МІНІСТЕРСТВО ОСВІТИ І НАУКИ УКРАЇНИ

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

КАФЕДРА КОНСТРУКЦІЇ ЛІТАЛЬНИХ АПАРАТІВ

ДОПУСТИТИ ДО ЗАХИСТУ
Завідувач кафедри
д.т.н, професор
________ Сергій ІГНАТОВИЧ
«__» _________ 2022 р.

КВАЛІФІКАЦІЙНА РОБОТА
ВИПУСКНИКА ОСВІТНЬОГО СТУПЕНЯ МАГІСТРА
ЗІ СПЕЦІАЛЬНОСТІ
«АВІАЦІЙНА ТА РАКЕТНО-КОСМІЧНА ТЕХНІКА»

Тема: «Утилізація та переробка електричних літальних апаратів та їх обладнання»

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Київ 2022

MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE

NATIONAL AVIATION UNIVERSITY

DEPARTMENT OF AIRCRAFT DESIGN

PERMISSION TO DEFEND
The head of the Department
Dr. of .Sc., professor
______ Serhiy IGNATOVICH
"___" ___________ 2022

MASTER DEGREE THESIS
ON SPECIALITY
"AVIATION AND SPACE ROCKET TECHNOLOGY"

Topic: "Disposal and recycling electric aircraft and its equipment"

Fulfilled by:	____________	**Ali TURABI**
Supervisor: **Ph.D., associate professor**	____________	**Vadim ZAKIEV**
Labor protection advisor: **PhD, associate professor**	____________	**Katerina KAZHAN**
Environmental protection adviser: **PhD, professor**	____________	**Lesya PAVLYUKH**
Standards inspector: **PhD, associate professor**	____________	**Volodymyr KRASNOPOLSKYI**

Kyiv 2022

НАЦІОНАЛЬНИЙ АВІАЦІЙНИЙ УНІВЕРСИТЕТ

Факультет аерокосмічний

Кафедра конструкції літальних апаратів

Освітній ступінь «Магістр»

Спеціальність 134 «Авіаційна та ракетно-космічна техніка»

Освітньо-професійна програма «Обладнання повітряних суден»

ЗАТВЕРДЖУЮ
Завідувач кафедри, д.т.н., проф.
_______ Сергій ІГНАТОВИЧ
«___» ___________ 2022 р.

ЗАВДАННЯ

на виконання дипломної роботи студента

Алі ТУРАБІ

1. Тема роботи **«**Утилізація та переробка електричних літальних апаратів та їх обладнання**»**, затверджена наказом ректора від 05 жовтня 2022 року №1861/ст.

2. Термін виконання проекту: з 06 жовтня 2022р. по 30 Листопад 2022 р.

3. Вихідні дані до проекту: Технологічні характеристики сучасних електричних літаків, сучасні методи переробки металів, композитів та шкідливих речовин.

4. Зміст пояснювальної записки: аналіз та пошук перспективних способів переробки компонентів електричних літальних апаратів та їх обладнання; аналіз існуючих методів, а також можливостей впровадження новітніх технологій переробки електричних літальних апаратів та їх обладнання в майбутньому; розробка нової концепції утилізації на основі існуючих та перспективних методів переробки; інтеграція запропонованих процесів у законодавчу базу.

5. Перелік обов’язкового графічного (ілюстративного) матеріалу: презентація Power Point, малюнки та схеми.

6. Календарний план-графік

№ пор.	Завдання	Термін виконання	Відмітка про виконання
1	Огляд літератури за проблематикою роботи. Аналіз способів переробки літаків.	06.10.2022–10.10.2022	
2	Проведення аналізу електрифікації авіаційного ринку.	11.10.2022–15.10.2022	
3	Аналіз концепції існуючих електричних літаків та їх комплектуючих.	16.10.2022–20.10.2022	
4	Проведення дослідження щодо важливості даної проблеми.	21.10.2022–27.10.2022	
5	Виконання розділів, присвячених охороні навколишнього середовища та праці.	28.10.2022–31.10.2022	
6	Збір необхідних матеріалів та написання пояснювальної записки.	01.11.2022–04.11.2022	
7	Перевірка, редагування та виправлення пояснювальної записки та оформлення дипломної роботи.	05.11.2022–10.11.2022	

7. Консультанти з окремих розділів

Розділ	Консультанти	Дата, підпис	
		Завдання видав	Завдання прийняв
Охорона праці	к.т.н., доцент Катерина КАЖАН		
Охорона навколишнього середовища	к.т.н., доцент Леся ПАВЛЮХ		

