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Towards SAF for Indonesia Based on a Review of The United States and The European Union

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ABSTRACT

Utilizing fossil fuels within the transportation segment significantly contributes to increased CO_2 emissions in the environment, thus requiring concerted efforts to reduce these emissions. Various studies indicate that the utilization of SAF in jet-powered aircraft contributes significantly to efforts to reduce CO_2 emissions, but there are various obstacles to its implementation. This study examines the main obstacles in the development of SAF, determines countries that can be used as benchmarks for SAF development, studies the development of SAF in selected countries, and describes the future development of SAF in Indonesia The approach employed in this consideration may be a Systematic Literature Review (SLR) utilizing auxiliary information from different sources. This study shows that the most boundaries to the advancement of SAF incorporate feedstock accessibility, supply chain, government support, technology readiness, and SAF selling price. The United States and the European Union (EU) are countries or regions that can be used as best practices for SAF implementation. They have succeeded in becoming producers and consumers, and have a roadmap for SAF development in their respective countries. Indonesia, with its abundant feedstock potential, technological expertise, and strong government support, has great potential to become a successful SAF implementer. Further research, policy formulation, and regulation development in SAF development are still needed, especially to align SAF prices with fossil fuel prices.

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Introduction

Climate change is among the environmental concerns currently being vigorously discussed on the global stage. Climate change is strongly influenced by global warming, which shows an increment within the normal temperature of the Earth over the last few decades [1]. This temperature rise can lead to rising sea levels, floods, bushfires, extreme temperatures, and droughts, which have significant impacts on humans [2]. This could be proven by the warming of the oceans, melting icy masses, rising ocean levels, and lessened snow cover within the Northern Hemisphere [3]. Human work within the over-the-top utilization of fossil fuels causes a rise in the concentration of Greenhouse Gases (GHGs), consisting of CO_2, CH4, N_2O, and water vapor, inside the climate driving global warming [4]. Fossil fuels, especially coal and normal gas, are major supporters of GHG emissions, and their impact on climate change ought to be considered worldwide [5]. The impact of these gases on urban transportation and healthcare, particularly in the form of volatile anesthetic agents, is a growing concern [6]. The urgency of addressing this issue is underscored by the prediction that global warming is projected to surpass 1.5°C in the 2020s and 2°C before 2050 [7]. The transportation sector is a significant factor in global GHG emissions, nearly 15% of total GHG emissions worldwide and more than 20% of CO_2 emissions related to energy use; aviation for 2.5% of worldwide CO_2 emissions, ships contribute 6.4-13.6% of volatile organic compounds (VOCs) and ozone formation potentials, and road transportation with estimates ranging from 15% to 20% of global emissions [8-10]. Meanwhile, annual growth in China's aviation CO_2 emissions was recorded 12.52% [11].

The need for sustainable policies to mitigate these effects is underscored by the potential reduction in life expectancy due to climate change [12]. A comprehensive approach to mitigating short-term and long-term global warming, including addressing non-CO_2 pollutants, is recommended [13]. The use of fuels, synthetic fuels, and bio-renewable energy sources are potential solutions to reduce these emissions [14]. The development of SAF is a critical response to the aviation industry's need to reduce carbon emissions [15]. The improvement of sustainable aviation fuels (SAF) could be a key focus in the aviation industry, with the potential to essentially diminish GHG emissions [16].

A range of countries are actively developing SAF technologies. In Sweden, there are identified lignocellulosic and electrofuel-based pathways as promising, with potential environmental benefits [17]. Similarly, in Brazil, there is highlighted the potential of bio-SAFs, particularly from sugar crops, to reduce GHG emissions [18]. In Europe, there is an emphasis on the need for a power mix based on renewable energies to attain critical environmental benefits [19]. The EU is additionally considering the potential of assembly its SAF targets in 2030 and 2050, with a focus on the unwavering quality and accessibility of biomass feedstocks [20]. In Nigeria, there is underscored the importance of addressing jet fuel scarcity and price volatility [21]. Norway and Sweden are at the forefront of sustainable policies, with Sweden leading in fiscal policy targets and the establishment of an independent fiscal council [22]. Sweden, in particular, has been recognized as the world's most sustainable country, with strict environmental policies and a focus on climate change projects, while the EU is exploring the potential of meeting SAF targets [20,23]. The International Air Transport Association (IATA) has recognized drop-in SAFs as a key methodology, and the US is considering the use of Carinata-based SAFs [15, 24].

Several countries have made significant strides in implementing SAF in recent years, a few nations are still inquiring about and improving the organization of SAF, while others have begun production but have not yet used it commercially. The European aviation sector investigating the utilization of elective fuels, with a focus on environmental and economic sustainability[19]. Norway, for illustration, has ordered the utilization of advanced biofuel in jet fuel, with a goal of 30% sustainable fuel by 2030 [25]. Brazil has also been a key player, with studies assessing the potential for SAF production and the need for sustainable conditions [18]. In the United States, a piecemeal approach is being taken, with a lack of cohesive federal policy and a reliance on voluntary programs [26]. Research and development efforts are underway in developed countries, with a focus on biofuels and the need for cost-effective production processes [27]. The commercialization status of renewable jet fuel production pathways is being reviewed, with the Hydroprocessed Esters and Fatty Acids pathway being the most developed [28]. The global development strategies for SAF production are being explored, with a focus on feedstock selection and technology improvement. The use of alternative fuels, including bio and synthetic fuels, is being reviewed, with a call for government support to accelerate the transition towards sustainable aviation [29]. There are various challenges and obstacles in the improvement and utilization of SAF. This study reviews the strategies used by the developed countries that have produced and used SAF to serve as a reference for other nations to develop and use SAF, especially Indonesia.

