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The adaptation of sustainable biojet fuels and its effect on aircraft engine maintenance

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Abstract. Aviation industries are looking into several resources for renewable and sustainable energy. Among those attention is focused in biojet fuel. This paper engages the issue of biojet fuel emissions that increase the environmental concern in the air transport sector. The paper presents the use of biojet fuel and its effect on aircraft engine maintenance through preliminary data collections, and a review of its development process in operations for time and goal. As conclusion, airlines management needs to adapt and adopt the transition to alternative fuels, especially given the global biofuel trend emerging due to the authority approval.

1. Introduction

In the recent years, there has been an increasing research interest in alternative energy due to aviation environmental pollution from the usage of fossil fuel [1, 2]. Among the many anticipated benefits of alternative energy, sustainability is considered as a global need that has to be measured. This is due to its reliability, economics and supply chain optimism [3]. According to other past researches, in Europe itself, 216 million tons of CO₂ emissions were produced in the year 2010. This is projected to be 334 million tons for optimistic scenarios in the year 2030 [4]. The reduction of emissions is considered to be more a matter of engine design than fuel technology. The adverse effects of the general degradation of combustion performance in kerosene for over 25 years cause emissions and engine life span to be in need of consideration, and this has led to a rapid demand for new and alternative fuel [5]. These rapid changes bring a serious effect in creating global carbon neutrality, where in this case, improvements in carbon engine outputs alone will not work. Adaptation and current work with new ‘alternative energy’ with zero carbon distributions will help to reduce air pollution that directly impacts the atmosphere [6]. Alternative energy in commercial aviation can be defined as using biojet fuel, gas to liquid, and hydrogen cells. The use of battery and hydrogen cells addresses some issues such as weight limitation, and thus it will not be discussed in this paper. Similarly, GTL or gas to liquid will not be considered in this article as it has an adverse feedback on the environment [7].

When alternative energy approaches sustainability, factors such overall efficiency of combustion process and level of the emissions produced are its crucial assets. A significant increasing amount of research has been carried out in providing the definitive evidence of performance for these alternative fuels in relationship to combustion chamber [8, 9, 10]. Nevertheless, this research area is still lacking. Essentially, air transportation has to ensure the future forecasting of 27,200 new airplanes worth 2.7 trillion that will be needed by 2025 to be embarked towards sustainability of the aviation business entities across the world. In fact, it is to be forecasted that the total CO₂ emissions due to commercial



aviation may reach 1.2 billion to 1.5 billion tonnes. It is becoming an important part of the airlines industry and associate to be part of a sustainability transition towards the environment.

Therefore, this study will present the knowledge of biofuel usage in the engine maintenance and also a review of its development in operations, specifically for time and goal. These clearly help the airlines to ensure the adaptation of the biojet fuel to its application in civil aviation. In fact, this study will also benefit to the policy maker or aviation authority in preparing the aviation industries to this new alternative energy resources.

2. The research method

This research reviews current maintenance programs as an approach to planning and constructing the way ahead in adaptation for the use of new alternative energy. Therefore, this study supports airlines in economic view and maintaining the safety of aircraft components for the engine. Doing so provides a reliable yet efficient way to examine and identify maintenance perspective. Information obtained was collected with deeper document analysis including report analysis from biojet fuel flight test and aircraft engine and maintenance manual. The approach implemented in the research involves acquiring an expert from the industries such License Aircraft Engineer in both airframe and engine, and the fuel workshop approval holder to form a line of reasoning to achieve the solution and provide preliminary result.

3. Aircraft engine emissions

Higher efficiencies of the engine provide an increase rate of performance. However, negative rate of performance of the turbine engine can also occur due to different level system losses, which can take many forms. The simplified internal flow shows the relevance, description and products from the gas turbine engine operation in an adaptation from research article in Table 1 [11].

