BRIEFING

APRIL 2021

Potential biofuel production pathways in Indonesia: Overview of processes, feedstocks, and types of fuel

Prepared by: Tenny Kristiana and Chelsea Baldino

In 2004, the Indonesian government developed a biofuel strategy under the National Energy Policy, and it was released as part of Presidential Regulation No. 5/2006, which promoted both biodiesel and bioethanol production.[1] Since then, the government has issued several more regulations to support the policy. One presidential decree helped form a national biofuel development team, and that team released a Blueprint on Biofuel Development in 2008.[2] More recently, the program was expanded to include more advanced liquid fuels and gasification projects.[3] The government has also started to encourage the use of biogas and biomass for the electricity sector.[4]

In order for biofuels policy to support Indonesia's commitment to low-carbon growth,[5] it is crucial to choose feedstocks that are sustainable and environmentally friendly. The country has abundant biomass sources, but some of them are carbon intensive. Additionally, many first-generation biofuels are made from food and feed crops and are associated with land use change emissions. Second-generation biofuels, meanwhile,

1 Anastasia Kharina, Chris Malins, and Stephanie Searle, *Biofuels policy in Indonesia: Overview and status report*, (ICCT: Washington, DC, 2016), https://theicct.org/publications/biofuels-policy-indonesia-overview-and-status-report

2 Ibid.

3 "Tingkatkan Penggunaan Energi Bersih, Pemerintah Dorong Pengembangan Green Diesel," EBTKE-ESDM, accessed November 26, 2020, http://ebtke.esdm.go.id/post/2020/07/21/2589/tingkatkan.penggunaan.energi.bersih.pemerintah.dorong.pengembangan.green.diesel?lang=en; "Kurangi Impor LPG, Gasifikasi Batubara jadi Kebijakan Strategis", ESDM, accessed November 26, 2020, https://www.esdm.go.id/id/media-center/arsip-berita/kurangi-impor-lpg-gasifikasi-batubara-jadi-kebijakan-strategis

4 "Analisis Biaya dan Manfaat Pembiayaan Investasi Limbah Menjadi Energi Melalui Kredit Program (Laporan Akhir),"(PKPPIM BKF Kementerian Keuangan RI dan UK LCF Programme, 2014), https://www.kemenkeu.go.id/sites/default/files/financing%20wte.pdf

5 The Government of Indonesia reconfirmed its commitment in the National Mid-term Development Plan at the conference on Low Carbon Development and Green Economy on 11 October 2018 in Bali: http://greengrowth.bappenas.go.id/en/goi-committed-to-low-carbon-development-and-green-economy/

Acknowledgments: This study was generously supported by the David and Lucile Packard Foundation. Thanks to Tommy Pratama, Martin Baker, and Fariz Panghegar of Traction Energy Asia, and to Stephanie Searle, for their reviews.

have lower carbon intensity because they use a wider variety of feedstocks such as non-food crops, wastes, and residues.

Here we provide a high-level overview of many of the biofuel production pathway options that are likely to be of interest to Indonesian policymakers. We cover the technological processes that are used to produce the fuel, the types of feedstocks that can be used, and the types of fuel produced.

The potential biofuel production pathways in Indonesia include several different technologies, feedstocks, fuel outputs, and blending rates, and these are summarized in Table 1.[6] Note that biofuel feedstocks are abundant in Indonesia and would not be a barrier to developing any of these pathways.

Table 1. Summary of the potential biofuel production pathways for Indonesia

Pathways	Feedstocks	Fuel types	1st or 2nd generation	Typical blending constraints
Biodiesel/fatty acid methyl ester (FAME)	Palm, used cooking oil (UCO), coconut, soybean, jatropha, animal fats	Biodiesel	1st	5% – 10% in most countries, but currently higher in Indonesia
Hydroprocessing	Palm, UCO, coconut, soybean, jatropha, animal fats	Drop-in fuels, e.g., hydrotreated vegetable oil (HVO) or renewable diesel, and hydroprocessed esters and fatty acids (HEFA)	1st	None
Conventional bio-ethanol	Sugarcane, molasses, sweet sorghum, cassava, corn	Ethanol	1st	5% – 15%
Cellulosic ethanol	Palm residues, rice straw, corn stalks, sugarcane bagasse, cassava stems, biological portion of municipal solid waste, demolition wood	Ethanol	2nd	5% – 15%
Gasification – Fischer-Tropsch synthesis	Natural gas, coal, petroleum coke, and the same kind of biomass as is used for cellulosic ethanol	Drop-in fuels, e.g. renewable diesel, jet fuel, gasoline	2nd	None
Anaerobic digestion	Palm oil mill effluent (POME), biodegradable waste, livestock manure, sewage sludge, agricultural residue, food waste	Biogas (which can be combusted into electricity or cleaned and compressed into methane)	1st	None

BIODIESEL (FATTY ACID METHYL ESTER)

Fatty acid methyl ester (FAME) is commonly referred to as biodiesel and is a type of first-generation biofuel. It is produced via transesterification, a relatively simple conversion process that can be undertaken using simple equipment. Biodiesel can thus be produced in small batches in small facilities and with relatively low capital expenses.[7]

FEEDSTOCKS

In Indonesia, biodiesel is produced mostly from palm oil, but it can be produced from several different kinds of feedstocks, including:[8]

6 For more detailed information on the hydroprocessing, cellulosic ethanol, and gasification pathways, see Chelsea Baldino et al., *Advanced alternative fuel pathways: Technology overview and status*, (ICCT: Washington, DC, 2019), https://theicct.org/publications/advanced-alternative-fuel-pathways

7 Josh Tickell, *Biodiesel America: How to Achieve Energy Security, Free America from Middle-East Oil Dependence, and Make Money Growing Fuel*, (Yorkshire Press, 2006) and John Duncan, "Cost of Biodiesel Production," prepared for Energy Efficiency and Conservation Authority, (2003), http://www.globalbioenergy.org/uploads/media/0305_Duncan_-_Cost-of-biodiesel-production.pdf

8 Debabrata Das and Jhansi Varanasi, *Fundamentals of Biofuels Production Processes*, (Boca Raton: Taylor & Francis Group, LLC, 2019).

» *Food crops containing edible oils*: palm, coconut, and soybean.

» *Wastes and residues*: animal fat (e.g., beef tallow, lard, poultry fat, and fish oils), used cooking oil (UCO), and residues from palm oil refining (e.g., palm fatty acid distillate and palm oil sludge).[9] Palm oil sludge is the floating residual oil that can be separated from palm oil mill wastewater.[10]

» *Non-edible oil crops*: jatropha, nyamplung (*Calophyllum inophyllum*), moringa oleifera, and pecan sunan.

