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# Sustainable Energy in Aviation with Reverse FMEA Analyses

N. G. E. AL-AGHBARI[1], JÓZSEF MENYHÁRT[2]

[1,2]University of Debrecen, Faculty of Engineering, Department of Vehicles Engineering. Hungary.
[1]nader_alaghbary@hotmail.com; [2]jozsef.menyhart@eng.unideb.hu (corresponding author)

*Abstract. This research aims to identify and evaluate the key challenges and obstacles hindering the adoption of sustainable energy in the aviation industry. The outcomes and insights derived from this research will be synthesized to provide a comprehensive overview of the opportunities and suggestions for the adoption of sustainable energy in the aviation industry. The objective of this study is to help the aviation industry's shift toward more sustainable energy sources in order to reduce its environmental footprint and mitigate the effects of climate change.*

*Keywords: Sustainable Energy, SAF, Fully Electric Airplanes, Hydrogen Fuel, Biofuel, Hybrid Airplanes, Synthetic Fuel, GHG Emissions, $CO_2$ Emissions*

## Introduction

The energy sector holds a pivotal role in modern life with a growing inclination towards the use of sustainable energy sources like wind, solar, and thermal energy. The aviation industry, being a significant emitter of greenhouse gases and a contributor to climate change, necessitates the exploration of alternative energy sources that are environmentally cleaner and more sustainable. This study aims to conduct a reverse Failure Mode and Effects Analysis (FMEA) to identify and analyze the challenges and barriers linked to the adoption of sustainable energy technologies in the aviation sector. It will also aim to evaluate the potential of Sustainable Aviation Fuels (SAFs) and electrification in contributing to sustainable energy generation within aviation industry, identify relevant stakeholders and their efforts in advancing sustainable energy, and provide recommendations to facilitate the adoption of sustainable energy in the aviation industry.

The challenges and opportunities confronting the aviation industry in the adoption of sustainable energy technologies are complex and diverse. However, with the right approach and support, the industry holds the potential to make significant progress in reducing its dependence on fossil fuels, thereby contributing to a more sustainable future.

## 1. Literature Review

### 1.1. Sustainable Energy

In the context of sustainable energy, it is crucial to distinguish between sustainable and renewable energy. Sustainable energy refers to energy that can fulfill current demand without compromising the

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ability of future generations to meet their own needs. Biofuel stands out as a unique form of renewable energy due to its combustion producing climate-altering greenhouse gases and its production depletes other natural resources. Nevertheless, biofuel remains a significant component of the sustainable energy revolution. The challenge in the case of biofuel lies in maximizing energy production while minimizing the environmental impact of biomass acquisition and fuel combustion. In a broader perspective, nuclear power can also be considered sustainable as long as it endures for future generations. A more stringent definition includes only energy sources expected to last within a relevant human lifespan, aligning with the primary focus of this paper. [1]

| Renewable energy ... | Sustainable energy ... |
|---|---|
| • Comes from sources that naturally renew themselves at a rate that allows us to meet our energy needs<br>• Includes biomass, geothermal, hydropower, solar and wind<br>• Not all renewable energy is also sustainable, but improving the sustainability of renewables and fossil fuels can have environmental benefits | • Comes from sources that can fulfill our current energy needs without compromising future generations<br>• Also involves collection and distribution; the energy must be efficiently acquired and distributed in order to be sustainable<br>• Includes geothermal, hydropower, solar and wind. |

*Figure 1. Difference between renewable and sustainable energy [2]*

## 1.2. Reverse FMEA Analyses

Failure Mode and Effects Analysis (FMEA) is a methodology employed to identify and evaluate potential failure modes, primary during the design phase of a product or system prior to its deployment. The primary goal of FMEA is to identify and mitigate potential failure modes and their consequences in order to improve the reliability and safety of the product or system and to reduce the risk of costly failures or accidents. Reverse FMEA, also known as Current Product FMEA, is a variation of FMEA used for recognizing and assessing potential failure modes in existing products or systems already in operation. The aim of Reverse FMEA is to identify and address potential failure modes to improve reliability and safety. Both FMEA and Reverse FMEA stand as valuable tools for identifying and addressing potential failure modes overall reliability and safety. [3]

Reverse FMEA is extensively applied in the automotive sector. Unlike the conventional top-down approach of FMEA, Reverse FMEA is a bottom-up validation process. There is no standardized format or methodology for Reverse FMEA. Its preparation may vary according to different customer requirements and manufacturing or operational technologies. [4] [5]

