forward. In 2020, there was an unusual drop in diesel demand due to the COVID-19 crisis, and thus the high biodiesel blending ratio was a special case. Should the fuel market recover, which is highly likely (Agarwal et al., 2020), and maintain a projected growth rate of 3.8% per year (BPPT, 2019), Indonesia would have to significantly scale up its biodiesel production to keep up with the rising fuel demand and the higher blending target that is in the government's plan.

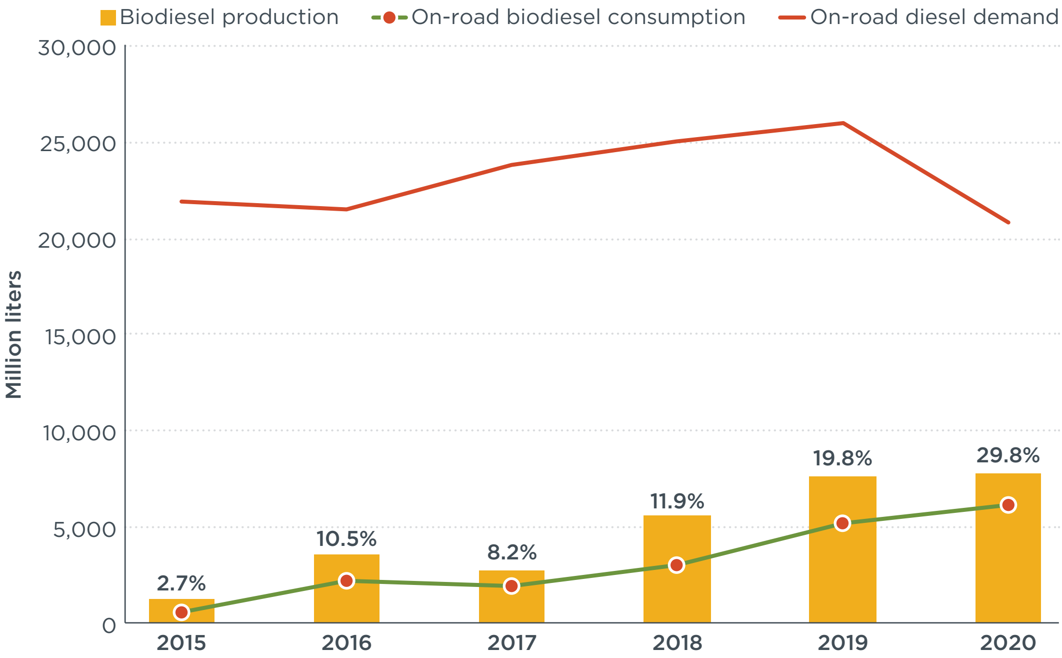

Figure 1. Biodiesel production and fossil diesel and biodiesel consumption in the on-road sector in Indonesia. Percentage values are blending rates. Source: United States Department of Agriculture (USDA, 2020). Note: 2019 and 2020 data are estimates by USDA.

In addition, Indonesia is also aiming to develop a renewable diesel industry. Renewable diesel requires more advanced fuel conversion technology than biodiesel, but it can be produced from the same oil and fat feedstocks as biodiesel. While biodiesel has to be blended in fossil diesel to be compatible with internal combustion engines, renewable diesel is a drop-in fuel that performs just as well as fossil diesel and does not require fuel blending from a technical perspective. Currently, the Indonesian government and Pertamina, the state oil company, are experimenting with trials of domestic renewable diesel production from palm oil (Kotrba, 2020). Exploiting new resources and diversifying feedstocks for biodiesel and renewable diesel is necessary for the continued expansion of both industries.

This study identifies and estimates the amount of feedstock that is currently wasted but could potentially be utilized for biodiesel and renewable diesel production in Indonesia. In a 2018 ICCT study, Kharina et al. assessed the opportunity of used cooking oil (UCO) to make Indonesia's biodiesel and found that UCO is inexpensive and abundant, but underutilized. In particular, easy-to-collect UCO, in other words, UCO from urban restaurants, could add about 4% to the biodiesel pool, and the cost of producing UCO biodiesel is 35% lower than palm biodiesel. In this study, we investigate other potential waste feedstocks.