PRODUCTION PROCESS

Vegetable oils like palm are highly viscous and cannot be used in vehicles without modifying the engine and fuel system.[11] For this reason, vegetable oils are typically converted to FAME for use in diesel vehicles, as FAME is closer in viscosity to fossil diesel fuels.[12]

All feedstocks require pretreatment to remove gums and other contaminants before undergoing transesterification (Figure 1). Waste oils in particular possess some contaminants such as free fatty acids (FFA), and these can reduce the quality and yield of biodiesel production.[13] There are several pretreatment methods:[14]

1. Blending low FFA oils with lower quality oils in a way that still produces biodiesel of a sufficient quality. This pretreatment method is widely practiced.
2. Conducting acid esterification with solid catalysts, which leads to cleaner biodiesel and glycerol with no water or salts.
3. Using the same degumming process that is used for crude palm oil refining to remove impurities like water, FFAs, and phospholipids (gums). Phospholipids block catalysts during the FAME production process and disturb the biodiesel and glycerol separation process.[15]

After pretreatment, the feedstock undergoes transesterification, where the oil reacts with methanol and a catalyst to produce biodiesel (FAME) and the by-products crude glycerin, wastewater, excess alcohol, and solid residues, such as soap.[16] The biodiesel producer uses catalysts to speed up the process and because non-catalytic transesterification requires higher temperatures and pressures, which is more expensive.[17] The crude biodiesel that results is washed with warm acidic water to remove residual methanol and salts, and then it is dried.[18]

9 Ab Gapor Md Top, "Production and Utilization of Palm Fatty Acid Distillate (PFAD)," *Lipid Technology* 22, no. 1 (2010): 11–13. https://doi.org/10.1002/lite.200900070

10 Nur Sulihatimarsyila et al., "Value-Added Products From Palm Sludge Oil," *Journal of Applied Sciences* 12, no. 11 (2012): 1199–1202. https://doi.org/10.3923/jas.2012.1199.1202. See the Anaerobic digestion section for more information.

11 Ayhan Demirbas. *Biodiesel: A Realistic Fuel Alternative for Diesel Engines*. (London: Springer, 2008).

12 Ibid.

13 Andre Ribeiro, Fernando Castro, and José Carvalho, "Influence of Free Fatty Acid Content in Biodiesel Production on Non-Edible oils," Waste: Solutions, Treatments and Opportunities International Conference, September 2011, https://core.ac.uk/download/pdf/55615141.pdf

14 Ahmed Tafesh and Sohbi Basheer, "Pretreatment Methods in Biodiesel Production Processes," in *Pretreatment Techniques for Biofuels and Biorefineries*, ed. Zhen Fang, (Berlin: Springer, 2013), 417–434.

15 Sangeeta Kanakraj and Savita Dixit, "A Comprehensive Review on Degummed Biodiesel," *Biofuels* 7, no. 5 (2016): 1–12. https://doi.org/10.1080/17597269.2016.1168021

16 Demirbas, *Biodiesel*.

17 Sadia Nasreen et al., "Review of Catalytic Transesterification Methods for Biodiesel Production," in *Biofuels State of Development*, ed. Krzysztof Biernat (London: IntechOpen, 2018), https://www.intechopen.com/books/biofuels-state-of-development

18 Demirbas, *Biodiesel*.

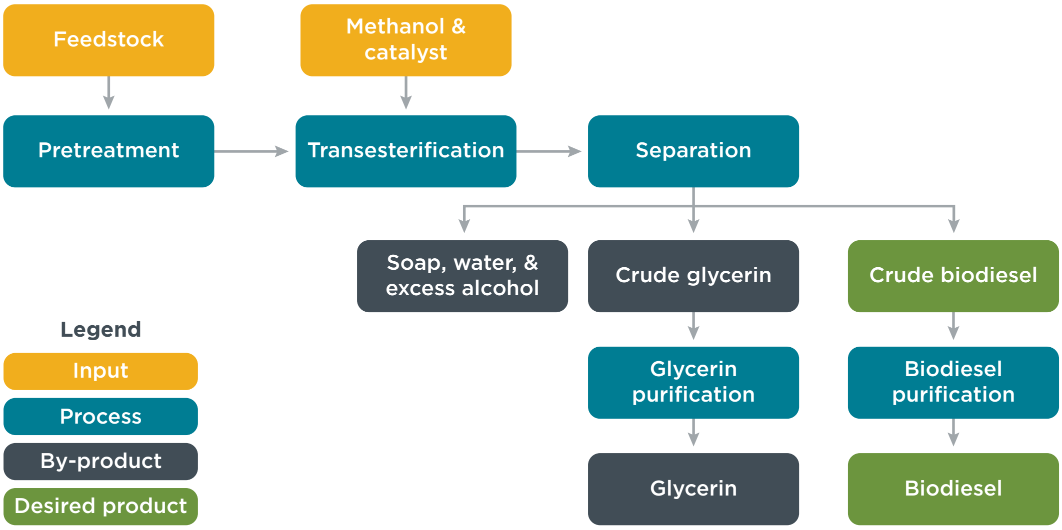

Figure 1. Simplified overview of transesterification.

Note: Adapted from Jorge Mario Marchetti, "A Comparison Between Raw Material and Technologies for a Sustainable Biodiesel Production Industry," in *Economic Effects of Biofuel Production*, ed. Marco Aurelio dos Santos Bernandes (Croatia: InTechOpen, 2011); and Demirbas, *Biodiesel*.

FUEL PROPERTIES AND BLENDING

Biodiesel is not fully compatible with conventional diesel vehicles and is typically blended into fossil diesel fuel at low percentages.[19] The Worldwide Fuel Charter only recommends up to 5% biodiesel blending in fossil diesel, because higher volumes lead to a reduction in fuel economy, degradation of some vehicle components and materials, and increases in pollutants in the exhaust.[20] While biodiesel blend rates vary by region, most countries with biofuel programs blend biodiesel at maximum rates between 5% and 10%.[21] Currently, Indonesia is the only country that has a higher biodiesel blending mandate of 30% (B30).

TECHNOLOGY STATUS

The non-edible oil crops listed as feedstocks above have been used at demonstration scale to produce biodiesel in several countries, including India.[22] Additionally, there is a potentially significant opportunity to produce waste-based biodiesel in Indonesia.[23] The use of waste oils as alternative feedstocks to palm oil has advantages, including that waste oils are cheaper than edible vegetable oils.

HYDROPROCESSING

Hydroprocessing is an overarching term for several processes that convert oils and fats into "drop-in" fuels, which can be blended at much higher rates than FAME for use in conventional diesel vehicles. Although hydroprocessing has long been used to

19 Demirbas, *Biodiesel*. Note that biodiesel contains a lot of oxygen, and that makes the fuel more corrosive compared to diesel. Moreover, it attracts water, which increases corrosion and brings damage to the vehicle parts.

20 For further explanation on the pollutant emissions, see Jane O'Malley, Stephanie Searle, and Tenny Kristiana, *Air quality impacts of palm biodiesel in Indonesia*, (ICCT: Washington, DC, 2021), https://theicct.org/publications/AQ-impacts-biodiesel-indonesia-jan2021

21 Tim Dallmann, "To B10 or Not to B10: Reference Fuel Debates Should Not Delay Adoption of World-Class Heavy-Duty Vehicle Emission Standards in Brazil," International Council on Clean Transportation, August 1, 2018, https://theicct.org/blog/staff/brazil-p8-reference-fuel-qs-20180801

22 Simon Gmunder et al., "Environmental Impacts of Jatropha curcas Biodiesel in India," *BioMed Research International*, (2012): 1–10. https://doi.org/10.1155/2012/623070.

23 Yuanrong Zhou, Stephanie Searle and Tenny Kristiana, *Opportunities for waste fats and oils as feedstocks for biodiesel and renewable diesel in Indonesia*, (ICCT: Washington DC, 2021), https://theicct.org/publications/waste-fats-and-oils-biodiesel-indonesia-en-mar2021

improve the quality and yields of petroleum products in crude oil refining, its use in biofuel production is a relatively recent development. In the road transportation sector, hydrotreated vegetable oil (HVO), the most common type of biofuel produced from hydroprocessing, is also known as renewable diesel or green diesel. HVO is a “drop-in” fuel because it is chemically almost identical to its fossil fuel counterpart; as a result, it can potentially be used in high-level blends—and even up to 100%, as pure HVO—in diesel vehicles.[24]

Hydroprocessing requires large-scale facilities and therefore greater capital investment. However, biological feedstocks can be co-processed with petroleum to lessen the capital expense.