Table 1. Description of simplified internal flow systems in turbine engine combustion systems

Relevance	Description	Products
Energy source	System delivering super-heated steam to represent combustion and compression process	Air $N_2 + O_2$
Energy transfer	System with heat transfers possible	$C_N H_M + S$
Energy conversion	System converting energy from super-heated steam to work	$CO_2 + H_2O + N_2 + SO_2 =$ <i>complete combustion</i> $CO_2 + H_2O + N_2 + O_2 + NO_x +$ $SO_x + HC + \text{Soot Particles} =$ <i>Actual combustion</i>

The product of the turbine engine is creating emissions. The exhaust gas is roughly about 70% CO_2 . A little less than 30% non- CO_2 emissions include water vapor (H_2O), and less than 1% each of nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrocarbons (HC), and black carbon (or soot) particles [12]. These emissions from standard Jet Fuel for aviation such CO_2 , H_2O and soot emissions will contribute directly to the environmental impacts, where these emissions are released directly into the upper troposphere and lower stratosphere. This is where the effects of the climate change are discussed in detail [13, 14, 15].

4. Biojet fuel for commercial engine

According to NASA research center on propulsion technology, their primarily focus will be on high-pressure engine core components and propulsion technologies, with the goals of lowering harmful emissions and fuel burn [16]. As mentioned earlier, improvements in the engine itself will not lead to zero carbon outputs. According to European Commission [17], in the biofuel flight path 2050, the target of European countries is to be established as a centre of excellence on sustainable alternative fuels, including those for aviation, based on a strong European energy policy. This will lead to more

biofuel projects and research. The decisive evidence shows biojet fuel need to come into the depiction. It is certainly true that advantage of biojet fuel because it can be a direct drop-in fuel. It is complimentary and compatible with the conventional jet fuel. With biojet fuels to displace the conventional jet fuel without the need to change the engine technology. Currently, there are over 300,000 commercial aircraft in the world. Since biojet fuel is complimentary and compatible with the conventional jet fuel, it will have a ready market of over 300,000 commercial aircraft [18].

The future base of aviation fuel research conducted by IATA described chemical and physical characteristics of the fuel and reviewed the contents of its requirements, which include heat content, fluidity, corrosion protection, and stability [19]. In 2008, the ground test was performed for CFM 56-7B for new alternative energy using biomass Algae and Jatropa for the bioJet fuel as a 50% mix to current jet fuel. It is the continuation of the test by Bio Spk that blends Jatropa-Jet A-1, Jatropa/Algae, Jet A and Camelina/Jatropa – Algae/JetA. The detailed result of composition, volatility, fluidity, combustion, thermal stability and contaminants can be seen in Table 2 from the Evaluation BioSPk report 2009 [20].

Table 2. Evaluation BioSPk report 2009 for different types of biomass versus traditional jet fuel

Property	Jet A/Jet A-1	Jatropa	Jatropa/Algae	Camelina/Jatropa/Algae
COMPOSITION				
Acidity, total mg KOH/g	0.10	0.002	0.001	0.003
Aromatics				
1. Aromatics, volume%	25	0.0	0.0	
2. Aromatics, volume%	26.5	0	0	0
Sulfur, mercaptan, mass%	0.003	<0.0001	<0.0001	<0.0001
Sulfur, total mass%	0.30	<0.0001	<0.0001	<0.0001
FLUIDITY				
Freezing point, °C	-40 Jet A	-57.00	-54.5	-63.5
Viscosity –20°C, mm ² /s	8	3.663	3.51	3.353
COMBUSTION				
Net heat of combustion, MJ/kg	42.8	44.3	44.2	44.2
Hydrogen content, mass %				
One of the following requirements shall be met:				
1. Smoke point, mm, or	25	0	0	0
2. Smoke point, mm, and	18	0	0	0
Naphthalene's, volume, %	3.0	<0.01	<0.01	<0.01
THERMAL STABILITY				
JFTOT (2.5 h at control temperature)				
Temperature, °C	260	340	340	300
Tube deposits less than	3	1	1	1
CONTAMINANTS				
Existent gum, mg/100 mL	7	0	<1	<1

The result from biojet fuel being used in all three flight tests can be concluded as positive outcomes as the reading is not just meeting the lower requirements aviation fuel needs but supersede the current jet fuel composition benefit. Enhanced composition in biojet fuel to be compared with conventional

fuel creating more advantages in term of carbon emissions, fuel efficiencies, components wear and tear and reduction in fuel cost and maintenance in prolong future.