Methods

This study examines several barriers and policy options in the use of SAF in selected countries to illustrate how the use of SAF can be implemented. Subsequently, the study extends to the context of Indonesia as the focus of this study. A comparative study with qualitative descriptive is conducted through the following five steps. The literature review is the main activity. The research stages are depicted in Figure 1:.

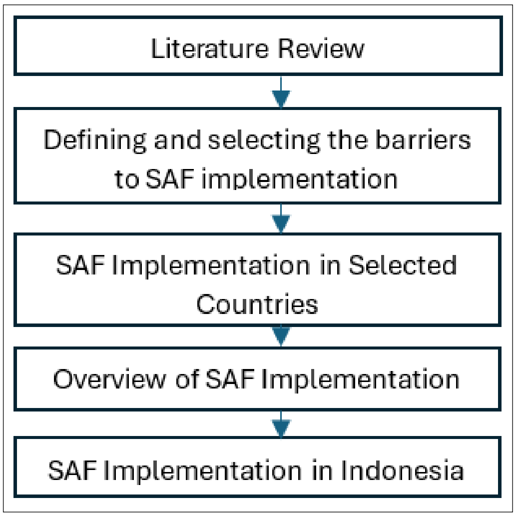

Figure 1: Activities of review for the implementation of SAF

In Step 1, the literature review was conducted by gathering articles from various sources, especially those indexed in Scopus, to get an the improvement of SAF at the worldwide level, studying various aspects related to SAF. In Step 2, the literature review was conducted by gathering articles from the Scopus website published between 2020-2024 with the keywords "barriers" and "sustainable aviation fuel". This initial literature review aimed to identify the barriers to implementing SAF. The author selected the 10 most relevant articles and then analyzed the obstacles in the development of SAF. Among the many obstacles in the development of SAF, the author selected five obstacles that, in the author's opinion, are the main barriers to the development of SAF, consisting of feedstock availability, supply chain, government support, technology readiness, and SAF selling price. In step 3, the literature review was conducted to identify countries/regions that have implemented SAF. In this case, the author specified three criteria: the country produces SAF, purchasers SAF, and has a roadmap for SAF utilization. According to the author, these three aspects indicate that a country has a strong commitment to implementing SAF. In step 4, a writing audit was conducted to understand the general overview of SAF implementation, focusing on the obstacles identified in step 2 involving selected countries/regions, but still considering supporting studies even outside the benchmark countries. The final step, step 5, is to analyze the potential development of SAF in Indonesia, with a focus on overcoming barriers to SAF implementation.

Results and Discussion

This section examines the findings of the study and provides a more comprehensive overview of the study findings. The results and discussion focus on how the implementation of SAF in the best practices countries and toward the development of SAF in Indonesia.

Barriers to Implementing SAF

The search results of the articles on the Scopus website published between 2020-2024 with the keywords 'Barriers' and 'Sustainable Aviation Fuel' yielded more than 10 articles, but in this case, the author chose the 10 most relevant articles.

Author	The Barriers of SAF Implementation
Ahmad [30]	technology, access to finance, social acceptance, policy and regulatory
Pechstein [31]	EU regulations requiring separate logistics for airport fuel tanks, which are technical, environmental and economical aspect
Trejo-Pech [32]	SAF production cannot competitively compete with fossil fuels due to price factors, supply chain without governmental incentives or related policies
McCollum [33]	The main barrier to using sustainable fuels is the limited feedstock supply
Brandt [34]	The inability to compete in selling prices and the size of investments for large-scale biorefinery industries
Cabrera [29]	Challenges in developing sustainable aviation fuels (SAF) include limited progress in fuel pathways, inadequate feedstock availability (especially for bio SAFs), sustainability issues with rising feedstock production, and insufficient support from authorities and institutions to transition from fossil fuels to renewables
Yang [35]	The endorsement and assessment process for sustainable aviation fuels (SAF) through ASTM D4054 requires significant costs and volumes
Engelmann [36]	The introduction of new technologies can be influenced by public support and acceptance, while moo open back and acknowledgment can influence the presentation of unused innovations technologies
Jager [37]	price is a barrier
Candrasekaran [38]	This research examines the capabilities of four different technologies to produce sustainable aviation fuels (SAFs) from bio-based sources.

Regarding the 10 studies above, it can be summarized that the barriers to the development of SAF are feedstock availability, supply chain efficiency government support, technology readiness, and selling price [29-38].

Selected Best Practices for SAF Implementation

The countries or regions selected as references for SAF implementation are based on 3 factors: the countries produce SAF, purchasers SAF, and have a roadmap for SAF utilization. In recent years, the aviation industry has been moving towards sustainability, marked by the increasing utilization of SAF worldwide. Across continents, airlines, governments, and industry stakeholders have embraced SAF as a viable alternative fuel for aircraft. ICAO member states have implemented policies and regulations to energize the utilization of SAF, offering subsidies, tax incentives, and orders for mixing SAF with conventional jet fuel. These measures not only accelerate the transition to sustainable aviation but also create a supportive environment for investment and innovation in this sector.

SAF-Producing Countries

Currently, several countries have succeeded in developing SAF. These countries have conducted research, innovation, and infrastructure development to develop and expand SAF production. According to IATA, the countries of North America, Europe, and Singapore are among the countries in the world that have currently or before the end of 2023 produced SAF, as shown in Figure 2 [39]. IATA also explained that in 2013, there were several additions of new facilities in several countries, including the USA (Calumet in Montana, Marathon in Martinez, and World Energy in Paramount), Italy (ENI in Livorno), UK (Phillips 66 in Lincolnshire), Spain (Repsol in Cartagena), and Singapore (Neste).