FEEDSTOCKS

While virgin vegetable oils are often the feedstock for hydroprocessing, HVO is also produced from waste oils and fats, such as used cooking oil and tallow. HVO production and FAME production use the same feedstocks but very different technological processes.

PROCESS

Pretreatment for HVO feedstock is similar to FAME, including degumming, and is optional depending on the kind of feedstock used. For example, producers usually use refined, bleached, and deodorized oils, and in that case, no pretreatment is needed.[25]

Hydrotreatment is the first stage of the hydroprocessing process (Figure 2). At reaction temperatures between 300°C and 390°C, hydrogen is added to the feedstock to break multi-chain fat molecules (triglycerides) down into single-chain fatty acids composed mainly of carbon, hydrogen, and oxygen.[26] Then, fatty acids either undergo hydrodeoxygenation, decarboxylation, or a combination of the two, in order to eliminate oxygen from the molecules, and this results in hydrocarbons composed purely of hydrogen and carbon.[27] The resulting fuel is more stable and has higher energy density than FAME, which still contains a high fraction of oxygen.[28]

24 ETIP Bioenergy, “Hydrogenated vegetable oil (HVO),” (2020), https://etipbioenergy.eu/images/ETIP_B_Factsheet_HVO_feb2020.pdf

25 Tim O’Mara. “Renewable Diesel Feedstocks: Pretreatment and Purification,” Burns & McDonnell, March 5, 2020, https://blog.burnsmcd.com/renewable-diesel-feedstocks-pretreatment-and-purification

26 ETIP Bioenergy, “Hydrotreatment to HVO,” (2019), https://www.etipbioenergy.eu/value-chains/conversion-technologies/conventional-technologies/hydrotreatment-to-hvo

27 Ibid., and Elvan Sari, “Green Diesel Production via Catalytic Hydrogenation/Decarboxylation of Triglycerides and Fatty Acids of Vegetable Oil and Brown Grease” (PhD diss., Wayne State University, 2013). Retrieved from https://core.ac.uk/download/pdf/56683753.pdf

28 Ibid.

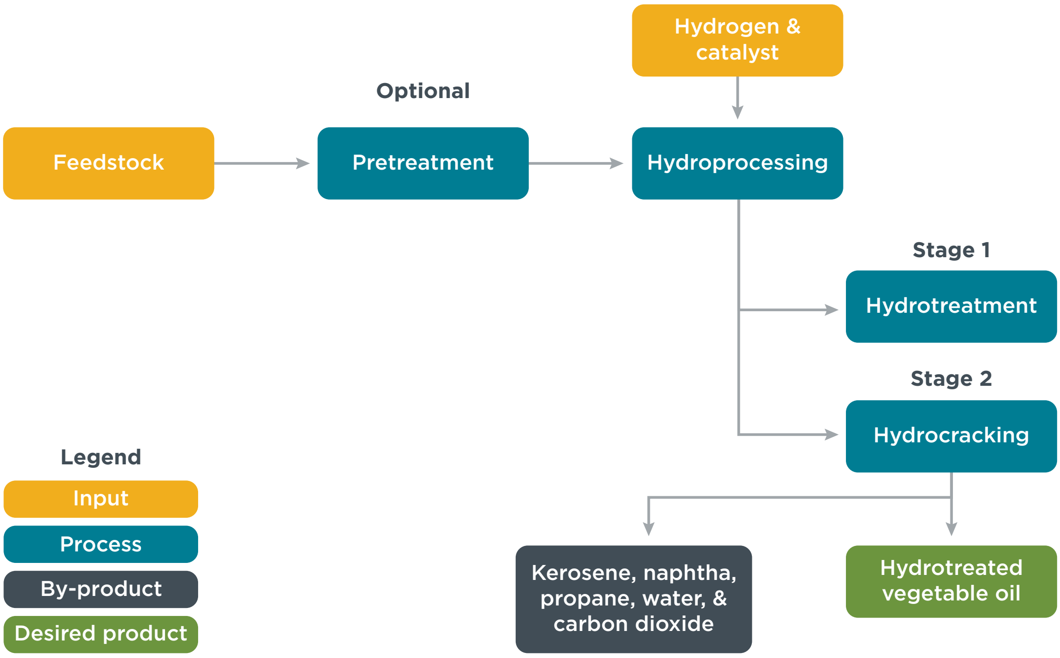

Figure 2. Simplified overview of hydroprocessing.

Note: Adapted from Baldino et al., *Advanced alternative fuel pathways*; and Adam Brown et al., *Advanced biofuels – Potential for cost reduction*, (IEA Bioenergy, 2020), https://www.ieabioenergy.com/publications/new-publication-advanced-biofuels-potential-for-cost-reduction/

Because these hydrocarbons are still relatively long, they would result in solid wax or very thick, viscous fuel. As an example, Figure 3 shows the molecular structure of paraffin wax. The second stage of hydroprocessing, hydrocracking, breaks down these long carbon chains into short carbon chains of higher value. Unlike hydrotreatment, which occurs at a mild temperature and pressure, hydrocracking adds hydrogen to the crude fuel mix at high temperatures and pressures in the presence of a catalyst (e.g., nickel/molybdenum, cobalt/molybdenum, or nickel/tungsten).[29] The result from this is a mixture of hydrocarbons that are then fed into a fractionator column to separate the different fuel types, such as diesel, gasoline, and kerosene; some amount of propane is also produced.[30] Figure 3 also shows the molecular structure of these types of fuels and demonstrates the shorter hydrocarbon chains that are produced from breaking apart the long wax molecules.

29 Savvas L. Douvaetzides et al., "Green Diesel: Biomass Feedstocks, Production Technologies, Catalytic Research, Fuel Properties and Performance in Compression Ignition Combustion Engines," *Energies* 12, no. 5 (2019): 1–42 https://doi.org/10.3390/en12050809 and Baldino et al., Advanced alternative fuel pathways.

30 Chamila Rajeeva Thilakaratne, "Understanding Catalytic Pyrolysis of Biomass for Production of Biofuels" (PhD diss., Iowa State University, 2016). Retrieved from https://lib.dr.iastate.edu/etd/15821/ and Brown et al., *Advanced biofuels*.