We evaluate four waste feedstocks for biodiesel and renewable diesel: inedible animal fats, waste fish oil, sludge palm oil (SPO), and tall oil. These feedstocks can be converted to biodiesel using simple, inexpensive technologies that are already used in Indonesia, or be converted to renewable diesel using more advanced technologies that are commercially viable in other countries, such as the United States. We assess the availability of the four waste feedstocks and the volumes of biodiesel and renewable diesel that could potentially be produced from them. We then estimate the level of diesel displacement and reduction in oil imports that could be achieved by this strategy and identify policy levers that could help scale up the use of waste feedstocks. This study provides insights for the Indonesian government about using diverse feedstocks to meet the country's ambitious biofuel targets in a sustainable way. While this study focuses on diesel displacements, we assessed the opportunity of gasoline displacement via cellulosic ethanol from palm residues in a recent study (Zhou et al., 2020b).

AVAILABILITY OF WASTE FEEDSTOCKS

In this section, we assess the quantity of inedible animal fats, waste fish oil, SPO, and tall oil that could be used for biodiesel and renewable diesel production in Indonesia. Specifically, we investigate current production of these feedstocks; current fate, such as disposal or other uses; and suitability for biodiesel and renewable diesel production. We then estimate the amount of biodiesel and renewable diesel that could be produced from each of the four feedstocks.

INEDIBLE ANIMAL FATS

Animal fats are by-products of livestock slaughtering. Some of these are edible and sold to the food market. Edible animal fats are valuable and will always be used preferentially in food. However, some animal fats from slaughterhouses are not of high enough quality for human consumption. These inedible animal fats can be used to feed animals or make oleochemical products, and they are also used to produce biodiesel and renewable diesel in some countries. For example, inedible animal fats account for about 10% of biodiesel production in the United States (Energy Information Administration, 2019). However, in Indonesia, inedible animal fats are generally thrown away (Brienen et al., 2014; Jumini, 2017).

Data on Indonesia's production of inedible animal fats is difficult to find. Although the Food and Agriculture Organization (FAO) provides data regarding the production, trade, stock, domestic supply, and consumption of animal fats in food or other sectors in Indonesia (FAO, 2019), this dataset does not separate edible and inedible animal fats. Therefore, to better estimate the amount of inedible animal fats that could be used for biodiesel, we used data from a previous ICCT study (Zhou, Baldino, & Searle, 2020a) that calculated the ratio of animal fat production, including both edible and inedible, per livestock meat production in the United States. We applied the ratio from that study to the meat production of beef, pork, and chicken in Indonesia, which we retrieved from the FAO. We then subtracted the amount used in food consumption, as reported by the FAO, from the calculated total animal fat production to estimate the inedible portion that could be deployed for biodiesel production.

Following this methodology and considering that about 0.14 gallons of biodiesel or 0.13 gallons of renewable diesel can be produced from 1 pound of fatty feedstock, we estimate that about 205,000 tonnes of inedible animal fats in Indonesia could be used to produce 240 million liters biodiesel or 230 million liters renewable diesel.

We note several caveats regarding this. First, the inedible fats that we evaluated are from livestock of cattle, pigs, and chickens and we did not consider the amount of fats from other kinds of livestock, such as lamb and duck. Such exclusion is expected to cause underestimation, but not to a large degree, as cattle, pigs, and chickens dominate the livestock market in Indonesia with a share that is over 90% (FAO, 2019). Second, using the U.S. animal fat production ratio is the best estimation due to the lack of other data, but does not speak specifically to Indonesia's situation, especially if there are differences in the fatness of the livestock due to different feed and raising methods, or if there are differences in slaughtering techniques. Third, we did not consider any exports of Indonesia's inedible animal fats as we wanted to estimate the maximum potential for domestic use. We followed this rule for all other feedstocks, as well.

WASTE FISH OIL

Waste fish oil can be extracted from three sources: (1) fish processing solid wastes, which are the unwanted parts of fish during product processing such as making fish fillet; (2) fish processing wastewater; and (3) waste fish, which is the unwanted whole fish that is discarded through the supply chain. Currently, in Indonesia, these wastes are not utilized, but fish oil can be used for biodiesel production. Indeed, Neste, a big biofuel producer, has been using fish oil from fish processing wastes as one of its feedstocks (Neste, 2020).

As detailed below, we estimate that total waste fish oil from the three sources is 240,000 tonnes in Indonesia, and this could be used to produce 280 million liters of biodiesel or 265 million liters of renewable diesel.

Fish processing solid wastes

We retrieved the data of marine and freshwater fish production in Indonesia from the FAO (FAO, 2019). Previously, FAO (2006) estimated that about 56% of the fish in Indonesia is consumed fresh, and the rest is processed. The solid wastes generated during fish processing are approximately half of the fish processed (Girish, Gambhir, & Deshmukh, 2017). The oil extraction rate from fish processing wastes, such as head and tail, is about 5% (Kasmiran, 2016).