Figure 2: SAF Project Operating 2023
Source: IATA, 2023

SAF-Purchasing Countries

The aviation sector considers accelerating SAF production necessary to achieve its objective of dividing CO_2 emanations by 2050 compared to 2005 levels, given SAF's potential to achieve over 90% greater efficiency in emissions reduction compared to fossil fuels [15]. The utilization of SAF by airlines, such as China Airlines (China), United Airlines (USA), KLM (Netherlands), Lufthansa (Germany), Cathay Pacific (Hong Kong), Southwest (USA), FedEx (USA), JetBlue (USA), and Qantas (Australia), is a strategic step to decrease carbon emissions and promote more sustainable aviation practices, as described by ICAO [40].

Roadmap SAF – Implementation Target

ICAO Member States have committed to implementing SAF to reduce CO_2 emissions, including setting targets for SAF adoption, implementing regulatory frameworks to support SAF production and distribution, providing financial incentives or subsidies for SAF adoption, and investing in research and development to advance SAF technology [15]. The CORSIA initiative promotes the use of lower carbon aviation fuels, which can be produced sustainably [41]. The use of SAF is key strategy for reducing the environmental impact of the aviation sector [16]. However, the deployment of multiple levers is needed to meet the emission reduction requirements [41]. The production of drop-in aviation biofuels is expected to increase, with a focus on cost-effective and environmentally friendly production routes [42]. SAF adoption targets in several ICAO member states are as follows: Indonesia aims for 2% by 2016, the United States aims for 5% by 2018, the European Union aims for 40% by 2050, the Nordic States aim for 3-4% by 2020, Germany aims for 10% by 2025, Israel aims for 20% by 2025, and Australia aims for 50% by 2050 [40].

Selected Countries and Regions for Best Practices in SAF Implementation

The selection of countries is made based on three criteria: the country produces SAF, purchasers SAF, and has a roadmap for SAF utilization. With the provided data, it is evident that the European United (EU) and the United States (USA) meet the criteria. The author would utilize the EU and the USA as benchmarks in the development of SAF, especially concerning Indonesia.

Implementation SAF

The implementation of SAF in this section focuses on its implementation in the United States and the EU. This section discusses how feedstock availability, supply chains, government support, technology readiness, and SAF selling prices are managed.

Feedstock Availability

The United States is making significant progress in producing and utilizing SAF, with a focus on the Pacific Northwest region [42]. Given the tight deadline to achieve the 2030 target and the necessary time to build SAF production infrastructure, that is an urgent got to center on commercially viable change technologies and feedstock pathways, with lipid-based pathways (fats, oils, and greases) being the main fuel source until 2030, supplemented by waste, woodland and rural buildup, and liquor pathways [43]. The USA leads globally in maize production at 35%, soybean production at 32%, and waste cooking oil production at 32%, providing ample sources of SAF feedstocks [40]. North America, particularly the United States is right now the biggest biofuel-producing region, contributing nearly 50% of global output, primarily from ethanol produced from maize feedstocks and to a lesser degree, biodiesel from soybean oil [40]. Lewis highlights the potential of waste feedstocks, such as squandered fats, oils, and oils, as well as trim and ranger service residues, for sustainable aviation fuel production [44]. However, Reimer notes that these alternatives are not yet cost-competitive with conventional fuels. Leila discusses the potential of oil shale and a respectively, to bridge the crevice between renewable jet fuel generation and military requirements [45]. The production of SAF from clean electricity and carbon dioxide is also being explored [46]. Regional trade is significant, with Canada heavily reliant on ethanol imports from the United States to meet its mixing necessities [47]. Therefore, the United States has abundant sources of SAF feedstocks and has experience in developing biofuels using domestic feedstocks.

In 2019, the larger part of biofuel generation within the European Union was inferred from first-generation biofuels made from food crops such as rapeseed, soy, palm oils, wheat, maize, and sugar beet, which are moderately simple to change over utilizing first-generation biofuel generation strategies [48]. However, there is a growing trend in the EU to shift from using food-based biofuels to alternative feedstocks, with about 80% of the feedstock utilized in EU biodiesel generation coming from virgin vegetable oils such as rapeseed, palm oil, and soy, with rapeseed oil being the most dominant feedstock (36%), followed by palm oil (30%) and 7% by soy [49]. In 2020, the EU reached a record high in the use of palm oil imports for biodiesel production, accounting for 58% of EU palm oil imports, while also utilizing 2.6 million tons of Used Cooking Oil (UCO) for biodiesel production or equivalent to 15% of total biodiesel production, with approximately 73% of UCO imports coming from third countries [50]. Numerous companies have reported their eagerly to enter the maintainable flying fuel (SAF) advertise by 2030, with an examination recommending that in case all existing biofuel workplaces in Europe were optimized for SAF era, potential capacity may reach around 2.3 million tons, and it is anticipated that over 60% of the European SAF supply in 2030 will be sourced from HEFA and Alcohol-to-Jet (AJT) pathway fuels, with the larger part of the vital feedstock comprising of utilized cooking oil, creature fats, squander oils, cover crops, and other feasible biomass [51]. The EU's biodiesel feedstock largely relies on imports, a policy approach that could also be applied to SAF development in the EU.