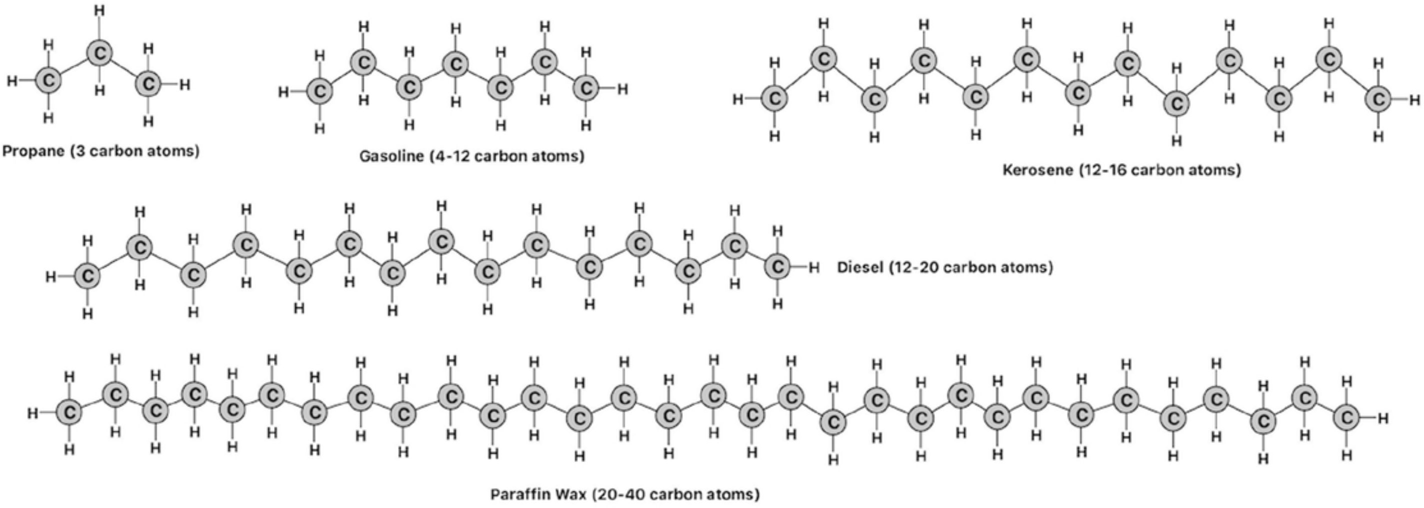

Figure 3. Molecular structure of different types of hydrocarbons.

FUEL PROPERTIES AND BLENDING

Because HVO stores well and does not easily attract dissolved water, there are not the same kind of corrosion problems that plague FAME.[31] Also unlike FAME, HVO does not cause increased tailpipe pollutant emissions, deposit formation that can clog engine parts, storage stability problems, or faster aging of engine oil.

Kerosene derived from hydroprocessing oils and fats is also referred to as hydroprocessed esters and fatty acids (HEFA). This can be blended up to 50% with fossil jet fuel (kerosene) and is considered a "drop-in" fuel.[32] Propane is a gaseous fuel that can be used in cooking and heating, among other applications. It can also undergo steam reforming to produce hydrogen, which can then be recycled for use in hydroprocessing.[33] Hydroprocessing can also potentially produce drop-in renewable gasoline, but this is not typically done for cost reasons.

TECHNOLOGY STATUS

Although there are currently no HVO facilities in Indonesia, the Indonesian government is developing a standalone HVO plant under the Medium-Term Development Plan (RPJM 2020-2024).[34] There are a number of HVO facilities in other countries. For example, Neste operates standalone HVO plants in Finland, the Netherlands, and Singapore.[35]

31 Athanasios Dimitriadis et al., "Evaluation of a Hydrotreated Vegetable Oil (HVO) and Effects on Emissions of a Passenger Car Diesel Engine," *Frontiers in Mechanical Engineering* 4, (2018): 1–19. https://doi.org/10.3389/fmech.2018.00007

32 For more detailed information on HEFA+ for aviation, see Nikita Pavlenko and Anastasia Kharina, *Policy and environmental implications of using HEFA+ for aviation*, (ICCT: Washington, DC, 2018), https://theicct.org/publications/policy-and-environmental-implications-using-hefa-aviation

33 Susan Van Dyk et al., "Drop-In' Biofuels: The Key Role That Co-processing Will Play in Its Production" (IEA Bioenergy, 2019), https://www.ieabioenergy.com/publications/new-publication-drop-in-biofuels-the-key-role-that-co-processing-will-play-in-its-production/

34 For further information, check Presidential Regulation No. 18/2020 - Appendix II, January 17, 2020, https://peraturan.bpk.go.id/Home/Details/131386/perpres-no-18-tahun-2020

35 NESTE, "Neste Manufactures Its High-quality Products in Finland, the Netherlands and Singapore." Accessed November 27, 2020, https://www.neste.com/about-neste/who-we-are/production

BIO-ETHANOL

CONVENTIONAL BIO-ETHANOL

Ethanol is an alcohol produced through the fermentation of sugars or starches. It is a first generation technology and can be used in special vehicles designed for higher use of ethanol. More commonly, though, it is blended into gasoline at certain levels.

Feedstocks

Sugar and starch-based crops are used to produce conventional ethanol. Starchy crops include corn, cassava, and wheat. Sugar crops include sugarcane, molasses, and sweet sorghum. The higher the starch or sugar content of the feedstock, the higher the ethanol yields and therefore the lower the conversion cost compared to other feedstocks. These feedstocks can be found in several provinces in Indonesia. East Java produces more than 50% of Indonesia's sugarcane, with Lampung, Central and West Java, South Sumatra, Sulawesi, and Nusa Tenggara accounting for the remainder.[36] Sweet sorghum is also produced in East Java, as well as in Central and West Java and East Nusa Tenggara.[37] Corn is mainly produced in East and Central Java, South Sulawesi, North Sumatra, and Lampung.[38] Lampung is the main producer of cassava, followed by East, Central, and West Java, and North Sumatra.[39] Indonesia also produces a small amount of wheat, but it relies on imports for most of its domestic consumption.

Process

As illustrated in Figure 4, there is no need to pretreat sugar crops and the cane juice goes straight for extraction from the cane. Meanwhile, starchy crops are generally milled, either wet or dry, into a powder or paste.[40] In wet milling, the grain is soaked or steeped in hot water to facilitate the separation of the grain into its component parts.[41] After pretreatment, starchy feedstocks undergo hydrolysis, where starches are broken down by enzymes into free sugars in order to make glucose that is ready for fermentation. The sugars are then converted into ethanol by microbes, generally yeast, through a biological, anaerobic process (i.e., a process with no or little oxygen) called fermentation.[42]

36 Badan Pusat Statistik, "Statistik Tebu Indonesia 2018," (2019). https://www.bps.go.id/publication/2019/11/22/9d2b03409986c2dcfcd43ae4/statistik-tebu-indonesia-2018.html

37 Herman Subagio, and Muh. Aqil, "Pengembangan Produksi Sorgum di Indonesia," Seminar Nasional Inovasi Teknologi Pertanian, (2013): 199–214. http://kalsel.litbang.pertanian.go.id/ind/images/pdf/prosiding/20%20herman.pdf

38 Badan Pusat Statistik, "Produksi Jagung Menurut Provinsi (ton), 1993–2015." Accessed June 2020, https://www.bps.go.id/dynamictable/2015/09/09/868/produksi-jagung-menurut-provinsi-ton-1993-2015.html

39 Badan Pusat Statistik, "Produksi Ubi Kayu Menurut Provinsi (ton), 1993–2015." Accessed June 2020, https://www.bps.go.id/dynamictable/2015/09/09/880/produksi-ubi-kayu-menurut-provinsi-ton-1993-2015.html

40 United States Department of Energy, "Clean Cities Fact Sheet" (2008), https://afdc.energy.gov/files/pdfs/43835.pdf

41 Ibid.

42 Wei-Cho Huang, and I-Ching Tang, "Bacterial and Yeast Cultures – Process Characteristics, Products, and Applications," in *Bioprocessing for Value-Added Products from Renewable Resources*, ed. Shang-Tian Yang, (Oxford: Elsevier, 2007), 185–223.