Based on these assumptions, we estimate the amount of fish oil that could be extracted from fish processing solid wastes in Indonesia to be 65,000 tonnes.

Fish processing wastewater

Theoretically, fish oil floating in fish processing wastewater could be collected in various ways, physically, chemically, or biologically (Show, 2008). Generally, about 18–60 liters of water is used to process each kilogram of fish (Thomas, 2016). We assumed 40 liters of water per kilogram of fish in this study and multiplied it by the above calculated processed fish amount. The oil content in the wastewater has a wide range, depending on the fish species and the processing operations (Colic et al., 2007; Show, 2008). Thomas (2016) found that the oil content in wastewater from processing herring, tuna, salmon, and catfish is in the range of 60 milligrams (mg) to 800 mg per liter of wastewater and for tuna specifically, it is 250 mg per liter. Since tuna is one of the major fish produced in Indonesia and its oil content value is relatively in the middle of the range, we used 250 mg per liter for an estimation. One study found that approximately two-thirds of the oil content could be extracted from the wastewater (Show, 2008).

Based on these assumptions, we estimate the available fish oil from fish processing wastewater in Indonesia to be 20,000 tonnes. Note, though, that collecting fish oil from wastewater might not be feasible right now in Indonesia, as the fish industry tends to dump wastewater into a river or ocean directly (NusaBali, 2015). In order to collect fish oil, it is necessary to centralize wastewater in one place, such as a wastewater treatment plant. This means that Indonesia would have to invest in such facilities first. Nonetheless, the Indonesian government is aiming to better treat wastewater from the fish industry (Nurcaya, 2020) and policymakers could incorporate fish oil collecting into policy design.

Waste fish

The FAO (2004) estimated a fish discard rate of about 8% in Indonesia. The oil extraction rate from whole fish is about 10% to 50%, depending on the fish species (Bonilla-Mendez & Hoyos-Concha, 2018). We chose a middle case and used 30% as the oil extraction rate.

Based on these assumptions, we estimate the amount of fish oil that could be extracted from waste fish in Indonesia is 155,000 tonnes.

SLUDGE PALM OIL

Sludge palm oil (SPO) is the residual oil floating on the palm oil mill effluent (POME), the wastewater coming out of the palm mills. POME contains a lot of organic matter and thus, according to Indonesian regulations, it must be treated before discharged into natural waterbodies. Currently, palm mills in Indonesia utilize a pond system for POME treatment; the POME goes through a series of ponds where organic matter is decomposed, and consequently SPO is not collected. Multiple studies have suggested that SPO can be skimmed off and used to make biodiesel (Bio-based News, 2019; Muanruka, Winterburn, & Kaewkannetra, 2019). SPO is also one of the waste feedstocks that Neste uses to produce biodiesel and renewable diesel (Neste, 2020).

According to a previous study, the amount of SPO generated at palm oil mills is about 2% of total palm oil production (Manurung, Ramadhani, & Maisarah, 2017). We collected Indonesia's palm oil production data from FAO (2019). We suspect that it would be hard to extract all SPO from POME and therefore used the same oil extraction rate as above, two-thirds oil from wastewater, for an estimation.

As calculated, about 500,000 tonnes of SPO in Indonesia could be used to produce 570 million liters biodiesel or 550 million liters renewable diesel. The future amount of SPO availability is likely to be higher than this for two reasons. One, the extraction rate might increase as technology develops, and two, SPO volume will increase as palm oil production increases.

TALL OIL

Tall oil is a by-product of the wood pulp and paper industry. In pulp manufacture, chemicals are used to separate out cellulose fibers, which are then used to make paper. The remaining solution is called black liquor and it consists of lignin and organic matters. This black liquor can be further processed to separate out crude sulfate soap, which can be turned into crude tall oil (CTO) through acidulation. Indonesia currently either exports CTO, mainly to other Asian countries, or distills CTO into other chemical products, such as tall oil fatty acids (United Nations, 2020). In other countries, several biofuel companies have pioneered CTO-based biofuels. For example, each year, UPM produces approximately 120 million liters of renewable diesel from CTO at its Lappeenranta Biorefinery in Finland (UPM, 2020). Additionally, the annual production by Sunpine in Sweden is about 105 million liters (Sunpine, 2020).