Shehab highlighted that the availability of feedstocks, derived from renewable resources and waste like waste oils, plant oils, and lignocellulosic biomass, poses a challenge to SAF development due to their limited availability [20]. Scaling up generation seem possibly lead to competition with nourishment crops and natural concerns. Johansson highlights the potential for competition between nourishment and bioenergy generation, with the previous proposing that bioenergy ranches seem appropriate, with the former suggesting that bioenergy plantations could appropriate significant ranges of cropland and brushing land. Environmental concerns are also raised by Alexander, who discusses the negative impacts of agrarian hones on the environment... In this way, recognizing the foremost promising and maintainable feedstocks through life cycle evaluation is pivotal to improve their use and assist the broad adoption of SAF [20]. In Kaasinen's study on the implementation of SAF in Finland, Norway, and Sweden, it is potential challenge lies within the dubious accessibility and fetched of feedstock, considering there are a few confinements on the utilize of food-based feedstock [52]. In this context, it indicates that countries with limited feedstock resources can rely on imports to meet their needs. However, meeting the standards of importing countries, such as the EU, can be challenging [53]. In terms of feedstock availability, the author concurs with Kasinen's view that countries with abundant feedstock have a greater opportunity to develop SAF, whereas countries with limited feedstock can develop SAF through imports. The United States and the European Union have exemplified this approach.

Supply Chain of SAF

In the United States, the SAF supply chain comprises the generation, collection, and dissemination of feedstock to SAF generation offices; the transformation of feedstock into fuel; and the transportation of the wrapped up fuel to the framework required for flying machine fueling [43]. Existing fuel certifications require that SAF be blended with customary powers, requiring coordination with the ordinary fly fuel industry [31]. The ASTM International Aviation Fuel Subcommittee plays a key role in evaluating and establishing specifications for new non-petroleum jet fuels [54]. The introduction of 100% SAF requires a focus on drop-in compatibility with existing aircraft and infrastructure [55]. Given that SAF production is still in its early stages, SAF supply chains are underdeveloped, potentially unique to each region, and likely require substantial resources and investment to establish. This initiative aims to support the expansion of SAF production by transitioning from pilot to large-scale production, conducting exhibit ventures to confirm supply chain coordinations and commerce models, and advancing public-private associations and collaboration with territorial, state, and local stakeholders. Government support is required within the progression of supply chain systems, counting transportation, capacity, and preprocessing coordinations, to progress efficiency and diminish costs and carbon concentrated inside the supply coordinations arranged from the producer's field to the alter office. The implementation of SAF in the USA requires a well-configured supply chain that considers environmental and social benefits [56]. Back the advancement of collection and gathering frameworks, counting transportation coordinations, to extend efficiencies and diminish taken a toll and carbon escalated of supply coordinations from the producer's field to the transformation office entryway [43].

In recent decades, European commercial aviation has seen significant growth, but this has come at the expense of environmental degradation, leading to increased GHG and CO_2 emissions into the atmosphere [57]. The growing demand for net-zero emissions has prompted the sector's supply chain to aim for a minimum least 55% lessening in GHG Emission underneath 1990 levels by 2030 and total decarbonization by 2050 [57]. While SAF is often seen as a ready-to-use solution, further efforts are needed to ensure its full compatibility with existing distribution systems, storage infrastructure, and aircraft. This indicates that future SAF supply chains will require logistics and blending facilities capable of scaling to meet the demand of hundreds of millions of tons [58]. In his research in Germany, it is concluded that the supply chain contributes 98-99% to the total costs incurred in SAF production, with the remaining 1-2% for flight operations [19].

Creating supply chain efficiency is crucial in America and Europe. They continue to conduct research and analysis to achieve cost-efficient supply chains for efficiency in the supply chain of SAF can be enhanced through various strategies. Martinez-Valencia suggests the inclusion of environmental and social benefits in the business model, while Bogdan proposes supply chain finance as a solution to reduce payment terms and improve financing efficiency [56, 59]. System dynamic simulation, as recommended by Zang , can be used to model, and analyze the dynamic behavior of the supply chain, leading to cost-effective decisions and lean flow [60]. Supply chain partners continually seek to enhance their coordination efforts, aiming to reduce stockpiles and enhance the speed at which goods and information flow. Strategies such as quick response (QR), efficient consumer response (ECR), and just-in-time (JIT) manufacturing are commonly employed to aid in this endeavor. Although information exchange is crucial for success, it alone is insufficient for achieving optimal outcomes [61].

Government Support

On July 14, 2021, the European Commission proposed a Regulation to the European Parliament and the Council aimed at ensuring equitable competition in sustainable air transport, identified as the ReFuelEU Aviation Regulation, which subsequently was ratified and functions as a regulatory framework for the promotion of SAF within the EU [51]. The European aviation industry is increasingly focused on reducing its carbon footprint, with a particular emphasis on the use of Sustainable Aviation Fuels [62]. The SWAFEA study, initiated by the European Commission, aims to provide policy makers with information and decision elements on the use of alternative fuels in aviation [63]. Barke highlights the potential of SAF in reducing environmental impacts, with the latter emphasizing the need for a sustainable scale-up framework [19]. However, Deane points out that the EU's Biofuel FlightPath Initiative has faced challenges, including higher costs and poor policy awareness [64]. The EU's Clean Sky initiative, particularly its sustainable and green engine program, is a key driver of innovation in this area [65]. The EU's 2030 Climate target plan underscores the importance of alternative energy sources in transport, including SAF [66].

The current utilization of SAF in the EU aviation sector remains minimal, accounting for less than 0.05% of add up to flying fuel consumption. To address this, the European Commission has proposed a SAF blending mandate for fuel supplied to EU airports. This mandate involves gradually increasing the minimum share of SAF in the blend from 2% in 2025 to 63% in 2050, alongside a sub-mandate for Power-to-Liquid SAF. Presently, certified SAF are allowed to be mixed with fossil-based jet fuel at the greatest proportion of 50%, unexpected on the feedstock-production pathway, but industry and fuel standard committees are investigating the potential for utilizing 100% SAF by 2030 [51].