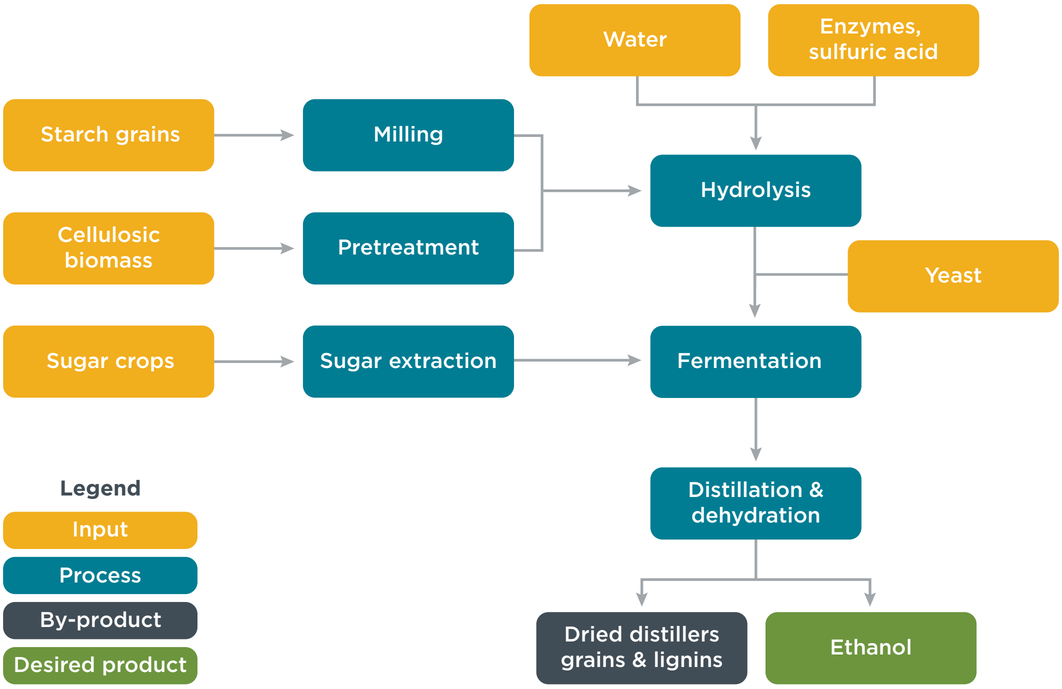

Figure 4. Simplified overview of fermentation.

Note: Adapted from Baldino et al., *Advanced alternative fuel pathways*; Das and Varanasi, *Fundamentals of Biofuels*; IEA-RETD, *Towards advanced biofuels: Options for integrating conventional and advanced biofuels production sites*, (Utrecht, 2016), http://iea-retd.org/archives/publications/res-t-bioplant; and Dominik Rutz and Rainer Janssen, *Biofuel Technology Handbook* (München: WIP Renewable Energies, 2007).

Finally, the mash is heated to separate out the ethanol. Because ethanol evaporates at a lower temperature than water, it is evaporated out first. When grains are used to produce ethanol, the leftover grain is referred to as distillers grains. Most of the starch has been removed, but distillers grains still contain some starch and also have substantial amounts of protein and fiber; as a result, they can be used, wet or dried, for livestock feed. [43] The distilled ethanol still contains some residual water and is called hydrous ethanol. Hydrous ethanol, also known as hydrated ethanol, has a water content typically between 5% and 7%.[44] Hydrous ethanol can be used in vehicles that are specially designed for it, and this is common in Brazil.[45] Alternatively, the residual water in the ethanol can be removed through various dehydration processes to produce anhydrous ethanol with a purity of more than 99%.[46] Worldwide, anhydrous ethanol is most commonly used in transportation.

Fuel properties and blending

Ethanol has a high octane, and so adding it to gasoline increases the octane number of the fuel. Most countries allow use of anhydrous ethanol blends of 5%–15% in gasoline in conventional vehicles. in the aforementioned gasoline vehicles designed for higher ethanol use, called "total flex-fuel vehicles," ethanol can be used at higher levels, up to

43 Stefan Schwietzke et al., „Ethanol Production from Maize," in *Molecular Genetic Approaches to Maize Improvement*, ed. Alan L. Kriz and Brian A. Larkins, (Springer, 2009), 347–364.

44 Russian Biofuels Association, "Fuel Bioethanol." Russian Biofuels Association. Accessed October 28, 2020, http://www.biofuels.ru/bioethanol/what-is-bioethanol/

45 Tadeu C. Cordeiro de Melo et al., "Hydrous Ethanol-Gasoline Blends–Combustion and Emission Investigations on a Flex-Fuel Engine," *Fuel* 97, (2012): 796-804. https://doi.org/10.1016/j.fuel.2012.03.018

46 Howard A. Saffy et al., "Energy, Carbon Dioxide and Water Use Implications of Hydrous Ethanol Production," *Energy Conversion and Management* 105, no. 15 (2015): 900–907. https://doi.org/10.1016/j.enconman.2015.08.039

100%.[47] In Indonesia, ethanol was at one time blended into gasoline at 2% (E2), but the program was stopped due to low availability of feedstocks and high ethanol prices.[48]

CELLULOSIC ETHANOL

Cellulosic ethanol is a second-generation biofuel and its conversion requires more advanced technology compared to the production of conventional ethanol.[49] It is made by breaking down cellulose, a very complex carbohydrate, into sugar before fermentation.

Feedstocks

Any type of biomass with high cellulose content can be used to produce cellulosic ethanol. In Indonesia, there are several feedstocks that could be available to produce cellulosic ethanol, including palm trunks and empty fruit branches, rice straw, corn stalks, sugarcane bagasse, cassava stems, municipal solid waste, demolition wood, and many more.[50]

Process

The conversion of cellulosic feedstocks requires more pretreatment compared to conventional bioethanol feedstocks. In some cases, these feedstocks must first be cleaned; this is especially true for straw and other agricultural residues harvested from the soil surface. The feedstock must also be broken down into small particles, similar to the milling of grains. There are different pretreatment methods, depending on the type of biomass. One pretreatment method that helps reduce particle size is steam explosion, during which the biomass particles are rapidly heated by high-pressure steam.[51]

The cellulosic feedstock is then hydrolyzed into sugars. This is more difficult than the hydrolysis of starch because cellulose is a much more complex carbohydrate.[52] Hydrolysis for cellulosic feedstocks can involve enzymes, acids, or a combination of both. From this point, the process continues similarly to that of conventional ethanol production, as shown in Figure 4.

Besides creating ethanol as its end product, the process also produces wastewater and lignin residue, both of which can be utilized for energy. Wastewater can be anaerobically digested and converted to biogas (see next section), while lignin can be combusted. Lignin can generate additional revenue if it is combusted to produce excess electricity that is sold to utilities or other users.[53] The amount of lignin by-product produced in the cellulosic ethanol process depends on the lignin content of the feedstock used. For example, wood has much higher lignin content than grasses.

Technology status

Cellulosic ethanol is in an early stage of commercialization and requires significant capital investment. There is also a potentially high operational cost for first-of-a-kind plants due to the complexity of the conversion processes and because the technology

---

47 R.J. Pearson, and J.W.G. Turner, "Using Alternative and Renewable Liquid Fuels to Improve the Environment Performance of Internal Combustion Engines: Key Challenges and Blending Technologies," in *Alternative Fuels and Advanced Vehicle Technologies for Improved Environmental Performance*, ed. Richard Folkson, (Woodhead Publishing, 2014), 52–89.

48 Pertamina, "Ethanol Dilemma." Accessed May 20, 2020, https://www.pertamina.com/id/news-room/market-insight/ethanol-dilemma

49 U.S. Department of Energy, "Clean Cities."

50 For more detailed information on palm oil residues availability in Indonesia, see Julia Paltseva, Stephanie Searle, and Chris Malins, *Potential for advanced biofuel production from palm residues in Indonesia*, (ICCT: Washington, DC, 2016), https://theicct.org/publications/potential-advanced-biofuel-production-palm-residues-indonesia

51 Yi Zheng, Zhongli Pan, and Ruihong Zhang, "Overview of Biomass Pretreatment for Cellulosic Ethanol Production," *International Journal of Agricultural and Biological Engineering* 2, no. 3 (2009): 51–68.