Different types of biojet fuel generation being used and each of this generation was analysed and were identified for Air transportation use by giving the potential to deliver in large quantities, for greener, cleaner, and cheaper fuel. This can be categorised as Jatropa and Camelina for the short term feedstock while algae and halophytes as long-term feedstock [21].

5. Engine maintenance

Current practice in aircraft operations and maintenance are being measured for aircraft's preventative maintenance. Future biofuel to be introduced into the aircraft fuel system requires no modification, but it demands further analysis on predicting maintenance schedules. The utilization of current standard fuel Jet, A-Jet A-1 to ASTM D7566 drop in bio jet fuel, such as Camelina, Jatropa and Algae types of oils, is analysed [22]. To develop quantification of maintainability for the new alternative energy being used in the fuel system components, two affected maintainability prediction techniques are considered: primary procedures and secondary procedures.

Primary procedures take into account the early development and the entire separate processes of design and diagnostic. This will give a very accurate list of data for predictions limited throughout the engine response [23]. The secondary procedure will be the earliest procedure which is applicable earlier in the components diagnostic routines inspection and troubleshooting procedures, where the failure rates of the components can be recorded and measured. Since there is no complete data analysis for the real development of the biojet fuel flow through the pump itself, this identical value can be used to project into the maintenance schedule and maintenance planning data in MRO similar to overall fuel flow throughout the entire system [24]. This can be seen in Figure 1, where fuel reflects design elements.

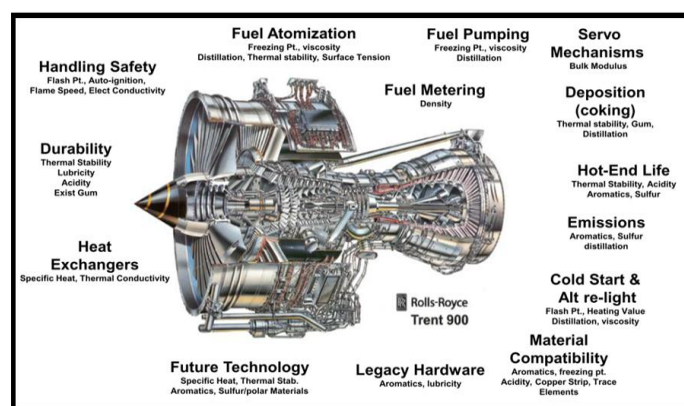


Figure 1. Fuel effects on engine design elements (Source: FAA)

6. Biojet fuel development – time and goal

In the aviation biojet fuel development context, it is acknowledged that the development needs to be focused in two different sets of scenarios namely time and goals. In term of time, more deliberate ideas can be developed when the process is focused on short term, medium term, and long term. This can be demonstrated in the adaptation of the elements of a featuring process for sustainable effectiveness in Table 3 [25]. As shown in Table 3, the development process in operations can be divided to six categories namely adaptation to MRO for biojet fuel, the purpose, the key outputs, tools, parties that involved and number of scenarios.

Table 3. Development process in operations time and goal adaptation [25]

	Short term	Medium term	Long term
Adaptation to MRO for biojet fuel	Observation through biojet fuel trending through test and schedule flight testing	Developing the gap for future biojet fuel and current jet fuel.	Identifying the business assumption for new fuel and disaggregating the development and strategic aims
Purpose	Identify adjustments to current strategic intent to optimize sustainable effectiveness	Develop boundaries for next version of robust strategic intent	Identify business assumptions and develop a range of possible future strategic plans
Key outputs	Operating decisions that change aggressiveness and differentiation	Identify capability investments	Identify potential capabilities to build team responses
Tools	Traditional environmental scanning tools, prediction markets, extreme strategizing	Ecosystem mapping base, best and worst case forecasts	Future scenarios
Who is involved	Top management -20 % Any boundary- spanner, current customers and relevant stakeholders	Top management 50%, Network and ecosystem community	Top management 30%, Board 75%, High-level government, NGO and community representatives, futurist
Number of scenarios	Zero, use goals instead	Three in current trajectory	Three of five scenarios of diverse conditions

The economic analysis in identifying the incentive and mechanism in understanding further the implication in biojet fuel usage will be vital. Subsidies, on the other hand, are forms of government financial support for activities believed to be environmentally friendly. Rather than charging a polluter for emissions, a subsidy rewards a polluter for reducing emissions [28]. The cost benefits of using biojet fuel remain unclear; this is often taken to support the view why Airlines is hesitant and reluctant to invest and adopt this new fuel. Some aspects derived from the resistant required further investigation. A more promising approach would be through risk assessment. At the risk offending the reluctant, the risks classification, must be examined more carefully [26]. It does suggest that the other factors will be a balance that can be drawn between risk and opportunity.