No data about Indonesia's annual CTO production was found and therefore we estimated it. Previous studies reported that the total CTO production in Asia was 90,000 tonnes in 2015 (Malins, 2017) and total pulp production in Asia was 32 million tonnes in the same year (FAO, 2018). Using these, we took the ratio of CTO production to pulp production and applied it to Indonesia's pulp production (FAO, 2018) for a rough estimation of actual tall oil production. We thus estimate the likely production of CTO in Indonesia to be 20,000 tonnes.

However, Indonesia has high potential to increase its CTO production through greater collection of crude sulfate soap and by acidulating more of that material into CTO. Theoretically, 20–50 kg of tall oil can be produced for each tonne of pulp (Malins, 2017). If we assume 40 kg tall oil per tonne pulp produced, we estimate that 270,000 tonnes of CTO could potentially be produced in Indonesia, which is more than tenfold higher than the estimated current production amount. We hypothesize that most of the oil available in black liquor in Indonesia is either not being separated from the black liquor or is combusted as crude sulfate soap for process heat and power. Acidulating it into CTO would allow use of this resource in biodiesel, which is a higher value product.

If utilizing CTO to its full potential, Indonesia could produce 310 million liters of biodiesel or 300 million liters of renewable diesel.

RESULTS AND DISCUSSION

BIOFUEL POTENTIAL FROM WASTE FEEDSTOCKS

We estimate that Indonesia is able to produce a total of 1.4 billion liters of biodiesel or 1.35 billion liters of renewable diesel from the four waste feedstocks analyzed in this study. This is in addition to the 3.2 billion liters of biodiesel or 3 billion liters of renewable diesel from another waste feedstock, UCO, as estimated in a previous ICCT study (Kharina et al., 2018). Table 1 summarizes the availability of each of the five waste feedstocks and the resulting biodiesel or renewable diesel production, and below that, Figure 2 demonstrates the biodiesel production potential from the five feedstocks and how each would have contributed to meeting Indonesia's B30 biodiesel target once the demand recovers to pre-pandemic levels.

Table 1. Annual availability of five waste feedstocks and the production of biodiesel or renewable diesel from their full availability

	Inedible animal fats	Waste fish oil	Sludge palm oil	Tall oil	Used cooking oil	Total
Feedstock availability (thousand tonnes)	205	240	500	270	2,700	3,915
Biodiesel production (million liters)	240	280	570	310	3,200	4,600
Renewable diesel production (million liters)	230	265	550	300	3,000	4,345

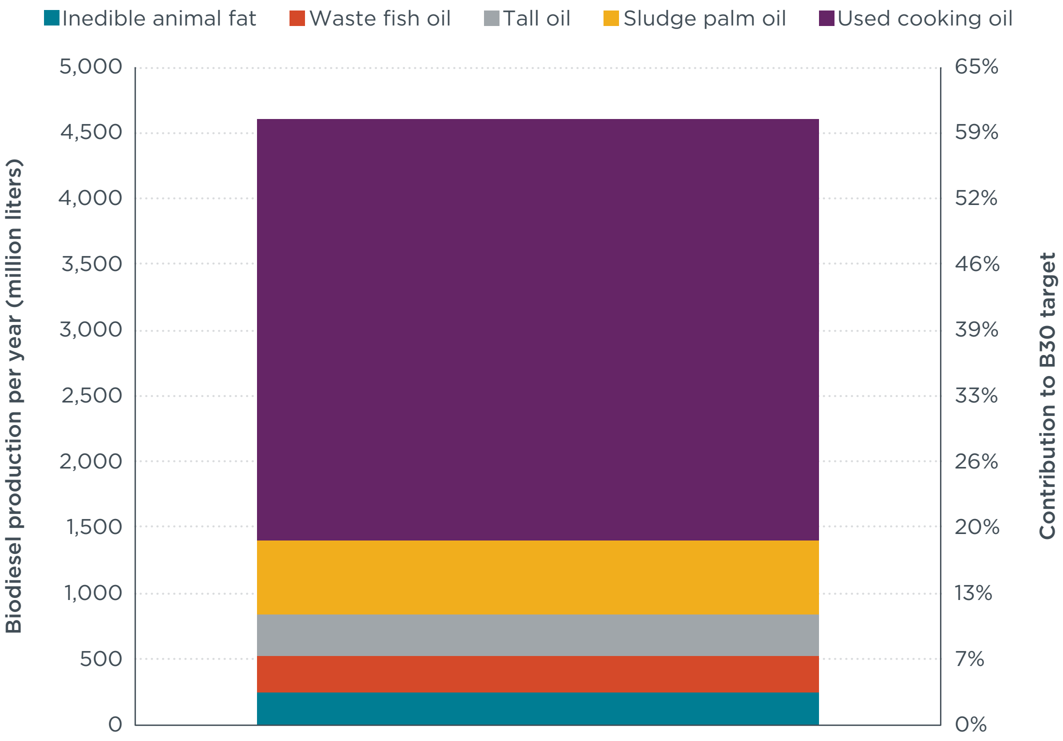

Figure 2. Annual biodiesel production from full availability of five waste feedstocks and their contributions to Indonesia's B30 blending target.