52 Baldino et al., *Advanced alternative fuel pathways*.

53 Tao Li, and Sudhakar Takkellapati, "The Current and Emerging Sources of Technical Lignins and Their Applications." *Biofuels, Bioproducts, & Biorefining* 12, no. 5 (2018): 1-32. https://doi.org/10.1002/bbb.1913

is not mature.[54] However, there is potential for future cost reductions. In particular, cellulosic ethanol production costs can be reduced if inexpensive feedstock is available; for example, a previous ICCT study found that using palm trunks can make cellulosic ethanol more economically competitive than the straw and stover used in many other countries.[55]

There are several standalone cellulosic ethanol plants worldwide. In Asia, Japanese companies Marubeni and Tsukishima Kikai Co., Ltd., have built a plant in Osaka that processes wood waste to produce 1.4 million liters of cellulosic ethanol per year. Additionally, the Verenium Corporation has built a 3 million liter per year plant in Saraburi, Thailand,[56] and an Indian company, Praj Industries Limited, has a demo plant and plans to set up an integrated cellulosic ethanol plant in Maharashtra.[57] China's first commercial cellulosic ethanol plant is in Shandong; it is owned by the Longlive Group and processes corn residues.[58]

GASIFICATION

Gasification is a thermochemical process that transforms carbon-containing material into usable fuels or chemicals by heating the feedstock in the presence of a small amount of oxygen, but not enough to allow combustion.[59] The is typically done under high temperature and pressure using air, oxygen, or steam as a gasifying agent. Gasification is a second-generation technology and must be combined with a fuel synthesis process to produce transportation fuels. These can include drop-in renewable diesel, gasoline, kerosene, compressed natural gas, methane stored at high pressure, or fuels that can be blended in diesel and gasoline at low blend rates, such as dimethyl ether (DME) and methanol.[60]

FEEDSTOCKS

Virtually any energy-carrying feedstock can be gasified. Commonly discussed gasification feedstocks include coal, natural gas, petroleum coke, and biomass. Gasification of coal is already widely used in many regions and is currently under development in Indonesia. Biomass can be a feedstock for gasification, either standalone or co-fed with coal.

There are a wide variety of potential biomass feedstocks for gasification, and these include agricultural residues, municipal solid waste, forest residues, lignocellulosic energy crops, and glycerin. Indonesia, as the world's leading producer of palm oil, has abundant palm oil residues that could be used for gasification, such as empty fruit bunches, palm kernel shells (PKS), palm fiber, and oil palm fronds, as well as glycerin

54 Monica Padella, Adrian O'Connell, and Matteo Prussi, "What is Still Limiting the Deployment of Cellulosic Ethanol? Analysis of the Current Status of the Sector," *Applied Sciences* 9, no. 21 (2019): 4523. https://doi.org/10.3390/app9214523

55 Yuanrong Zhou et al., *Techno-economic analysis of cellulosic ethanol in Indonesia using palm residues*, (ICCT: Washington, DC, 2020), https://theicct.org/publications/techno-economic-cellulosic-ethanol-2020

56 Climate Technology Centre & Network, "Cellulosic Ethanol." Accessed June 29, 2020, https://www.ctc-n.org/technologies/cellulosic-ethanol

57 Anuj Chandel, and Rajeev Sukumaran, *Sustainable Biofuels Development in India*, (Springer, 2017).

58 Bioenergy International, "Ethanol Development in China," September 20, 2016, https://bioenergyinternational.com/biofuels-oils/ethanol-development-in-china#:~:text=China's%20first%20commercialized%20cellulosic%20ethanol,value%20products%20using%20proprietary%20technology.

59 Vineet Sikarwar, and Ming Zhao, "Biomass Gasification," *Encyclopedia of Sustainable Technologies Volume 3* (2017): 205-216. https://doi.org/10.1016/B978-0-12-409548-9.10533-0

60 Transport & Environment, *CNG and LNG for vehicles and ships – The facts*, (October 2018), https://www.transportenvironment.org/sites/te/files/publications/2018_10_TE_CNG_and_LNG_for_vehicles_and_ships_the_facts_EN.pdf

from biodiesel production.[61] Using biomass for gasification in Indonesia could help the country meet its renewable energy goals.[62]

PROCESS

Feedstocks must be pretreated before gasification and this generally includes screening, converting feedstock into small particles, and drying. Drying is the most important part of pretreatment because it helps to improve the efficiency of gasification.[63] There are some other pretreatment methods, including torrefaction and pelletization.[64] Torrefaction is a thermal treatment, while pelletization dries the biomass and compresses it into pellets with lower volume and higher energy density. These pellets are easy to store, transport, and use in energy conversion.[65]

After pretreatment, the feedstock is ready for the gasifying reactor. There are a few types of reactors. Each type has different advantages and disadvantages and several distinct reactions occur in the gasifier:[66]

1. **Dehydration**: High heat evaporates any moisture still present in the feedstock. The steam produced serves a purpose in subsequent reactions.
2. **Pyrolysis (also known as devolatilization)**: As the biomass heats up, carbon-containing molecules, like lignin and cellulose, break down into gaseous components such as CO_2 and condensable vapors such as char (a high carbon substance) and water.
3. **Gasification**: The char reacts with CO_2, water, and oxygen in the presence of heat to form carbon monoxide, hydrogen, and methane. This mix of gases is called syngas. Any remaining char is a high-carbon, solid by-product.

FURTHER FUEL PROCESSING

The syngas from gasification can be combusted to generate electric power or processed further to generate synthetic fuels. Contaminants such as sulfur, nitrogen, and chloride compounds should be separated from syngas during the cleanup stage (see below) since these are hazardous pollutants and can cause catalyst poisoning for downstream fuel production.[67]

Before syngas can be processed further it needs to be cleaned, and this can occur under two routes, known as "hot" and "cold." Both routes employ mature technology, and the hot gas cleanup focuses on removing tars, particulate matter, and sulfur.[68] It provides advantages in thermal efficiency, process simplicity, and potential for cost reduction compared to the cold route.[69] However, the cold route is used more widely

61 For a detailed explanation on the potential for advanced biofuel production from palm residues in Indonesia, see Paltseva, Searle, and Malins, *Potential for advanced biofuel production*.

62 For further explanation on biomass gasification option for Indonesia, see Tenny Kristiana, "Gasifying Palm Residues: Helping Indonesia Go Renewable," International Council on Clean Transportation, June 16, 2020, https://theicct.org/blog/staff/gasifying-palm-residues-helping-indonesia-go-renewable.