7. Preliminary data collection

This questionnaires Phase 1 discusses the data analysis and findings from 40 questionnaires completed by individuals who are working in Aviation industries in Malaysia, Spain, Saudi Arabia and Singapore. The result can be seen in all figure and table below. Details explanation can be concluded in discussions and analysis. Four sections of questionnaires has been handed out consisting of:

- Section A: Personal (biographical) data
- Section B: General knowledge on biojet fuels
- Section C: The feasibility of biojet fuels in aviation
- Section D: Impact of the usage of biojet fuels

7.1. Section A

The targeted group was Aviation personnel whose has more than four years' experience in handling aircraft and more accurate towards Engine or Aircraft systems. The data was collected from various Aviation company included Malaysia, Saudi Arabia, Singapore. The random sample of 40 participants provided an in-depth understanding of the general knowledge on alternative biofuel, the feasibility of biojet fuels in aviation and its impact. The selection process was identified through each participant's role in the use or testing of alternative fuel.

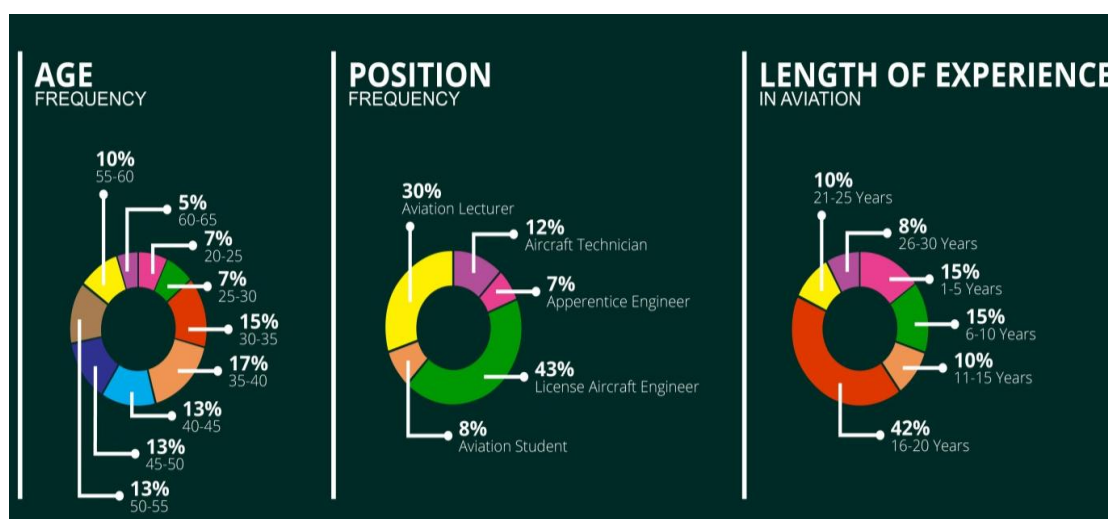


Figure 2. Respondents age, position and length of experience

7.2. Section B

When addressing the question in this section B, it focuses in how good biojet fuels to the environment, to aircraft engines, and reducing fuel cost by using the biojet fuels. The questions (B1, B3, and B5) have the highest value of this section - Moderate by 50%. This is shown in Figure 3 that average respondents know about biojet fuel, it is used in aircraft and airlines. With the second highest with 20%, the respondents have very low knowledge in biojet fuel. Most of the respondents rated the second question until fourth question, (B2-B4) as very high.