Alternative fuels are expected to play a significant role within the EU within the coming long time due to European Directives promoting renewable energies and reducing greenhouse gas emissions in transportation, while the demand for aviation services is expected to continue growing in the Netherlands, contingent upon the regulatory framework governing the aviation sector [67]. ReFuelEU Aviation mandates that all fuel suppliers at EU airports provide a minimum percentage of sustainable aviation fuels (SAF) as low-carbon alternatives to kerosene, derived from biofuels (excluding biofuels produced from food and feed crops), recycled carbon aviation fuels, or synthetic fuels, with the minimum SAF percentage set to increase from 2% in 2025 to 70% in 2050 (European Union Aviation Safety Agency & European Environment Agency, 2023).

In the United States, a collaborative effort involving the Department of Energy (DOE), Department of Transportation (DOT), and Department of Agriculture (USDA) spearheaded the development of the SAF Grand Challenge Roadmap. The SAF Grand Challenge1 is a U.S. government-wide approach to working with industry to reduce cost, improve supportability, and grow generation to attain 3 billion gallons per year of residential feasible flying fuel generation that accomplishes a least of 50% decrease in life cycle GHG compared to customary fuel by 2030 and 100% of anticipated flying jet fuel utilize, or 35 billion gallons of yearly generation, by 2050 [43]. This initiative engaged the Environmental Protection Agency (EPA), various government bodies, and a range of stakeholders from national laboratories, universities, non-governmental organizations (NGOs), as well as the aviation, agricultural, and energy sectors entrance [43].

The Inflation Reduction Act of 2022, incorporates a two-year charge credit for SAF blenders, followed by a three-year assess credit for SAF producers, along with a $290 million grant program over four years for projects involving SAF production, transportation, blending, or storage, as well as the development, exhibit, or application of low-emission aviation technologies [43]. Eligibility requires SAF to generally achieve at least a 50% change in GHG emissions execution over the life cycle compared to customary jet fuel. The assess credit, beginning at $1.25/gallon for slick SAF, increments with each rate point of enhancement in life cycle emissions execution, up to $1.75/gallon [43].
The United States has put in put different measures to energize

the appropriation of SAF, such as Investment Tax Credit (ITC) programs to encourage SAF, Blender's Tax Credit (BTC), the Producer's Tax Credit (PTC), extract charge alleviation would help venture reasonability and generation financial matters, recognize SAF natural benefits through carbon estimating and other frameworks, make auxiliary SAF request, and illustrate US government commitment to SAF to energize venture improvement [68]. In the United States, federal rules and voluntary programs are in place, but a more defined federal policy is needed [26]. The implementation of SAF in the USA has been supported by a mix of federal and state policies, as well as regional and private efforts [26]. The Southern United States has received significant government support for SAF production from Brassica Carinata [69]. However, the lack of a cohesive federal policy has been noted as a challenge [26]. The role of government support in promoting SAF uptake, particularly during and post-pandemic, has been emphasized [70]. The U.S. is expanding its law and policy to incentivize the use of SAF, with a particular focus on federal, state, and regional programs [26].

Government support will be crucial in expediting and easing the shift towards sustainable aviation [29]. Meanwhile, measure the affect of diverse approach alternatives on the financial practicality of SAF generation innovations, highlighting the require for arrangement aid [71]. Santos stresses the importance of government support in research and development, approach and directions, financing contracts, business-to-business motivating forces, and business-to-consumer incentives [70]. Lewis explain that some regulations provide incentives with specific requirements for the use of renewable/low-carbon fuels, including the European Union's Renewable Energy Directive (EU RED), the U.S. Renewable Fuel Standard (RFS2), and California's Low Carbon Fuel Standard (CA LCFS) [44]. Under the EU RED and the U.S. Renewable Fuel Standard (RFS), fills must experience certification by national and deliberate plans to meet criteria for carbon lessening, anticipating carbon stock consumption, and maintaining a strategic distance from affect on exceedingly biodiverse lands, with the EPA deciding fuel volume prerequisites based on their natural affect [44].

Based on the studies, it is evident that the role of governments in America and Europe in the development of SAF is highly significant. This strengthens the viewpoint of several researchers that the government's role is crucial in the development of SAF. Government policy interventions are critical for reducing GHG emissions in the aviation sector. While the International Civil Aviation Organization (ICAO) aims to tackle GHG emissions from international aviation on a global scale, the effectiveness of these efforts largely hinges on the decisions and policy actions taken by individual sovereign states or nations.

Technology Readiness

The technologies used for processing SAF production include FT-SPK for feedstocks like coal, natural gas, and biomass blended at 50% with fossil fuels, HEFA-SPK for vegetable oils and fats blended at 50% with fossil fuels, HFS-SIP for biomass used in sugar production blended at 10% with fossil fuels, FT-SPK/A for managing feedstocks like coal, natural gas, and biomass with a maximum blending ratio of 50%, and ATJ-SPK for biomass with a maximum blending ratio of 30% [40]. The utilization of these technologies on an international scale is illustrated in Figure 3.2, distributed across various countries.