Once the fuel market recovers to its pre-COVID-19 level, using these five waste feedstocks can meet almost 60% of the biodiesel volumetric target set by the Indonesian government and can replace about 16% of on-road diesel demand, when taking into consideration the different heating values of biodiesel and fossil diesel. Among the five feedstocks, UCO presents the greatest amount. However, we note that this is the technical potential assuming nationwide collection from all sources, to be consistent with our estimates for other waste feedstocks. It would be difficult to reach this level of UCO collection in the near term, given that Indonesia currently lacks a systematic collection effort. SPO also shows great potential and its availability is likely to increase in the future alongside rising palm oil production and technology improvements in residual oil extraction.

BENEFITS OF WASTE FEEDSTOCKS

Using waste feedstocks for biofuels brings multiple benefits. In addition to helping to meet targets for biofuel blending rates, it would help reduce Indonesia's need for fuel imports. In 2018, fuel was approximately 17% of Indonesia's imports by value (World Bank, 2020) and Indonesia imported 6.5 billion liters of diesel in the same year (USDA, 2020). Using the five waste feedstocks could reduce diesel imports by 65%. Biofuels from waste feedstocks can thus also contribute to narrowing Indonesia's trade deficit, in line with government trade strategy (The Jakarta Post, 2019).

The socio-economic benefits that can result from using waste feedstocks include lower costs for biofuel producers, more job opportunities, and improved sustainability. Some of the waste feedstocks we examined are currently thrown away, and as they have little economic value otherwise, biofuel producers would not pay much to purchase these feedstocks. For example, the cost of producing UCO biodiesel is 35% lower than palm biodiesel in Indonesia as a result of lower feedstock price of UCO (Kharina et al., 2018), and we expect similar cost reduction from the other waste feedstocks. And regarding jobs, in 2017, approximately 180,000 people worked in the biodiesel industry in Indonesia (IRENA, 2018). According to a U.S. study (Richards, 2013), producing 4.6 billion liters of biofuel from the five waste feedstocks in this study is likely to support more than 28,000 jobs. This would increase the biofuel industry employment pool in Indonesia by more than 15%.

Additionally, the sustainability benefits are myriad. First, utilizing wastes can avoid improper disposal and thereby help address local environmental issues. Whenever inedible animal fats, fish wastes, or UCO are dumped without proper treatment, it causes adverse environmental impacts. These include the production of toxic and non-degradable compounds that exist in the environment for many years; the suffocation of animals and plants by an oil coating and destruction of local habitats; eutrophication in waterbodies, which leads to poor water quality and species endangerment; clogged drainage and water treatment systems; foul shorelines; and rancid odors (FAO, 1996; U.S. Environmental Protection Agency, 2000; NusaBali, 2015). Utilizing waste feedstocks for biofuel can help mitigate these environmental issues.

Second, biofuels made from waste feedstocks typically offer significant greenhouse gas (GHG) reductions compared to fossil fuels. The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) model allows for the lifecycle assessment of GHG performance of various alternative fuels, including biodiesel and renewable diesel, and is applied in multiple biofuel policies, including the U.S. Renewable Fuel Standard (RFS). We used the GREET model to estimate waste biofuel's total GHG emissions throughout its lifecycle—feedstock extraction, fuel production, and combustion. Of the five waste feedstocks considered here, GREET only provides data on inedible animal fats and UCO, and for these, the total GHG emissions are approximately 25 grams of carbon dioxide equivalent (gCO_2e) per megajoule (MJ) of biodiesel or 15 gCO_2e per MJ of renewable diesel. The carbon intensity of fossil diesel, meanwhile, is about 98 gCO_2e/MJ, and that means that replacing fossil diesel with waste biofuel can reduce GHG emissions by more than 70%. Assuming the carbon intensity of each of the five types of waste biofuel is 25 gCO_2e, replacing fossil diesel with the 4.6 billion liters of waste biofuel from our analysis can cut about 12 million tonnes of CO_2e per year, equivalent to 1.4% of Indonesia's national GHG emissions

(World Resources Institute, 2018). Waste biofuel can thus contribute to Indonesia's Nationally Determined Contribution targets, which include a 29% GHG reduction below business-as-usual by 2030.