63 Jin Hu, Jin, Fei Yu, and Yongwu Lu, "Application of Fischer-Tropsch Synthesis in Biomass to Liquid Conversion," *Catalysts* 2, no. 2 (2012): 303–326. https://doi.org/10.3390/catal2020303

64 Ibid.

65 Ibid.

66 For more information, see Baldino et al., *Advanced alternative fuel pathways*.

67 Ronaldo Goncalves dos Santos, and Andre Cardoso Alencar, "Biomass-Derived Syngas Production via Gasification Process and its Catalytic Conversion into Fuels by Fischer Tropsch Synthesis: A Review," *International Journal of Hydrogen Energy* 45, no. 36 (2020): 18114–18132. https://doi.org/10.1016/j.ijhydene.2019.07.133

68 Patrick Woolcock and Robert Brown, "A Review of Cleaning Technologies for Biomass-Derived Syngas," *Biomass and Bioenergy* 52, (2013): 54–84. https://doi.org/10.1016/j.biombioe.2013.02.036

69 Ibid.

because it is more effective at removing nearly all contaminants and can also recover sulfur as a by-product.[70]

In Indonesia, syngas from coal gasification is synthesized into dimethyl ether (DME), methanol, and mono ethylene glycol (MEG), a colorless liquid used in the manufacture of polyester fibers and films, bottles and packaging containers, and engine coolants.[71] Syngas can also be used as feedstock to produce hydrogen, methane, and drop-in liquid transportation fuels, including diesel, gasoline, and naphtha. In North America, Fulcrum BioEnergy (United States) and Enerkem (Canada) have biomass gasification facilities to produce liquid biofuel. In the United Kingdom, BioSNG uses gasification of wastes to produce methane. Meanwhile, in Finland and the Netherlands, there is some biomass co-gasification with coal plants.[72]

There are various fuel synthesis technologies that convert the syngas from gasification into liquid and gaseous fuels. The Fischer-Tropsch (FT) synthesis process is of particular interest because it produces drop-in renewable diesel and renewable jet fuel (Figure 5). It is important that the syngas be cleaned before undergoing FT, because impurities such as sulfur in the syngas can contaminate the catalyst used during the FT synthesis process, which is an expensive component.[73]

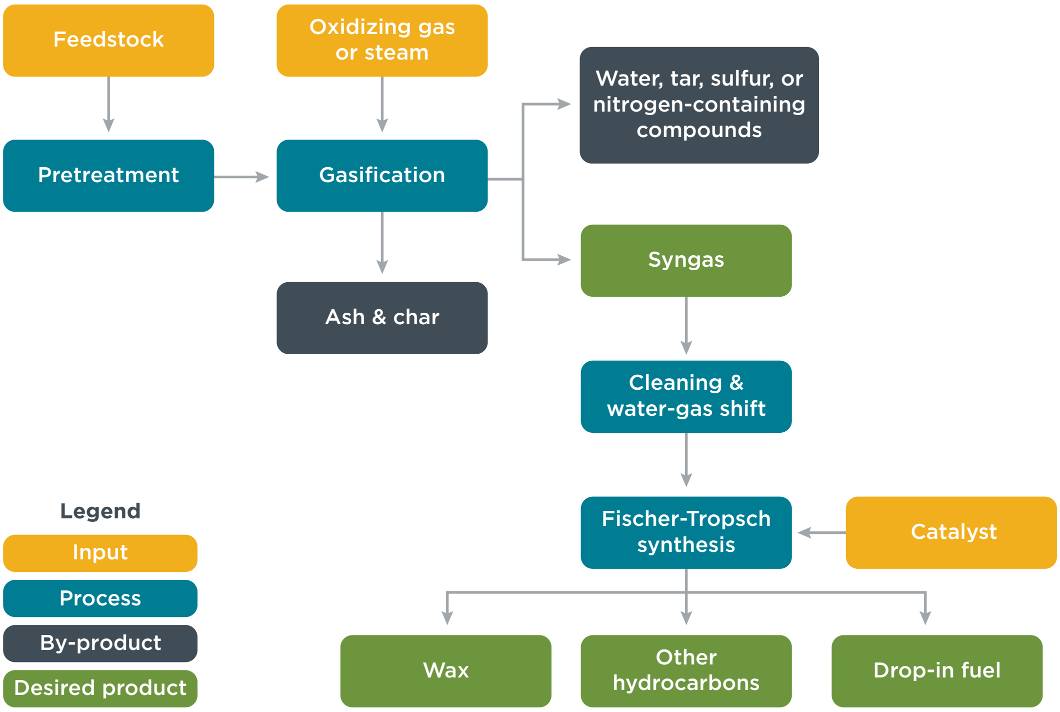

Figure 5. Simplified overview of gasification.
Note: Adapted from Baldino et al., *Advanced alternative fuel pathways*.

The final products from FT are drop-in renewable diesel, gasoline, propane, kerosene (jet fuel), and waxes. The exact composition of this slate of products can be modified, for example to produce a greater fraction of kerosene. Since the syngas is cleaned before refining, the products from FT are sulfur and nitrogen free. The FT diesel

70 Ibid.

71 Mohsen Moayed and Leila Mahdavian, "Recycling Monoethylene Glycol (MEG) From the Recirculating Waste of an Ethylene Oxide Unit." *Open Chemistry* 15, no. 1 (2017): 167–174. https://doi.org/10.1515/chem-2017-0018; and Bukit Asam, "Menteri BUMN dukung penuh PTBA lakukan gasifikasi batu bara." Accessed June 08, 2020, http://www.ptba.co.id/id/berita/detail/1175/menteri-bumn-dukung-penuh-ptba-lakukan-gasifikasi-batu-bara

72 Sergios Karatzos, James McMillan, and Jack Saddler, *The potential and challenges of drop-in biofuels*, (IEA Bioenergy, 2014), https://www.ieabioenergy.com/wp-content/uploads/2018/02/Task-39-Drop-in-Biofuels-Report-FINAL-2-Oct-2014-ecopy.pdf.

73 Baldino et al., *Advanced alternative fuel pathways*.

product is similar to petroleum diesel in terms of density, viscosity, and energy content. It is considered superior to petroleum diesel due to its high cetane number and low aromatic content, and it produces lower air pollution when combusted.[74] FT diesel can be blended with petroleum diesel in any proportion without modifying the engine.[75]

The gasification process can also be optimized for hydrogen production, which could then be used in hydrogen fuel cell vehicles or for hydroprocessing. Hydrogen production from FT can be increased by conducting a water-gas shift reaction on the syngas from gasification, in which the steam reacts with carbon monoxide to produce hydrogen and CO_2.[76] It uses catalysts, and the iron oxide-based type is more commonly used than copper-based catalysts.[77]

TECHNOLOGY STATUS

Gasification typically has high capital costs due to the high temperature required, the complexity of the process, and the need for various heat-cool and compression cycles.[78] Unlike coal gasification, the commercial potential of biomass gasification is in the early stage of development.[79] A challenge for biomass gasification is that it produces tar, which can clog the equipment. Further work is therefore needed to reduce tar production and improve methods of removing it from the gasification equipment.

ANAEROBIC DIGESTION

Anaerobic digestion is a first-generation, commercially mature technology that converts many types of wet biomass into biogas. With its high concentration of methane, which is the same as natural gas, biogas is energy-rich and can be combusted on-site for energy. Alternatively, biogas can be cleaned—removing the CO_2 and impurities—into pure methane and used in natural gas infrastructure, in vehicles, and for other purposes. Impurities in biogas can include hydrogen sulfide and water vapor, and hydrogen sulfide is of particular concern because it can corrode engines.[80]

FEEDSTOCKS

Feedstocks for anaerobic digestion are generally wet, such as biodegradable waste, food waste, livestock manure, sewage sludge, and agricultural residues; the latter must be co-digested with wet feedstocks.[81] In Indonesia, biogas can be collected from covered palm oil mill effluent (POME) ponds. POME is a waste from the palm oil milling process and an environmental hazard typically treated in ponds before it can be released into waterways. POME contains fruit residue, oil, and organic matter, and it naturally releases biogas as it decomposes.