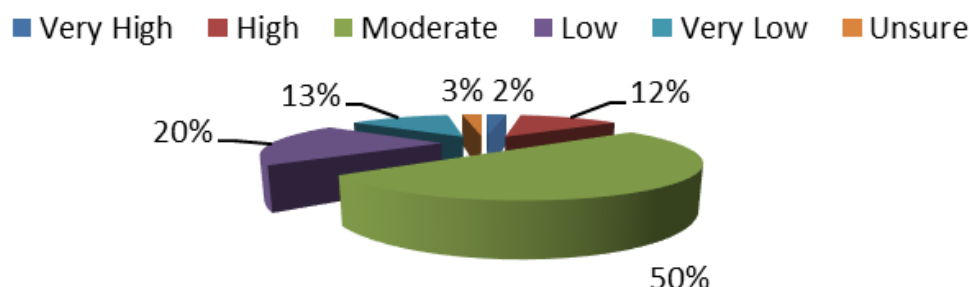


Figure 3. Section B: personal knowledge about biojet fuels in aviation

7.3. Section C

The first question (C1) probed if the biojet fuel is safe for the aviation industry. Most of the respondents agree with that statement only nine respondents (23%) are not sure. For the second question until fourth question, (C2, C3, and C4), the respondents averagely answered as moderate. The questions are more on the technical side if the biojet fuels will be used in aircraft engines. The questions asked about the modification is required to the engine if using biojet fuels, level adaptation to biojet fuel will be easier if that happened, and low technical feasibility changing from normal fuel (Jet A/Jet A-1 to biojet fuel) is needed. The last question (C5) however, they agree that biojet fuels will be widely used in future leaving three respondents unsure.

7.4. Section D

Figure 5 identifies the impact of biojet fuel usage. First question (D1) asked the respondents if biojet fuels lead to a better environment, most of them rated as very high and high. The second question (D2) asked if biojet fuels provide better fuel costs, the common answer is moderate. For questions (D3) and (D4), the respondents averagely answered as moderate. The questions are about biojet fuels will

increase engine performance, and saving airlines fuel cost. The last question (D5) asked if sustainable biojet fuels can be achieved. Most of the respondent rated as moderate.

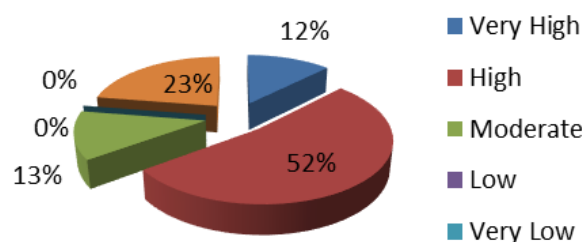


Figure 4. Section C: the feasibility of biojet fuels in aviation

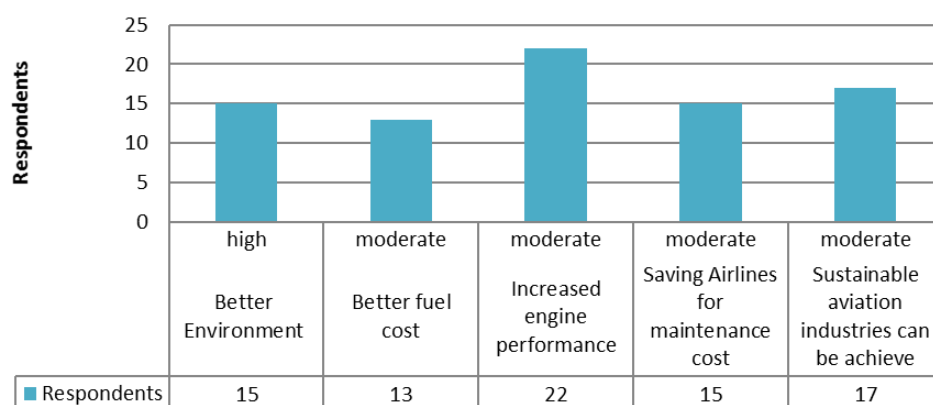


Figure 5. The impact on using biojet fuel

Questionnaires forms that have been conducted have been major contributors to this research. As preliminary data research, few important of conclusions can be made from this finding. It can conclude that the level of knowledge of new green technology, especially biojet fuels are still at a moderate level, among the personnel in the industry. Also from the results, it shows that biojet fuels knowledge is at 25% at the lower rate or unsure. The airlines or aviation personnel is aware and opened to the application of the biojet fuels in the aviation industry. From this research, respondents aware that biojet fuels are safe to be used in aviation. This is because more than 25 airlines already tested or conducted the biojet fuel flight as Figure 7 and Table 3. Besides, biojet fuels release zero gas emission compared to current fossil fuels. Even more, safety and fuel quality specifications are of tremendous importance in the aviation sectors. The technical requirements for aviation biojet fuels are; a high-performance “fuel (that can withstand a range of operational conditions)”, a fuel that does not compromise safety, a fuel that can directly substitute traditional jet fuel aviation, and also a fuel that meets the required performance target. The feasibility of biojet fuel adaptation on Aviation industries is also giving results by 52% at the higher rate.