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## 1.3. Technologies Used for Sustainable Energy

Various technologies are currently under development or in use for generating sustainable energy in the aviation industry. These technologies include:

- Biofuels, produced from various carbon-based feedstocks, including plant materials, represent a renewable energy source. Biofuels have the potential to reduce greenhouse gas (GHG) emissions in comparison to conventional fossil fuels, because the carbon dioxide released during combustion is recently absorbed by the plants used for biofuel production. There are two main types of biofuels: primary biofuels, usable without additional processing, and secondary biofuels, requiring mixing with traditional fuels or modification for internal combustion engines. Biofuels are categorized into three generations based on feedstocks and production technologies. Despite some environmental impacts such as emissions during production and changes in land use, biofuels have the potential to achieve an up to 80% reduction in GHG emissions compared to traditional fossil fuels. [6][7]
- Synthetic fuels, categorized as fourth-generation biofuels, are a type of renewable energy source produced from power, water, and carbon dioxide. [8] Synthetic fuels can be generated through solar power, known as solar-to-liquids (STL fuels), or other forms of power, referred to as power-to-liquids (PTL fuels). The production process involves electrolysis to convert renewable power and water into hydrogen, which is then used to synthesize hydrocarbons through a reaction with carbon dioxide or carbon monoxide. Synthetic fuels have the potential to be less polluting compared to fossil fuels due to their combustion and lower levels of heavy metals and sulfur pollutants. The competitiveness of synthetic fuels depends on factors such as solar conversion efficiency and the availability of a sustained supply of $CO_2$. [9]
- Using hydrogen as a fuel, whether in a fuel cell or as a motor fuel, represents another technology with the potential to substitute traditional fossil fuels in the aviation industry. When used in an internal combustion engine, hydrogen generates solely water vapor and nitrogen oxides, without producing carbon dioxide. Hydrogen can be produced akin to the electrolysis of water, involving the synthesis of hydrogen from renewable power, water, and carbon dioxide or carbon monoxide. Fuel cells, which use hydrogen and oxygen to generate electricity and water, are a promising alternative to internal combustion engines due to their enhanced efficiency, flexibility and lower environmental impact. However, there are challenges to the widespread adoption of hydrogen fuel and fuel cells, including the need for new infrastructure and the requirement for precise storage and handling conditions for the fuel. [10]
- The development of hydrogen-driven aircraft and helicopters is of paramount importance. Some studies have shown that CO2 emissions can be reduced by up to 50%. [11] [12] However, a notable challenge lies in the fact that hydrogen has a much lower energy density than conventional fuels, necessitating increased hydrogen storage capacity onboard aircraft. [13] [14] Developments indicate that the first test flights could commence as early as 2028. Current research and development show that hydrogen propulsion can be used for short, medium and regional flights. Nevertheless, for longer distances, conventional hydrocarbon fuels remain the most suitable. [15] However, research is also underway to develop long-range aircraft powered by hydrogen. [16] [17]

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- Hydrogen is increasingly recognized as a crucial aviation fuel for the future, despite safety concerns stemming from historical incidents such as the Hindenburg disaster. Today's hydrogen-powered vehicles undergo rigorous safety assessments prior to deployment. On board aircraft, hydrogen tanks include continuous monitoring for temperature, pressure, leaks, etc. Unlike conventional fuels, hydrogen has a higher self-ignition temperature, mitigating risks like ignition from sources such as cigarettes for example. With right safety protocols in place, hydrogen-powered aircraft can achieve safety standards comparable to those of traditional aircraft. [16] [18] [19] [20]
- The use of electricity to power aircraft is not a new concept, the first electric aircraft dates back to the late 19th century. There are two main types of electric aircraft: hybrid electric aircraft, using a combination of an internal combustion engine and an electric propulsion system, and fully electric aircraft, exclusively powered by electricity stored in a battery. While a fully electric aircraft holds the potential to reduce fuel consumption, pollution and noise compared to traditional aircrafts, there are still technological challenges related to battery storage and energy density that need to be addressed. Renewable energy sources, including wind, solar, and hydroelectric power, can contribute to generating the electricity required to power electric aircraft. It is imperative, however, to minimize the reliance on hydrocarbons or other fossil fuels when possible in order to maintain the sustainability of the technology. [21]

# 2. Reverse FMEA Analyses of the Challenges of Adopting Sustainable Energy Option (SAFs & Electrification) in Aviation

Reverse FMEA is a proactive risk management tool integral for identifying and prioritizing potential challenges associated with the adoption of sustainable energy options in the aviation industry. The implementation of Reverse FMEA involves several steps, each to be executed accordingly.