8. Дата видачі завдання: 5 жовтня 2022 року

Керівник дипломної роботи ____________ Вадим ЗАКІЄВ

Завдання прийняв до виконання ____________ Алі ТУРАБІ

NATIONAL AVIATION UNIVERSITY

Aerospace faculty

Department of aircraft design

Educational Degree «Master»

Specialty 134 «Aviation and space rocket technology»

Educational professional program «Aircraft equipment»

APPROVED BY
Head of Department, Dr. Sc., prof.
________ Sergiy IGNATOVYCH
«___» _________________ 2022

TASK

For the master degree thesis

Ali TURABI

1. Topic: "Disposal and recycling electric aircraft and its equipment", approved by the Rector’s order № 1861 "05" October 2022 year.
2. Period of work execution: from 05 October 2022 year to 30 November 2022 year.
3. Initial data: Technological characteristics of modern electric aircraft, modern methods of processing metals, composites and harmful substances.
4. Content: analysis and search for promising ways to recycle electric aircraft components and their equipment; analysis of existing methods, as well as the possibilities of introducing the latest technologies for recycling electric aircraft and their equipment in the future; development of a new concept of recycling based on existing and promising recycling methods; integration of the proposed processes into the regulatory base.

6. Thesis schedule:

№	Task	Time limits	Done
1	Review of literature on the problems of work. Analysis of ways to recycle aircraft.	06.10.2022–10.10.2022	
2	Analysis of the electrification of the aviation market.	11.10.2022–15.10.2022	
3	Analysis of the concept of existing electric aircraft and their components.	16.10.2022–20.10.2022	
4	Conduct a study on the importance of this problem.	21.10.2022–27.10.2022	
5	Implementation of sections devoted to environmental protection and labor.	28.10.2022–31.10.2022	
6	Collecting the necessary materials and writing an explanatory note.	01.11.2022–04.11.2022	
7	Checking, editing and correcting the explanatory note and designing the thesis.	05.11.2022–10.11.2022	

7. Special chapter advisers

Chapter	Consultants	Date, signature	
		Task Issued	Task Received
Labor protection	Ph.D., associate professor Katerina KAZHAN		
Environmental protection	Ph.D. professor Lesya PAVLYUKH		

8. Date of issue of the task: 8 October 2021 year

Supervisor: ____________ Vadim ZAKIEV

Student: ____________ Ali TURABI

РЕФЕРАТ

Пояснювальна записка кваліфікаційної роботи магістра «Утилізація та переробка електричних літальних апаратів та їх обладнання»

97 с., 23 рис., 2 табл., 34 джерел

Об'єктом дослідження є електричні літальні апарати та їх обладнання.

Предметом дослідження є аналіз та пошук перспективних способів переробки компонентів електричних літальних апаратів та їх обладнання використовуючи сучасні технології та правові основи переробки списаних літаків виробником.

Метою роботи є формування концепції ефективної утилізації та переробки електричних літальних апаратів та їх обладнання.

Методи дослідження та розробки полягають у аналізі існуючих методів, а також можливостей впровадження новітніх та перспективних технологій переробки електричних літальних апаратів та їх обладнання в майбутньому. У роботі використовуються наявні науково-дослідні роботи з переробки металів, композитів, елементи живлення та авіаційних конструкцій.

Практична цінність роботи полягає в розробці нової концепції утилізація та переробка електричних літальних апаратів та їх обладнання на основі перспективних методів та інтеграція запропонованих процесів у законодавчу базу, що дозволить істотно скоротити час переходу на нову модель переробки, та матиме позитивний вплив на екологію.

Матеріали роботи можуть бути використані в авіаційній промисловості та в навчальному процесі для студентів інженерних спеціальностей, а також у сфері переробки та утилізації вживаних електричних літальних апаратів та їх обладнання.

Електричний літальний апарат, обладнання повітряних суден, переробка, утилізація, літій-іонний акумулятор, електрифікація

ABSTRACT

Master degree thesis "Utilization and recycling electric aircraft and its equipment"

97 pages, 23 figures, 2 table, 34 references

Object of study electrical aircrafts and their equipment.

Subject of study is the analysis and search for promising ways to recycle components of electric aircraft and their equipment using modern technologies and regulatory foundations for the recycling of decommissioned aircraft by the manufacturer.

Aim of master degree thesis is to form the concept of effective utilization and recycling of electric aircrafts and their equipment.

Research and development methods consist of the analysis of existing methods, as well as the possibilities of introducing the latest and promising technologies for the processing of electric aircraft and their equipment in the future. The thesis uses existing research works on the processing of metals, composites, batteries and aircraft structures.