As conclusion, this researched questionnaires shows that awareness led to where the safety in biojet fuel usage is very crucial. The cost has a high impact when coming to new alternative fuel, as increasing in cost will create a huge hurdle to the Aviation industries. The policy is creating a medium resource that can lead to projection in the adoption of biofuel in aviation industries. From this questionnaires its objectives; as being a major contribution to the feasibility biojet fuels and its impact on the aviation industry in the context of Malaysian environment has been achieved.

8. Biofuel drop in and successful roadmap flight (test and schedule)

Airlines need to adapt to the new energy, but the most necessary part is ensuring that it can be used effectively without any alteration to the systems, and it is affordable to maintain it. The ASTM D4054 was developed as a guide related to testing and procedures ensuring certification of drop in alternative fuels have remained unchanged to the limitation of engine operating and aircraft operations, as well as

aircraft flight manual as in Figure 6 below. Besides, this indicator needs to relate and ensure that the transition into the prolonged future towards engine systems can continually perform its function in the levels of reliability and safety [27].

The development of biofuel technology for commercial aviation has made extraordinary advances in the last eight years. On February 23, 2008, a Virgin Atlantic B747/400 with General Electric CF6-80C2 engines became the first commercial aircraft in making a flight with a mix of 80% conventional kerosene and 20% first generation biofuel, produced from coconut oil and seeds of babassu palm tree. Since then, more than fifteen airlines have tested the operational possibilities of different aviation biofuels with satisfactory results from the technical point of view. The current testing in May 2016, was by Cathay Pacific using Airbus 350 with the mix of 10% blend fuel by Farnasene. Details world map on biojet fuel test in three different continental can be seen on Figure 7 below. Details summary on biojet fuel flight test in Asia Pasific region since 2008 until the year of 2016 can be seen in Table 3.



Figure 6. ASTM D4054- Drop in alternative fuel with unchanged operating limitation (Source: ASTM)

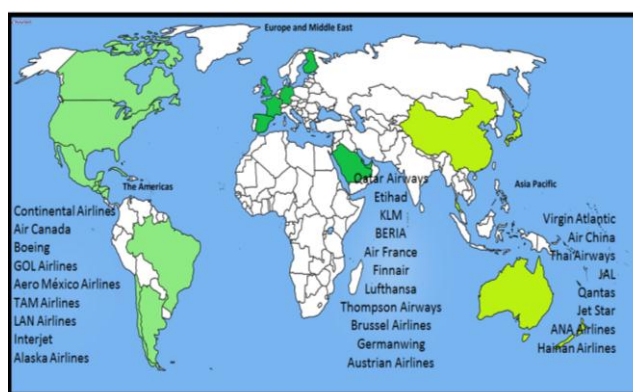


Figure 7. Biojet fuel flight test and scheduled flight according to the region

Table 3. A summary of biofuel tests performed on commercial flights in Asia Pacific

CARRIER	AIRCRAFT	PARTNERS	DATE	BIO-FUEL	BLEND	DESTINATION
Virgin Atlantic	B747-400	Boeing, GE Aviation	23.02.2008	Coconut Babassu	20% one engine	Amsterdam-London
Air New Zealand	B747-400	Boeing, Roll Royce	30.12.2008	Jatropha	50% one engine	Two-hour flight test
JAL	B 747-300	Boeing, P&W, Honeywell UOP	30.01.2009	Camelina, Jatropha, Algae blend	50% one engine	Demo flight
Air China (CA)	B747-400	Boeing, Petro China, Honeywell UOP	June 2011	Jatropha	50% of one engine	Test Beijing airspace
Thai Airways TG	B777-200	Rolls Royce, Boeing, SkyNRG	21.12.2011	Castor seed	One engine	Bangkok-Chiang Mai
Qantas	A330	Airbus	April 2012	Cooking Oil	50%	Sydney-Adelaide
ANA	B737 Dream-liner	Boeing	April 2012	Cooking Oil	10% blend	Evertt's Paine Field (KPAE) to Haneda Airport (HND)
Jetstar	A320	Airbus	April 2013	Cooking Oil	50% Blend	Melbourne - Hobart
Hainan Airlines	737-800	Boeing	March 2015	Cooking Oil	50% Blend	Shanghai to Beijing
Cathay Pacific	A350 -900	Airbus/ Amyris-Total	May 2016	Farnesane	10% Blend	Toulouse to Hong Kong