## 2.1. Identification of the System

The system being analyzed:

- the aircraft themselves and their relevant systems and components,
- the fuel supply chain,
- maintenance processes,
- regularity requirements,
- other stakeholders such as airlines, aircraft manufacturers, and airports.

## 2.2. Identification of the Potential Failure Modes

In this section failure modes hindering the adoption of sustainable energy options are identified:

- Aircraft engine or system failures resulting from SAFs or electrification: This failure mode occurs when SAFs or electrified aircraft systems prove incompatible with the existing systems of the aircraft, posing a risk of system failure.

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- Failures in fuel supply chain: This failure mode arises from disruptions in the supply chain of SAFs or electrification due to shortages or contamination caused by improper management of production, storage, transportation or distribution.
- Maintenance failures: This failure mode occurs when maintenance personnel lacks proper training or certification to work on aircraft powered by SAFs or electrification. This inadequacy may result in incorrect repairs or maintenance procedures causing additional failures or safety risks.
- Technical failures: This failure mode occurs when the technologies involved in the use of SAFs or electrification are not reliable or fail to perform as expected, causing failures in the overall system.
- Regulatory failures: This failure mode occurs when regulatory requirements related to the adoption of SAFs and electrification are not adequately followed, leading to non-compliance or other issues.
- Stakeholder failures: This failure mode occurs when key stakeholders such as airlines, aircraft manufacturers, or airports are not prepared or equipped to adopt SAFs or electrification, causing disruptions in the system.
- Public acceptance failures: This failure mode occurs when there is a lack of awareness or understanding among stakeholders or the general public regarding the benefits and importance of SAFs or electrification, leading to a reluctance to adopt these options.

## 2.3. The Potential Effects of each Failure Mode

In reverse FMEA the potential effects of potential failure modes are evaluated to prioritize them and develop preventive measures to mitigate the risk of those failure modes.

- Failure of aircraft engines or other systems may include engine or system failure, increased operating costs, and the risk of accidents or incidents. These failures can lead to costly repairs or replacements, reduced efficiency or productivity for the airline, and potentially even injury or fatality, as well as damage to the aircraft and other property.
- Fuel supply failure may include fuel shortages, fuel contamination and increased operating costs. These failures can disrupt flight schedules, reduce the efficiency or performance of the aircraft, and result in additional costs.
- Maintenance failures may lead to delays, increased operating costs, and risk of accidents or incidents. These failures may disrupt flight schedules, contribute to additional costs, and pose safety risk.
- Technical failures may result in reduced performance or efficiency, maintenance challenges, and an elevated risk of accidents or incidents. These failures can lead to increased operating costs, disruptions to flight schedules, and potential injuries or fatalities, as well as damage to the aircraft and other property.
- Regulatory failures in the adoption of sustainable aviation fuels and electrification may result in non-compliance with regulations, fines, and damage to reputation, leading to reduced demand and

potential financial losses. It is important to follow regulatory requirements to avoid these consequences.

- Stakeholder failures in the adoption of SAFs or electrification can lead to disruptions in flight schedules, increased operating costs, and the risk of accidents or incidents. These may result in delays or cancellations, reduced efficiency or productivity for the airline, and pose safety.
- Public acceptance failure in the use of sustainable aviation fuels (SAFs) or electrification in the aviation industry could result in reduced demand and revenue for airlines, lack of funding and support for necessary infrastructure, and damage to the reputation and financial losses for airlines and other stakeholders.

## 2.4. The Likelihood and Severity Ratings to each Failure Mode

The FMEA spreadsheet was collaboratively developed with the active participation of student pilots, involving 9 pilot students. The content of the table reflects the experience gained during the student pilots' studies and flight operations.