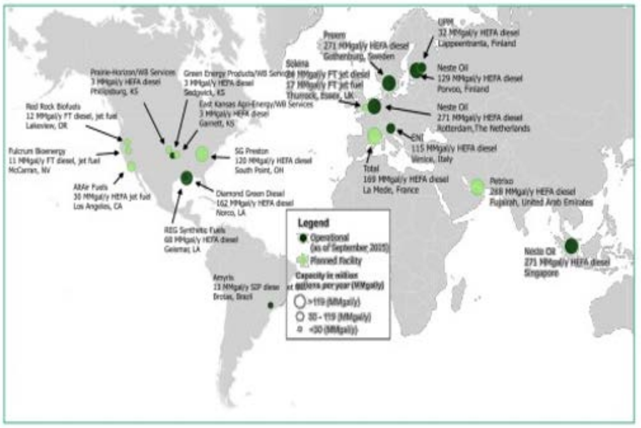

Figure 3.1 The Distribution of the SAF Production Process Technologies Worldwide

Source: ICAO [40]

Lipids serve as the primary source material for producing SAF using the HEFA process, constituting the majority of the feedstock required to achieve the U.S. target of 3 billion gallons per year by 2030, approximately 90% according to assessments of planned projects set to be operational by 2030 [43]. Meanwhile, Tanzil compared the utilization of Triglyceride-based HEFA technology against five lignocellulose-based technologies, consisting of Fischer-Tropsch synthetic paraffinic kerosene (FT-SPK), Fischer-Tropsch synthetic kerosene with aromatics (FT-SKA), direct sugar to hydrocarbon (DSHC) or synthesized iso-paraffins (SIP), Virent's Bio Forming (VB) or hydro deoxygenated synthesized kerosene (HDO-SK), catalytic hydro thermolysis (CH), alcohol to jet (ATJ), fast pyrolysis (FP), and hydro processed depolymerized cellulosic jet (HDCJ), using standardized criteria, the findings indicated that HEFA emerged as the most competitive option due to its high fuel yield and comparatively affordable SAF selling price ranging from 0.88 to 3.86 USD per liter [72].

An assessment informed that optimizing all current biofuel plants in Europe to produce SAF at maximum capacity could yield around 2.3 million tonnes, with HEFA and Alcohol-to-Jet pathway fuels projected to contribute over 60% of Europe's SAF supply by 2030 [51]. Meanwhile,HEFA is the foremost common elective drop-in jet fuel with approximately 360,000 tonnes of capacity within the European Union in 2018 [73]. An advantage of HEFA fuels is that the framework is as of now put to back expansive production volumes. For case, Neste as of now works on two plants that can prepare around 1 million tons of squander oils a year with plans to extend its Singapore plant to more than twofold its current capacity by 2022 [74].

The HEFA innovation is directly the foremost progressed, with HEFA powers being the sole elective as of now in commercial utilize [41]. HEFA-jet is delivered in clumps by a few large-scale commercial offices around the world and can be mixed with customary fuel up to 50%, even though later flight trials have tried 100% HEFA [28]. Outstandingly, flying industry pioneers such as Airbus, Rolls Royce, and the German Aviation Center (DLR) conducted the inaugural commercial traveler fly flight utilizing 100% SAF with HEFA-fuel given by Neste [75]. A division of the fuel created from these refineries might be utilized as HEFA fuel, whereas the leftover portion of the item slate comprises renewable diesel as a drop-in diesel substitute as well as light items such as propane. Even though refinery item slates are often optimized for diesel substitutes, optimizing for a better jet fuel division and occupying the item slate from the street to flying segments can be done quickly and less extravagantly than making a completely modern SAF capacity [76]. Pavlenko gauges that HEFA fills are likely to be the cheapest source of SAF within the close term, calculating generation costs as moo as €0.88 per liter, twice the taken toll of petroleum-based fly fuel generation, whereas other transformation forms fetched as much as eight times the cost of petroleum fuel [77].

Based on several studies, currently, the use of HEFA technology is the primary choice for the production process technology for implementing SAF. In the future, of course, the use of SAF production technology will continue to be developed and enhanced to reduce costs incurred during the production process.

SAF Selling Price

The U.S. jet fuel right now retails at around $2.85 per gallon whereas SAF costs are at $6.69 per gallon, as per information from commodities and vitality estimating office Argus Media [78]. The current cost of producing HEFA is estimated to be three to four times higher than the cost of producing fossil jet fuels, and Carbon pricing could significantly assist in transitioning from traditional fossil fuel-based energy consumption to biofuels [79]. SAF produced via gasified energy crops costs more than four times the taken toll of fossil-based jet fuel [80]. A wide run of potential fuel offering costs (0.81–5.00 EUR/L) has been evaluated due to the accessibility of different pathways, with a few courses competent of accomplishing over 90% emission reserve funds compared to fossil jet fuel. There is a pressing need for the aviation industry to accelerate the scale-up of SAF production and the immediate challenge lies in establishing a sustainable framework for scaling up and aligning all stakeholders involved in aviation [15].

In 2021, the U.S. government provided $4.3 billion in assistance for SAF openings, counting a $3 billion credit ensure, $175 million in inquire about subsidizing for advances to decrease SAF carbon emanations, and over $61 million to development biofuels and bolster low-cost SAF pathways by the FAA [81]. In 2022, the U.S. government issued the Inflation Reduction Act policy, which includes incentives to use SAF up to $1.75 per gallon, incentives for infrastructure grants of $245 million, and the Sustainable Aviation Tax Credit — Build Back Better Agenda with a tax credit for 50% or more lifecycle GHG reduction [81].

In the EU, Progressed SAFs can take a toll of €1 to €2 per liter, more than three to five times the toll of routine petroleum jet fuel, depending on feedstock and transformation pathway [77]. The development of SAF in Germany has not yet achieved market penetration economically, where the use of synthetic kerosene, PEM, and SOEC, results in higher costs compared to fossil kerosene, with a comparison of 786% and 588% higher than fossil variants [19]. Member states actualizing EU mandates may subsequently got to couple SAF targets with motivations or punishments [77].

Based on existing research, it is confirmed that the selling price of SAF is higher than that of fossil fuels, so the role of the government in setting SAF prices and providing various incentive schemes becomes crucial.

Implementation of SAF in Indonesia

Indonesia is an archipelagic country blessed with abundant natural resources. Indonesia's Government has issued regulations to demonstrate its seriousness in achieving the Net Zero Emission (NZE) target.