9. Conclusions

Biofuels developments in an advance generation are a crucial evaluation in ensuring the sustainability of the aviation industries. Detailed information on the adaptation and adoption towards biojet fuel in the turbine aircraft fuel system suggests that viability of all the process regarding minimising the costing, especially in reducing the maintenance and operating costs. The reliability and maintainability will be the key factors for the success of deployment of commercialization of biojet fuel for aviation industries, especially in commercial aviation. The urgencies, risks, and opportunities of this new alternative energy need to be broadened in various aspects for sustainability to reach and achieve its destination. Maintainability in the aircraft system, on the other hand, measures the right direction in supporting the quest to meet high sustainability goals by implementing biojet fuel. Moreover, biofuels may provide valuable economic opportunities to communities that can develop new sources of income – including in many developing nations.

9.1. Maintenance view

A direct impact of the maintenance program of this new alternative energy can easily be focused on economics cost benefit. As long as the price of petroleum remains high, the fossil source continues to be sufficient, the concerns about the environment persist, and then the interest in alternative jet fuels derived from non-petroleum sources will continue to grow. Despite the presence of technical hurdles and the growing necessity for further measurement and study on the costs and benefits, alternative jet fuels appear to be both technically and economically feasible in engine maintenance system because considerable momentum and coordinated work have resulted in recent years.

Most of the turbine maintenance is driven by the highest temperature against the average temperature which the parts is subjected. If the biojet fuel can improve and provide uniformly burnt in the combustor section, the engine will last longer on the wing, and it is proving to have an immense maintenance cost benefit. The fuel producers and fuel researchers need to ensure that the new fuel complies with the material to the standard of engine hot sections. Throughout many biofuel flight tests being conducted since 2008, most of the engines using biofuel have more optimum temperature compared to engines that used normal fuel. With this evaluation, it is acknowledged that in the long run, without a doubt, the use of biofuel will offer the benefit to the maintenance. With the reduction of fuel consumption and the specific requirements meet, prevention maintenance can safely be attained, and the components can reach beyond standard life hours/cycle or even more. Above all, maintenance department will be able to allow the operator or airlines to identify whether using biojet fuel is beneficial and sensible in term of overall operating cost.

9.2. Sustainability of biojet fuel

The economic analysis in identifying the incentive and mechanism in understanding further the implication in biojet fuel usage will be vital. Subsidies, on the other hand, are forms of government financial support for activities believed to be environmentally friendly. Rather than charging a polluter for emissions, a subsidy rewards a polluter for reducing emissions [28]. Although knowledge of biojet fuel is considered a necessity for sound decision making in aviation, the airlines company and the aviation authority needs to reset the action in taking this new alternative energy to the next level to create the sustainable growth. The value required to interconnect increasingly with various departments of the airline, the organizational strategy, structure, systems, final results and feedback (increasing or decreasing the cost). The global aviation world need to be underpinned by the awareness of the good effect of the usage of biofuel on engine process and procedure. In fact, the support by the policy and regulatory framework also is recognised as a pre requisite for a successful biojet fuel implementation across the globe.

Referring to the previous study on biojet fuel in in other research streams, there is a white space in the aviation biojet fuels that looks into economic perspectives through the use of biojet fuel in aviation, which needs further attention. Future research should look into how, when and by whom activities to strengthen the importance of biojet fuel for aviation sustainability in the future. This study ideally shall enable us to create new theoretical insights of the usage of biojet fuel and extend the knowledge of its effect on aircraft engine maintenance which is infrequently explored.

Acknowledgments

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