When determining likelihood and severity ratings for each failure mode, various factors were taken into account. These factors include the probability of the failure occurring, the potential impact of the failure on safety, operations, and other stakeholders, as well as the potential for the failure to be mitigated or avoided. The rating scale ranges from 1 (least likely/least severe) to 10 (most likely /most severe).

| | **Likelihood** | **Severity** |
|---|---|---|
| **Failure of aircraft engines or other systems** | 8 | 9 |
| **Fuel supply chain failures** | 6 | 8 |
| **Maintenance failures** | 5 | 7 |
| **Technical failures** | 7 | 8 |
| **Regulatory failures** | 3 | 6 |
| **Stakeholder failures** | 4 | 8 |
| **Public acceptance failures** | 6 | 5 |

*Table 1. The likelihood of each failure mode in Pareto chart*

## 2.5. The Risk Priority Number (RPN) for each Failure Mode and Prioritization

The Risk Priority Number (RPN) is a score used in FMEA to evaluate the potential risks associated with a particular failure mode. It is calculated by multiplying the likelihood of the failure, the potential severity of the consequences in case of failure, and the likelihood of detecting the failure before it causes harm. The RPN is used to prioritize failure modes and guide the selection of suitable risk mitigation measures where the failure modes with the highest RPNs should be addressed as a priority (Table 2.).

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| | Likelihood | Severity | RPN |
|---|---|---|---|
| **Failure of aircraft engines or other systems** | 8 | 9 | 72 |
| **Fuel supply chain failures** | 6 | 8 | 48 |
| **Maintenance failures** | 5 | 7 | 35 |
| **Technical failures** | 7 | 8 | 56 |
| **Regulatory failures** | 3 | 6 | 18 |
| **Stakeholder failures** | 4 | 8 | 32 |
| **Public acceptance failures** | 6 | 5 | 30 |

*Table2. The like hood of each failure mode in Pareto chart*

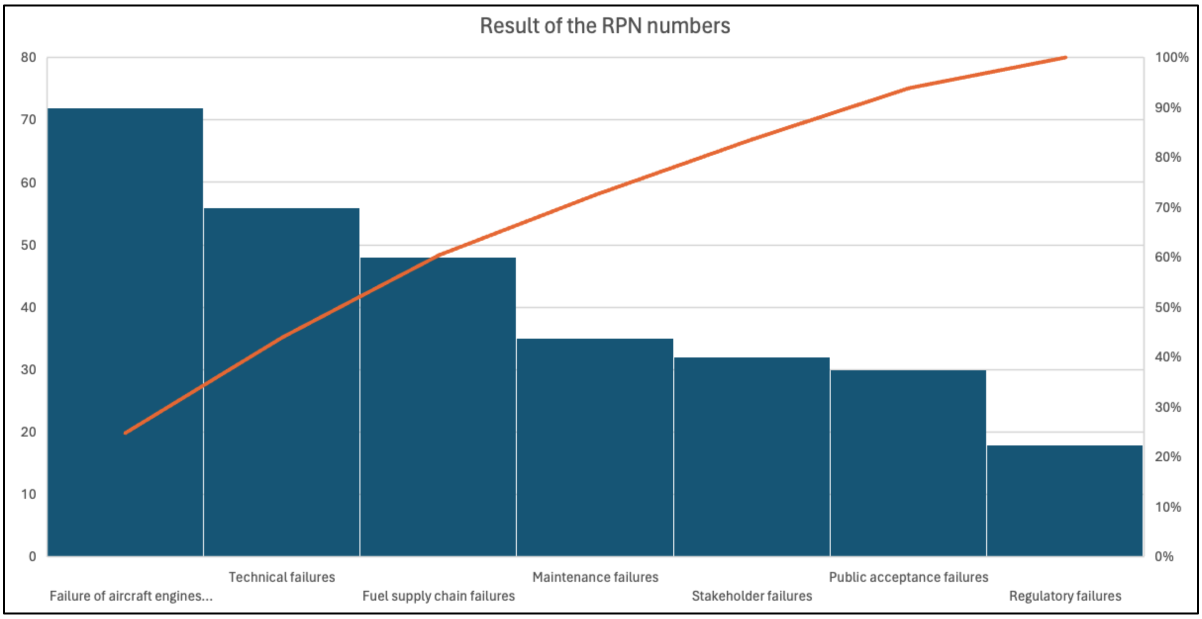


*Figure 2. The Risk Priority Numbers in Pareto chart*

## 2.6. Identification of Controls or Design Changes

The objective is to identify potential failure modes and their associated effects in order to prevent them from occurring. To accomplish this, controls or design changes are identified and implemented to eliminate or mitigate the risk of failure.