Lastly, such waste-to-energy practice falls within the emerging idea of "circular economy," a system that encourages diminishing resource inputs and reuse. The Indonesian government is currently developing a national action plan to create a circular economy ecosystem in the country (Yasmin, 2020). Therefore, it appears to be a good time for Indonesia to include using waste feedstocks for biofuels in its agenda.

POLICY SUPPORT

Government support is needed to expand the collection and utilization of waste feedstocks for biofuel production. We identify three main policy recommendations that would help establish a mature biofuel market using waste feedstocks in Indonesia.

First, the Indonesian government could explicitly include waste feedstocks under the national biofuel policies. In Indonesia, the central government is responsible for approving and regulating any fuel-related activities, and it is necessary for the government to allow waste feedstocks to be eligible for use in biofuel production and counted toward biofuel blending mandates. This would not only signify to feedstock suppliers that waste feedstocks have this alternative use, but also build the demand for these feedstocks from biofuel producers. Integrating waste feedstocks in the biofuel program also diversifies the feedstock supply chain and thus supports its sustainability.

After feedstock eligibility is achieved, the national government could provide financial incentives to encourage biofuel producers to use waste feedstocks. Particularly, policymakers could adopt the same formula as used for the palm biodiesel subsidy, which covers the price gap between biodiesel/renewable diesel and fossil diesel. We expect that the subsidy amount needed to support waste biodiesel would be less than for palm biodiesel because waste feedstocks are cheaper than palm feedstocks. Another possible avenue is for local governments to provide loans at preferential rates of interest to small, local biodiesel producers. Certain waste feedstock suppliers, such as the livestock and fish industry, are located in remote areas and are far from existing biofuel plants. To reduce transportation costs, it is more economical to convert these waste feedstocks into biofuel locally, and special loans could help local businesses overcome any barriers related to upfront investment.

However, even with the economic benefits, lack of awareness might prevent suppliers from collecting these waste feedstocks. Thus, educational efforts are also needed to scale up collection, and building awareness among feedstock suppliers is necessary because, for the most part, they are used to throwing away these materials. The national government, local governments, and civil society organizations could collaborate to design training programs to educate feedstock suppliers regarding the value of waste-to-energy. Such programs could also help overcome potential technical difficulties in waste collection and treatment. For example, palm mills probably need technical support for extracting SPO from POME.

In addition, the national government could promote the collection of waste feedstocks under policies other than biofuel policies, such as the above-mentioned circular economy action plan and waste management regulations. Addressing waste feedstocks in multiple policies would signal strong support for these feedstocks and could effectively encourage their collection.

CONCLUSIONS

There is great potential in using waste feedstocks to produce biofuels in Indonesia. At present, inedible animal fats, waste fish oil, and SPO are not collected, and tall oil is not exploited to its full potential. Additionally, there is large potential in UCO, although significant efforts are required to collect it. We propose that Indonesia take advantage of all of these waste feedstocks by using them to make biofuels and prioritizing the use of the fuel domestically. We estimate that 4.6 billion liters of biodiesel or 4.35 billion liters of renewable diesel could be produced from these five waste feedstocks.

Utilizing waste feedstocks could enable Indonesia to reach its biofuel blending target and bring multiple benefits. To support and scale up waste feedstock utilization, the Indonesian government could provide policy support in various ways. First and foremost, the national government would need to make a regulation that explicitly states that waste feedstocks are eligible and integrates waste feedstocks in the national biofuel program. As a biodiesel support fund has proven to be very successful in promoting palm biodiesel, this argues for similar subsidies for waste feedstocks. Local governments could also provide loans at preferential interest rates to small, local biofuel producers who use waste feedstocks. Other national and local supports, such as technical support and educational programs, would also help form a sustained and healthy supply chain of the feedstocks.