Feedstock Availability

The current development of SAF is predominantly dominated by plant-based sources, accounting for 75% [47]. The Ministry of Energy and Mineral Resources of Indonesia (2015) identified 13 plants in Indonesia that can be utilized to produce biodiesel and bioethanol, including palm oil, Sunan candlenut, cassava, pongamia, sugar palm, castor bean, coconut, pongamia, corn, sugarcane, rubber, sago, and sorghum [82]. However, Nugroho stated that only three potential feedstocks exist that are palm oil, used cooking oil, and sugarcane [83].

Indonesia is the world's largest producer of palm oil. In 2018, global palm oil production reached 72 million tons, Indonesia accounted for 57% of this production or equivalent to 41 million tons, while Malaysia produced around 27% or 20 million tons, approximately 84% of the total global palm oil production comes from these two countries [84]. Currently, palm oil has been employed in formulating Bio-avtur J2.4, a fuel mixture incorporating 2.4% palm kernel oil, which has been subjected to ASTM 1655 standard tests for application in Jet A-1 aircraft engines, meeting the ASTM 1655 requirements as "technical criteria" [83].

One of the feedstocks that can be used for SAF in Indonesia is Used Cooking Oil (UCO). Currently, one of the feedstocks used for SAF in Europe is UCO, mostly imported from abroad, including Indonesia [85]. The Ministry of Energy and Mineral Resources explained that national palm oil consumption reached 16.2 million kilolitres and about 40-60% of this amount is UCO or equivalent to 6.46 to 9.72 million kilolitres [86]. Only around 3 million kilolitres of UCO was successfully collected in Indonesia, or only 18.5% of the total national palm oil consumption.

Sugarcane is another feedstock that can be used. The projected sugar production until 2026 is 2.83 million tons, while domestic sugar consumption in the same year is projected to reach 6.86 million tons, indicating that Indonesia's national sugar production remains insufficient to meet domestic demands, lagging significantly behind Brazil, the world's leading sugarcane producer, with an average production of 757.08 million tons of sugarcane from 2016 to 2020, accounting for 38.90% of the total global sugarcane production, according to estimates by the Ministry of Agriculture [87]. With the status of sugarcane feedstocks still being imported, the author believes it would be inappropriate to develop SAF based on sugarcane, as it may disrupt the distribution of sugarcane needs domestically.

Indonesia possesses abundant raw material potential and can become the world's largest producer of Renewable Energy Resources [88]. In terms of biodiesel production, Indonesia currently stands as the world's largest producer of biodiesel [89]. This is evidenced by the successful development of B30, which is a biodiesel blend comprising 30% vegetable oil derived from palm oil, making it one of the highest vegetable-blend fuels in the world [90]. Additionally, biodiesel has been developed using feedstocks from Calophyllum inophyllum, Aleurites trisperma, coconut, and microalgae [91-94]. With experience in developing biodiesel from various feedstocks, Indonesia has a significant opportunity to develop SAF on a large scale using various feedstocks.

Supply Chain of SAF

An effective and efficient supply chain significantly influences the production costs of SAF [19]. One of the strategies selected by America and Europe, which is to synergize the SAF supply chain with the fossil fuel supply chain, can be followed by establishing SAF production centers in areas that are already centers for the production of fossil fuels owned by PT. Pertamina which owns a total of 9 refineries, consisting of 8 active refineries and 1 inactive refinery (Nugraha et al., 2020. The production of biofuels, including SAF, will be carried out at refineries owned by Pertamina [95]. The eight active refineries are in Figure 3.2.

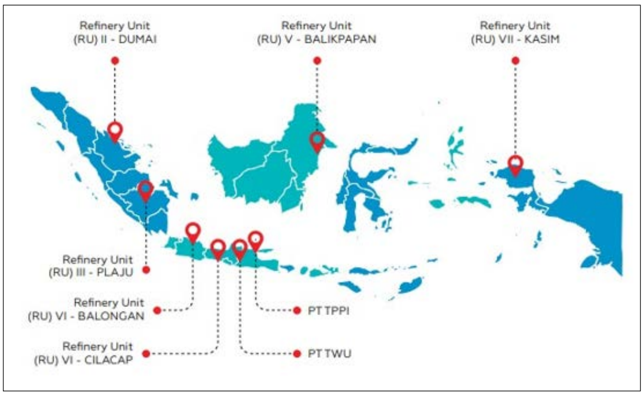

Figure 3.2 Refineries Fossil Fuel in Indonesia
Source: Pertamina Energy Institute [96]

Considering the locations of these 8 refineries, Indonesia can develop SAF production at the same sites to streamline the SAF production supply chain. Therefore, Indonesia needs to develop an effective and efficient supply chain model. For the mass production stage, a study is needed to ensure that the production supply chain does not have a significant impact on production costs.

Government Support

These regulations are formulated through various levels of government organizational structures, including the Presidential Regulation on National Energy Policy in 2006, the Presidential Regulation on the Implementation of Carbon Economic Value for the Achievement of Nationally Determined Contribution Targets, and GHG Emission Control in National Development in 2015. Meanwhile, the Government Regulation on the National Energy Policy in 2014, and the Ministerial Regulation of the Ministry of Energy and Mineral Resources that has targeted the blending of SAF produced by Indonesia should reach a minimum of 2% in 2016, 3% in 2020, and 5% in 2025. Furthermore, Indonesia has produced a biofuel blend made from palm kernel with a composition of 2.4%, which is produced by Pertamina and named J2.4 [97]. The Ministry of Transportation issued a Ministerial Decision in 2023 has designated SAF as one of the main activities in the National Action Plan of the GHG Movement in the transportation sector.