- Failure of aircraft engines or other systems: Design changes for aircraft manufacturers and suppliers should include ensuring that components and systems used in SAFs and electrified aircraft meet safety standards, including materials resistance and adherence to proper installation and maintenance procedures. Controls for operators should involve the implementation of a comprehensive maintenance plan, proper personnel training and obtain certifications. Establishing a secure and reliable fuel supply chain with proper storage and handling procedures is imperative. Additionally, necessary infrastructure and safety protocols should be in place for handling and storing SAFs.

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- Technical failures: Designing systems to be compatible with a wide range of SAFs and electrified propulsion systems, developing testing and maintenance procedures, providing training for maintenance personnel, and developing safety systems to detect and mitigate any potential risks.
- Fuel supply chain failures: Establishing a network of reliable suppliers, adopting quality assurance measures, setting up adequate infrastructure, tracking and monitoring fuel supply and usage, implementing a regular maintenance schedule, providing safety protocols and procedures, along with educational material and training programs for personnel involved in the fuel supply chain.
- Maintenance failures: Actions include implementing proper training and certification for maintenance personnel, establishing standard procedures, quality control, safety checks, using simulation, testing, research and development to improve safety and reliability.
- Stakeholder failure: Mitigating stakeholder failure involves implementing standards and guidelines, providing incentives, education and training, establishing infrastructure, partnerships, certifications, and enforcing regulations for the proper use of SAFs and electrification in aviation.
- Public acceptance failures: Mitigating public acceptance failure includes actions such as education and outreach, public engagement, regulatory changes, oversight, and industry collaboration to increase public understanding and support for SAFs and electrification.
- Regulatory failures: Mitigation of regulatory failures includes establishing a comprehensive framework with clear guidelines for safety, certification and operational requirements, clear information and training for industry stakeholders, certification process, oversight, tracking and monitoring of the use of SAFs and electrification.

## 2.7. Implementation of the Controls or Design Changes and Verify their Effectiveness

To implement and verify the effectiveness of the controls and design changes for SAFs and electrification in aviation, a comprehensive plan should be established, including the following step:

- Develop a timeline for implementation, including necessary steps and resources.
- Create a testing and evaluation process for the controls and design changes to ensure they meet safety, performance, and reliability requirements.
- Develop a system for tracking and monitoring the implementation, and addressing any issues that arise promptly.
- Develop a system for verifying the effectiveness of the controls and design changes through regular evaluations.
- Create a system for reporting and documenting the results of the implementation process, including any issues and the corresponding resolutions.

Implementation should be done in stages, with an emphasis on strengthening existing infrastructure and processes such as training, certification, safety protocols and procedures. Measurements should be

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taken at each stage to verify effectiveness and monitored over time. Regular inspections and audits should be conducted to ensure compliance with regulations and guidelines related to the use of SAFs and electrification.

### 2.8. Update of Reverse FMEA

- Conduct a periodic update of the Reverse FMEA to account for any changes in the system or process under analysis.
- Assess potential risk factors associated with new technologies or industry priorities.
- Review existing Reverse FMEA to identify potential areas of concern and new risks.
- Evaluate existing controls and design changes and make necessary adjustments to address emerging risks.
- Review the results of tests and evaluations to ensure they meet safety, performance, and reliability requirements.
- Develop a plan to address new risks identified during review and implement it.
- Establish a system for regular reviews and updates of the Reverse FMEA to promptly address any changes in the system or process.

## 3. Opportunities and Recommendations

### 3.1. Production Economics

The production economics of sustainable aviation fuels (SAF) is a crucial factor in their adoption by the aviation industry. Various methods, including Fischer Tropsch, electrolysis, bacterial conversion, and solar-to-fuels, are employed in SAF production, each presenting its unique challenges that needs to be addressed. For SAF to compete with traditional jet fuel, it must be produced at a similar or lower cost. Improving the efficiency of production processes, scaling up production, and reducing the cost of feedstocks can all contribute to reducing the production cost of SAF and making it more competitive with fossil-derived jet fuel. [22]

### 3.2. Public Awareness

It is crucial to transparently communicate the challenges and limitations of transitioning to SAF, including the current cost and availability of SAF in comparison to traditional fossil fuels, as well as the required infrastructure and logistics for widespread SAF adoption. By providing this information to stakeholders, the aviation industry can work to build support and understanding for the transition to more sustainable energy sources. It is also important to engage with and listen to the concerns and suggestions of stakeholders in order to overcome any barriers to SAF adoption and to find the most effective solutions for the transitioning to a more sustainable aviation sector. [23]