REFERENCES

Agarwal, R., Agarwal, V., Hansmann, T., Lath, V., Tan, K.T., & Yi, Z. (2020). *Ten ways to boost Indonesia's energy sector in a postpandemic world*. Retrieved from McKinsey & Company, https://www.mckinsey.com/industries/oil-and-gas/our-insights/ten-ways-to-boost-indonesias-energy-sector-in-a-postpandemic-world

Bio-based News. (2019, August 26). Mineral oil groups ramp up HVO production in EU. Retrieved from http://news.bio-based.eu/mineral-oil-groups-ramp-up-hvo-production-in-the-eu/

Bonilla-Mendez, J.R., & Hoyos-Concha, J.L. (2018). Methods of extraction refining and concentration of fish oil as a source of omega-3 fatty acids. *Corpoica Sciencia y Tecnología Agropecuaria, 19*(3), 645–668. doi: 10.21930/rcta.vol19_num2_art:684

BPPT. (2019). *BPPT outlook energi Indonesia 2019*. Retrieved from https://www.bppt.go.id/dokumen/outlook/outlook-energi

Brienen, M., Cavenagh, B., Vliet, W.V., & Copier, M. (2014, June 20). Meeting the challenge of Indonesia's growing demand for poultry. *WATTPoultry.com*. Retrieved from https://www.wattagnet.com/articles/19161-meeting-the-challenge-of-indonesia-s-growing-demand-for-poultry

Colic, M., et al. (2007). *Case study: Fish processing plant wastewater treatment*. Retrieved from Clean Water Technology Inc., https://www.cwt-global.com/Files/files/2007-07-29-fish_processing_wastewater.pdf

Energy Information Administration. (2019). *Monthly biodiesel production report archives*. Retrieved from https://www.eia.gov/biofuels/biodiesel/production/archive/2018/2018_12/biodiesel.php

Food and Agriculture Organization. (1996). *Management of waste from animal product processing*. Retrieved from http://www.fao.org/3/X6114E/x6114e00.htm#Contents

Food and Agriculture Organization. (2004). *Issues associated with low value/trash fish*. Retrieved from http://www.fao.org/3/ae934e/ae934e06.htm

Food and Agriculture Organization. (2006). *The republic of Indonesia*. Retrieved from http://www.fao.org/fi/oldsite/FCP/en/IDN/profile.htm

Food and Agriculture Organization. (2018). *Forest products 2016*. Retrieved from https://paperonweb.com/FAO2016.Paper.pdf

Food and Agriculture Organization. (2019). *FAOSTAT*. Retrieved from http://www.fao.org/faostat/en/#data

Girish, C.R., Gambhir, M.M., & Deshmukh, T. (2017). Production of biodiesel from fish waste and characterization of produced biodiesel. *International Journal of Civil Engineering and Technology, 8*(9), 1-6.

Gorbiano, M.I. (2019, August 12). Jokowi wants 30% biodiesel in cars as soon as January next *year. The Jakarta Post*. https://www.thejakartapost.com/news/2019/08/12/jokowi-wants-30-biodiesel-in-cars-as-soon-as-january-next-year.html

Hidalgo, M., & Puerta-Fernandez, E. (2017). Fermentation of glycerol by a newly discovered anaerobic bacterium: adding value to biodiesel production. *Microbial Biotechnology, 10*(3), 528–530. doi: 10.1111/1751-7915.12709

International Renewable Energy Agency. (2018). *Renewable energy and jobs: Annual review 2018*. Retrieved from https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/May/IRENA_RE_Jobs_Annual_Review_2018.pdf

Jumini, S. (2017). Alternative fish feed production from waste chicken feathers. *International Journal of Science and Applied Science: Conference Series, 1*(2), 144–152. doi: 10.20961/ijsascs.v1i2.5140

Kasmiran, B. (2016). *Comparison and evaluation of the quality of fish oil and fishmeal extracted from the heads of yellowfin tuna (Thunnus albacares) and albacore tuna (Thunnus alalunga)*. Nations University Fisheries Training Programme, Iceland [final project]. Retrieved from https://www.grocentre.is/static/gro/publication/329/document/britney16prf.pdf

Kharina, A., Searle, S., Rachmadini, D., Kurniawa, A.A., & Prionggo, A. (2018). *The potential economic, health and greenhouse gas benefits of incorporating used cooking oil into Indonesia's biodiesel*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/UCO_Biodiesel_Indonesia_20180919.pdf

Kotrba, R. (2020, July 23). Pertamina to scale up renewable diesel production in Indonesia. *Biodiesel Magazine*. Retrieved from http://www.biodieselmagazine.com/articles/2517089/pertamina-to-scale-up-renewable-diesel-production-in-indonesia

LeGendre, C., Logan, E., Mendel, J., & Seedial, T. (2009). *Anaerobic fermentation of glycerol to ethanol. Senior Design Reports (CBE)*. 5. Retrieved from https://repository.upenn.edu/cgi/viewcontent.cgi?article=1004&context=cbe_sdr

Li, Y., Qiu, Y., Zhang, X., Zhu, M., & Tan, W. (2019). Strain screening and optimization of biohydrogen production by *Enterobacter aerogenes* EB-06 from glycerol fermentation. *Bioresources and Bioprocessing, 6*, 15. doi:10.1186/s40643-019-0250-z

Malins, C. (2017). *Waste not want not: Understanding the greenhouse gas implications of diverting waste and residual materials to biofuel production*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Waste-not-want-not_Cerulogy-Consultant-Report_August2017_vF.pdf

Manurung, R., Ramadhani, D.A., & Maisarah, S. (2017). One step transesterification process of sludge palm oil (SPO) by using deep eutectic solvent (DES) in biodiesel production. *AIP Conference Proceedings 1855*, 070004.