Additionally, the Ministry of Transportation, together with the Ministry of Energy and Mineral Resources, has established a collaboration to create a comprehensive roadmap for SAF development. The ministries and institutions also collaborate in research on feedstock development, production process technology development, feasible incentive implementation, and airline ticket pricing.

Technology Readiness

Since 2020, PT Pertamina (Persero) in collaboration with ITB and the Ministry of Energy and Mineral Resources has initiated the development of bio-jet fuel, successfully producing biojet fuel with a percentage of 2.4% or J2.4, with PT Pertamina (Persero) and ITB conducting co-processing trials of kerosene with vegetable oil to produce a prototype biojet fuel product, followed by a series of fuel material characteristic tests encompassing flash point density, freeze point, JFTOT thermal stability, aromatic content, cloud point, lower heating value (LHV), viscosity, and specific gravity [96]. The increasing interest in coprocessing liquid intermediates, such as lipids, biocrudes, and FT liquids, within existing petroleum refineries, particularly targeting fluid catalytic crackers (FCC) and diesel hydrotreaters for insertion points, reveals a challenge in achieving high renewable molecule content in jet fuel due to current ASTM D1655 limitations and uncertainties in quantifying green molecule content, yet even low coprocessing volumes could yield significant impacts at the large scale of refinery operations [98]. There are several technologies available for producing SAF sourced from biological and organic waste, with the HEFA process being the most widely used technology for commercial SAF production at present, dominating the global SAF production process up to 95% [96].

Pertamina, one of Indonesia's state-owned enterprises, has extensive experience in fossil fuel production processes. Pertamina will produce biofuels, including SAF, at Pertamina refineries with a target capacity reaching 200 thousand barrels per day for hydrotreated vegetable oils (HVO) and HEFA by 2060 [95]. Indonesia, through its state-owned company Pertamina, has the experience and established plans to produce SAF utilizing HEFA technology.

SAF Selling Price

The selling price of SAF is generally still higher compared to fossil fuel prices worldwide. Breakthrough policies are needed to make SAF prices economically feasible. Currently, in Indonesia, policy formulations are being studied for non-fiscal incentives by the Ministry of Transportation, fiscal incentive policies by the Ministry of Finance, pricing formulations of SAF by the Ministry of Energy and Mineral Resources, and opportunities for tax holiday for SAF development by the Ministry of Investment.

Conclusion and Recommendation

Currently, countries worldwide are racing to develop SAF, but there are still many obstacles, especially in feedstock availability, supply chain issues, government support, technology readiness, and SAF selling price. To address these obstacles, it is advisable to emulate countries that have successfully implemented SAF as a benchmark. The countries that should be considered best practices are those with a clear roadmap for SAF implementation, engaged in SAF production, and utilizing SAF. The United States and the EU meet the criteria of countries that can be considered best practices.

The United States has successfully implemented SAF. They have an abundant supply of SAF feedstocks, as the U.S. is the largest producer of maize, soybean, and waste cooking oil in the world and will use lipid-based pathways (fats, oils, and greases) being the main fuel source until 2030, supplemented by waste, woodland and rural buildup, and liquor pathways [40, 43]. Technologically, the use of HEFA technology in SAF production is well-established and highly ready for SAF production, dominating the global SAF production process up to 95% and The United States has the experience and capability to use HEFA in fuel production [40, 96]. The United States makes supply chain system to back the advancement of collection, gathering frameworks, production, transportation from the producer's field to the transformation office entryway, thus integration of the SAF supply chain with fossil fuels has also been successful [43]. Government support has been exceptional, with clear roadmap development, regulations related to SAF, and various incentives provided, such as The SAF Grand Challenge1, Environmental Protection Agency (EPA), and the Inflation Reduction Act of 2022. The challenge still faced is the high selling price of SAF, considering that the price of SAF is still 3-4 times higher than fossil fuel, although the United States has issued various incentives, such as ITC, BTC, and PTC. So it is suggested that the U.S. prepare regulations, policies, and research to create pricing formulas to narrow the gap between SAF and fossil fuel prices [78].

The EU has combined feedstocks produced by EU member states and imports from other countries to meet its feedstock needs [50]. The EU has issued various regulations, and policies, including incentives for SAF producers, demonstrating the EU's full support for SAF development to achieve its emission reduction targets, such as EU RED, Clean Sky Initiative, The EU's 2030 Climate target plan [66, 99]. In terms of production technology, particularly HEFA technology, the EU is highly experienced, including the development of other technologies aimed at making SAF production processes even more efficient [40]. Similar to the United States, the EU faces challenges in SAF pricing, so it is recommended that the EU create regulations and policies that support technological and management breakthroughs expected to align SAF prices with fossil fuel prices.

Meanwhile, Indonesia is an archipelagic country rich in SAF feedstocks. It is identified that Indonesia has the potential for feedstocks such as palm oil, Sunan candlenut, cassava, pongamia, sugar palm, castor bean, coconut, pongamia, corn, sugarcane, rubber, sago, sorghum, and used cooking oil [82]. Indonesia is the world's largest producer of palm oil and coconuts, produces a significant amount of UCO exports it to various countries, and has the opportunity to develop various feedstocks on an industrial scale [87]. Technologically, Indonesian state-owned oil companies are highly experienced in producing fuel by HEFA [88]. Government support in Indonesia with various regulations and policies is also very good. In terms of supply chain efficiency, Indonesia has several refinery points that can be synergized with the SAF supply chain [88]. For the selling price of SAF, various studies are also being conducted to ensure that the price is not significantly different from fossil fuel prices, including studies on incentives. Therefore, Indonesia has a great opportunity to implement SAF in the future. It is recommended to conduct studies that can support the integrated implementation of SAF [100-116].

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