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## 3.3. Industrial Partnership

Another way to increase the adoption of SAF is through partnerships with airlines and aircraft manufacturers. These companies have a significant interest in reducing their carbon emissions and can play a key role in driving the demand for SAF. Through collaborations with these companies, SAF producers can secure long-term contracts and establish a reliable market for their products. Additionally, these partnerships can help to bring attention to the benefits of SAF and encourage other companies in the aviation industry to adopt it. [24]

## 3.4. Policies

Governments have various policy instruments at their disposal to incentivize the adoption of sustainable energy in the aviation industry through policy. One way is through carbon pricing, involving placing a monetary value on carbon emissions in order to encourage people to consider the social costs of using fossil fuels and to encourage investment in low-carbon or neutral-carbon sectors. Carbon pricing can manifest as carbon taxes or emissions trading systems. Another way that governments can incentivize the adoption of sustainable energy in aviation is through sales mandates, which require energy suppliers to ensure that a certain percentage of the energy they offer is sourced from renewable or low-impact sources. Governments can also provide subsidies for the production or use of sustainable aviation fuel (SAF) and can implement renewable portfolio standards that require a certain percentage of energy to come from renewable sources. Regulatory measures, such as fuel efficiency standards for aircraft or limits on carbon emissions contribute to fostering sustainable energy adoption in aviation. Finally, governments can also support research and development of new technologies in the sustainable energy sector to reduce cost and improve the performance of SAF. [25]

# 4. Interference and Conclusion

Sustainable aviation fuel (SAF) is currently the most viable option for reducing emissions in the aviation industry due to the unavailability of commercial battery and hydrogen fuel cell technology. While biofuels and synthetic fuels are being considered as short-term alternatives, they pose environmental concerns and entail higher production costs. Hydrogen, considered a medium-term option, is a feasible choice, but requires modifications to current aircraft designs and raises issues related to flammability and efficiency. In the long term, electric, hybrid, and fuel cell airplanes are anticipated to become commercially viable and could be a breakthrough for the industry, but their implementation is currently limited by technological and infrastructure challenges.

The aviation industry is seeking to embrace sustainable energy sources to mitigate its impact on climate change and reduce dependency on fossil fuels. Viable options for sustainable energy in the aviation industry include sustainable aviation fuels, biofuels, synthetic fuels, hydrogen and electricity. Each of these options come with their own unique challenges related to production, delivery and storage, but has the potential for achieving carbon neutrality. To increase the adoption of sustainable energy in the aviation industry, the sector can invest in research and development, collaborate with governments to establish standards and regulations, and engage with the public to support these technologies. Policy levers such as subsidies and carbon pricing can also be implemented to encourage the adoption of sustainable energy.

# References

[1] Henshaw, P, "Sustainable Energy: What, Why, and How?" In: Vasel, A., Ting, DK. (eds) *Advances in Sustainable Energy. Lecture Notes in Energy*, vol 70. Springer, pp1-5

[2] Hu-Chen Liu, Long Liu, Nan Liu, ˇ" Risk evaluation approaches in failure mode and effects analysis: A literature review", *Expert Systems with Applications*, Vol 40, Issue 2,2013

[3] Nadir Yilmaz, Alpaslan Atmanli, "Sustainable alternative fuels in aviation", *Energy*, Vol 140, Part 2, 2017,pp 1378-1386,

[4] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," *IEEE Transl. J. Magn. Japan*, vol. 2, pp. 740-741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 198

[5] Doliente, S. S., Narayan, A., Tapia, J. F. D., Samsatli, N. J., Zhao, Y., Samsatli, S., 2020. Bio-aviation Fuel: A Comprehensive Review and Analysis of the Supply Chain Components, *Frontiers in Energy Research*, Volume 8, DOI: 10.3389/fenrg.2020.00110

[6] Judith L Walls, Andreas Wittmer "*Sustainable Aviation – A Management Perspective*", Switzerland AG 2022

[7] Ahmad Baroutaji, Tabbi Wilberforce, Mohamad Ramadan, Abdul Ghani Olabi,"Comprehensive investigation on hydrogen and fuel cell technology in the aviation and aerospace sectors", *Renewable and Sustainable Energy Reviews*, Vol 106, 2019, pp 31-40