PROCESS

In a tightly closed container, microorganisms decompose the biomass into CO_2 and quickly run out of oxygen. At this point, a different set of microorganisms that do not require oxygen continue to consume the biomass through anaerobic (without oxygen)

---

74 Multimedia Working Group, *Multimedia evaluation of renewable diesel*, (California Air Resources Board, 2013), https://ww3.arb.ca.gov/fuels/multimedia/meetings/renewabledieselstaffreport_nov2013.pdf

75 Baldino et al., *Advanced alternative fuel pathways*.

76 Meng Ni et al., "An Overview of Hydrogen Production from Biomass," *Fuel Processing Technology* 87, no. 5 (2006): 461–472. https://doi.org/10.1016/j.fuproc.2005.11.003

77 Baldino et al., *Advanced alternative fuel pathways*.

78 Karatzos et al. , *The potential and challenges of drop-in biofuels*.

79 Ibid.

80 Clare Lukehurst, and Angela Bywater, *Exploring the viability of small scale anaerobic digesters in livestock farming*, (IEA Bioenergy, 2015), https://www.ieabioenergy.com/publications/exploring-the-viability-of-small-scale-anaerobic-digesters-in-livestock-farming/

81 ETIP Bioenergy, "Raw Biogas." Accessed May 20, 2020, https://www.etipbioenergy.eu/value-chains/products-end-use/intermediates/raw-biogas.

digestion. Without oxygen, these microbes cannot fully break down biomass into CO_2 and instead produce mostly methane (50%–75%), with some CO_2 (25%–50%), and small amounts of hydrogen, ammonia, and other trace gases (Figure 6).[82]

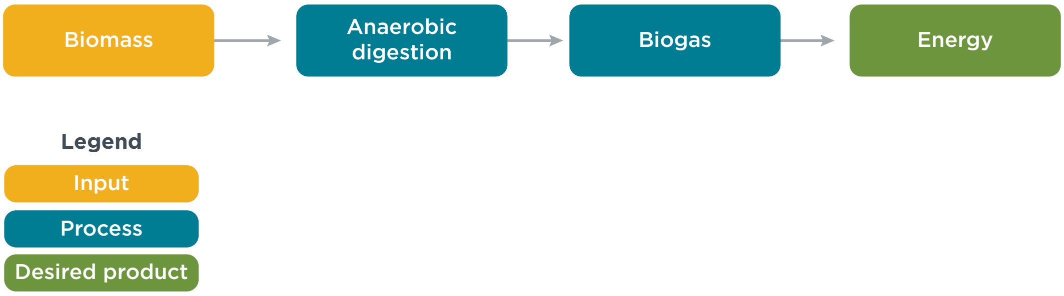

Figure 6. Simplified overview of anaerobic digestion.

Note: Adapted from Teodorita Al Seadi, *Good practice in quality management of AD residues from biogas production*, (IEA Bioenergy, 2001), http://213.229.136.11/bases/ainia_probiogas.nsf/0/70996A6A88900B70C125753F005B70AD/$FILE/IEA%20BUENAS%20PR%C3%81CTICAS%20DA.pdf

TECHNOLOGY STATUS

Biogas is currently being produced from POME in Malaysia.[83] In Indonesia, the palm oil industry has been interested in this process since 2011, and the government has provided some support. Indonesia's Ministry of Energy and Mineral Resources has created feed-in-tariffs for Independent Power Producers (IPP) who generate electricity from biomass and biogas; these allow them to make power advantageous purchase agreements (PPAs) with the state-owned electricity company (PLN).[84] For example, an IPP producing biogas with 1.6 MW electricity capacity has had a PPA contract with PLN since 2013.[85]

SUMMARY OF DEVELOPMENTS IN INDONESIA

All of the pathways discussed above are commercially available, and each pathway's state of development in Indonesia is summarized in Table 2. Indonesia has growing biodiesel, conventional bioethanol, and biogas (through anaerobic digestion) industries. The hydroprocessing and gasification pathways, meanwhile, are in the early stage of development, and the cellulosic ethanol discussion is just beginning. The Indonesian government mostly supports biofuel production through issuing regulations, pushing state-owned enterprises, or providing subsidies, such as the BPDPKS for biodiesel and conventional ethanol using the state budget.

82 M.R. Atelge et al., "Biogas Production From Organic Waste: Recent Progress and Perspectives," *Waste and Biomass Valorization* 11, no. 3 (2020): 1019–1040, https://doi.org/10.1007%2Fs12649-018-00546-0

83 More information on POME treatment in Malaysia can be found in Bidattul Syirat Zainal et al., "Integrated System Technology of POME Treatment for Biohydrogen and Biomethane Production in Malaysia," *Applied Science* 10, no. 3 (2020): 951. https://doi.org/10.3390/app10030951

84 New and Renewable Energy Directorate General, "Sosialisasi Peraturan Menteri ESDM Nomor 27 Tahun 2014" (2014), http://ebtke.esdm.go.id/post/2014/11/03/703/sosialisasi.peraturan.menteri.esdm.nomor.27.tahun.2014

85 Ministry of Energy and Mineral Resources, "Melihat lebih dekat pembangkit listrik biogas komersil pertama di Indonesia" (2017), https://www.esdm.go.id/en/media-center/news-archives/melihat-lebih-dekat-pembangkit-listrik-biogas-komersil-pertama-di-indonesia

Table 2. Biofuel production pathways status in Indonesia

Pathways	Business scale	Total production	Government support	Development status
Biodiesel/FAME[a]	20+ facilities	8.4 million kl	yes	mature and growing
Hydroprocessing[b]	1 (Pertamina)	1,000 bpd	yes	early stage and in progress
Conventional Bio-ethanol[c]	2 facilities	40,000 kl	yes	mature
Cellulosic Ethanol	0	0	yes/no	early study
Gasification[d]	4–7 facilities	6+ million metric ton DME	yes	planned and in progress
Anaerobic Digestion[e]	(no data, likely numerous)	30 MW	yes	growing

[a] Business scale: APROBI, "Anggota Aprobi." Accessed October 27, 2020, https://aprobi.or.id/partners/; total production: APORBI, "Data Produksi dan Distribusi Biodiesel Hasil Rekonsiliasi EBTKE." Accessed October 27, 2020, https://aprobi.or.id/project/

[b] Pertamina, "Successful Trial of Processing 100% Palm Oil into Green Energy, Pertamina is Ready to Produce the First D-100 in Indonesia," July 15, 2020, https://pertamina.com/en/news-room/news-release/successful-trial-of-processing-100-palm-oil-into-green-energi-pertamina-is-ready-to-produce-the-first-d-100-in-indonesia-

[c] EDSM, "Rencana Strategis: Direktorat Jenderal Energi Baru, Terbarukan dan Konservasi Energi 2020-2024." Accessed December 11, 2020, http://ebtke.esdm.go.id/post/2020/10/01/2648/rencana.strategis.renstra.ditjen.ebtke.2020-2024

[d] Only coal gasification to produce syngas, without FT synthesis process to produce drop-in fuels. Projection from PTBA DME production and Pertamina 4 factories, 1.4 million metric tons each. Source: "Pertamina Akan Bangun 4 Pabrik Gasifikasi Batu Bara," CNN Indonesia, February 26, 2020, https://www.cnnindonesia.com/ekonomi/20200225204252-85-478093/pertamina-akan-bangun-4-pabrik-gasifikasi-batu-bara

[e] MEMR RE Directorate projected potential power generation of 1.5 GW from POME. Source: Direktorat Jenderal Energi Baru Terbarukan dan Konservasi Energi, "Diskusi Alternatif Pemanfaatan Biogas Berbasis POME," October 4, 2018, http://ebtke.esdm.go.id/post/2018/10/04/2029/diskusi.alternatif.pemanfaatan.biogas.berbasis.pome