Muanruka, P., Winterburn, J., & Kaewkannetra, P. (2019). A novel process for biodiesel production from sludge palm oil. *MethodsX*, 6, 2838–2844. doi: 10.1016/j.mex.2019.09.039

Neste. (2020). *Waste and residues as raw materials*. Retrieved from https://www.neste.com/companies/products/renewable-fuels/renewable-raw-materials/waste-and-residues

Nurcaya, I.A.H. (2020, May 21). Ministry of Industry center develops biological liquid waste treatment technology. *Bisnis Indonesia*. Retrieved from https://ekonomi.bisnis.com/read/20200521/257/1243458/balai-kemenperin-kembangkan-teknologi-pengolahan-limbah-cair-biologi

NusaBali. (2020, November 20). Fish factory disposes of waste into river, residents protest. Retrieved from https://www.nusabali.com/berita/792/pabrik-ikan-buang-limbah-ke-sungai-warga-protes

Richards, E. (2013). *Careers in biofuels*. Retrieved from the U.S. Bureau of Labor Statistics https://www.bls.gov/green/biofuels/biofuels.htm

Show, K. (2008). Seafood wastewater treatment. In Jiři Klemeš, Robin Smith and Jin-Kuk Kim, (Eds.), *Handbook of water and energy management in food* processing (pp. 776–801). Woodhead Publishing. ISBN 9781845691950

Sunpine. (2020). *Tall diesel*. Retrieved from https://www.sunpine.se/en/produkter/talldiesel/

The Jakarta Post. (2019, December 12). Our country can't be pressured: Jokowi talks trade strategies. Retrieved from https://www.thejakartapost.com/news/2019/12/12/our-country-cant-be-pressured-jokowi-talks-trade-strategies.html

Thomas, S. (2016). *Wastewater generation by seafood processing plants located in and around Aroor, Kerala, India: Status, characterization and treatment using stringed bed suspend bioreactor* (doctoral dissertation). Retrieved from https://pdfs.semanticscholar.org/821b/b5ddc568fccef59a09d79165c36b7f24dc58.pdf

United Nations. (2020). *UN Comtrade database*. Retrieved from https://comtrade.un.org/

UPM. (2020). *UPM Lappeenranta Biofuels*. Retrieved from https://www.upm.com/businesses/upm-biofuels/

U.S. Department of Agriculture. (2020). *Indonesia biofuels annual report 2020*. Retrieved from https://apps.fas.usda.gov/newgainapi/api/Report/DownloadReportByFileName?fileName=Biofuels%20Annual_Jakarta_Indonesia_06-22-2020

U.S. Environmental Protection Agency (2000). 40 CFR Part 112: *Oil pollution prevention and response; Non-transportation-related facilities; Final rule*. Retrieved from https://www.govinfo.gov/content/pkg/FR-2000-06-30/pdf/00-13976.pdf

World Bank. (2020). *World integrated trade solution*. Retrieved from https://wits.worldbank.org/about_wits.html

World Resources Institute. (2018). *Climate Watch*. Retrieved from https://www.climatewatchdata.org/

Yasmin, N. (2020). *Indonesia launches circular economy initiative with Denmark, UNDP*. Retrieved from https://jakartaglobe.id/business/indonesia-launches-circular-economy-initiative-with-denmark-undp/

Zhou, Y., Baldino, C., & Searle, S. (2020a). *Potential biomass-based diesel production in the United States by 2032*. Retrieved from the International Council on Clean Transportation, https://theicct.org/sites/default/files/publications/Potential_Biomass-Based_Diesel_US_02282020.pdf

Zhou, Y., Searle, S., Pavlenko, N., Kristiana, T., Sudaryadi, & Amukti, R.H. (2020b). *Techno-economic analysis of cellulosic ethanol in Indonesia using palm residues*. Retrieved from the International Council on Clean Transportation, https://theicct.org/publications/techno-economic-cellulosic-ethanol-2020