[8] Poonam Tripathy (2020);" Overview On Electric Propulsion Systems"; *International Journal of Scientific and Research Publications (IJSRP)* 10(12), p10846

[9] The Royal Society, "*Policy briefing Sustainable synthetic carbon-based fuels*" 2017, ISBN: 978-1-78252-422-9, https://royalsociety.org/-/media/policy/projects/synthetic-fuels/syntheticfuels-briefing.pdf, (Downloaded : 2022.12.20. 15:15)

[10] Sustainable Aviation Biofuels Work Group November 2020 Final Report,

[11] USDOE Office of Energy Efficiency and Renewable Energy technical report 2017 , "*Alternative Aviation Fuels: Overview of Challenges, Opportunities, and Next Steps*" ,doi:10.2172/1358063

[12] Stephen Naimoli, "Deep Decarbonization Pathways", CSIS Report 2020

[13] "*Renewable Energy vs Sustainable Energy: What's the Difference?",* https://energy.sais.jhu.edu/articles/renewable-energy-vs-sustainable-energy/ (Date of download: 2022.12.15. 10:25)

[14] Airbus: Hydrogen, *An important decarbonisation pathway*, https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen (Date of download: 2024.03.25. 16:09)

*DOI: 10.21791/IJEMS.2024.012*


[15] IEA 50: *Hydrogen*, https://www.iea.org/energy-system/low-emission-fuels/hydrogen (Downloaded: 2024.03.25. 16:14)

[16] EASE Light: *Hydrogen and its potential in aviation*, https://www.easa.europa.eu/en/light/topics/hydrogen-and-its-potential-aviation (Downloaded: 2024.03.25. 16:14)

[17] University of Michigan, *Center for Sustainable Systems: Hydrogen Factsheet*, https://css.umich.edu/publications/factsheets/energy/hydrogen-factsheet (Downloaded: 2024.03.25. 16:27)

[18] Clean Aviation: *Hydrogen-powered aviation*, https://www.clean-aviation.eu/hydrogen-powered-aviation (Downloaded: 2024.03.25. 16:44)

[19] Talal Yusaf, Abu Shadate Faisal Mahamude, Kumaran Kadirgama, Devarajan Ramasamy, Kaniz Farhana, Hayder A. Dhahad, ABD Rahim Abu Talib: Sustainable hydrogen energy in aviation – A narrative review, *International Journal of Hydrogen Energy*, Volume 52, Part C, 2024, Pages 1026-1045, ISSN 0360-3199, https://doi.org/10.1016/j.ijhydene.2023.02.086.

[20] Honeywell – Aerospace Technologies: *Honeywell Explores Future Of Hydrogen-Powered Aircraft*, https://aerospace.honeywell.com/us/en/about-us/blogs/honeywell-explores-future-of-hydrogen-powered-aircraft?utm_source=google&utm_medium=cpc&utm_campaign=23-aero-ww-dsa-blogs&utm_content=dyn-en-lp&gad_source=1&gclid=Cj0KCQjwwYSwBhDcARIsAOyL0fiyBj2tbMFIo10DsVpQ819zSoRJhl02lZsy38CDqCii8CC1277HKAkaApI2EALw_wcB (Downloaded: 2024.03.25. 16:47)

[21] Hydrogen Safety: *Hydrogen's intrinsic properties make it safer than jet fuel*, https://hydrogen.aero/hydrogen-safety/ (Downloaded: 2024.03.25. 17:38)

[22] Simple Flying: How Hydrogen Compares To Jet Fuel In *Terms Of Safety*, https://simpleflying.com/hydrogen-vs-jet-fuel-safety-comparison/ (Downloaded: 2024.03.25. 17:43)

[23] Science and Tech: *Hindenburg – German airship*, https://www.britannica.com/topic/Hindenburg, (Downloaded: 2024.03.25. 17:49)

[24] Plexus International: *What is Reverse FMEA*, https://plexusintl.com/us/blog/what-is-reverse-fmea/ (Downloaded: 2024.03.25. 17:58)

[25] AuditComply: *Reverse FMEA, a Big Revolution for Automotive*, https://www.auditcomply.com/2020/02/13/reverse-fmea-a-big-revolution-for-automotive/, (Downloaded: 2024.03.25. 17:58)


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