Practical value of the work lies in the development of a new concept of recycling and recycling of electric aircraft and their equipment based on advanced methods and the integration of the proposed processes into the legislative framework, which will significantly reduce the time of transition to a new model of recycling, and will have a positive impact on the environment.

The materials of the master's diploma can be used in the aviation industry and in the educational process for students of engineering specialties, as well as in the field of processing and recycling of used electric aircraft and their equipment.

Electric aircraft, aircraft equipment, recycling, disposal, lithium-ion battery, electrification

CONTENT

BBREVIATIONS

OEM – Original Equipment Manufactures

LC – Life Cycle

AMARG – Aerospace Maintenance and Regeneration Group

IATA – International Air Transport Association

USM – Used Serviceable Material

MRO – Maintenance, Repair and overhaul

IEA – International Energy Agency

ICAO – International Civil Aviation Organization

CORSIA - Carbon Offsetting and Reduction Scheme for International Aviation

ATS – Air Transport System

SAF- Suitable Aviation Fuel

LCSA – Life Cycle Sustainability Assessment

SHDB – Social Hotspot Database

LCIA – Life Cycle Impact Assessment

FRD – Fossil resource Depletion

ALO – Agricultural Land Occupation

LCC – Life Cycle Cost

RoP – Risk of Poverty

FTS – Fischer-Tropics Synthesis

BtL – Biomass to Liquid

PtL – Power to Liquid

MEM – Membrane Electrolysis

PAMELA – Advanced Aircraft End-Of-Life Management Process

AFRA – Aircraft Fleet Recycling Association

CRIAQ – Quebec Consortium for Research and Innovation in Aerospace

INTRODUCTION

Rapid processes of European integration and accepted international environmental standards force everyone aviation companies to intensify their activities to reduce the negative impact on environment. Exacerbation of the global environmental and economic situation related to environmental degradation depletion of natural resources and changes climate on Earth, showed that all states including Ukraine, fundamentally new moves to the internal and external economic policies through which it is possible to form an improved strategy of mutual of society and nature in market conditions economy and thus implement the declared at the United Nations Conference on Environment and Development (Rio 92) and the Paris Agreement November 4, 2016) are world-renowned sustainable development.

According to these principles recently there is a steady global trend in the world introduction of environmentally friendly and energy effective technologies. According to a number of studies, electric transport will not be able to develop until the problem of recycling and disposal of batteries is solved.

The electrification of transport has become a major challenge for all manufactures.

Electric vehicle batteries are starting to become a new environmental problem. From the report published in the journal Nature, it becomes clear that its scale cannot be compared with the CO2 emission problem. The researchers concluded that it is urgent to put the disposal and processing of lithium-ion batteries on stream. And there are several reasons for this.

Today the problem of recycling and recycling components of aircraft their resource is one of the main for the whole aerospace industry. Every year it gets bigger the amount of aerospace technology accumulated- is on various sites, occupying and polluting large areas of land.

Therefore, the question of proper handling aircraft that decommissioned, the implementation of processes recycling and aviation recycling is becoming increasingly niche.

PART 1

THE IMPORTANCE OF RECYCLING DECOMMISSIONED AIRCRAFTS

The environmental awareness is increasing in all fields of life. People increasingly try to avoid environmentally polluting products and services. The government in many countries already passed laws on different fields of the industry, forcing them to acknowledge the whole lifecycle of their products and improve their sustainability. Since the year of 2000 for example, the European automotive industry [1] is directly addressed by the European Directive 2000/53/EC ma-king manufacturers responsible for their products end-of-life. Until now, there is no regulation directly addressing the aircraft end-of-life, which is commonly justified by a small number of retired aircraft. Yet, with a look at forecasts of aircraft manufacturers, this justification will lose its fundament in the coming years. With an expected air traffic growth of at least 4.3 % annually, around 40 000 commercial aircraft deliveries are expected until the year 2038. Boeing expects 56 % of these to accommodate the market growth while the remaining deliveries will replace around 75 % of the current fleet over the next two decades. This leads to an amount of approximately 19 000 commercial aircraft retiring from service during the next 18 years. (Boeing 2019, Airbus S.A.S. 2019 and Embraer 2019)[2] The increasing expectation of a regulation and an increasing civil and market pressure led to a change in the aviation industry where OEMs (Original Equipment Manufacturers) began to consider the aircraft end-of-life already during the design and research on aircraft recycling is being pushed by the industry and academic institutes. The recent years brought up new technologies, processes and a whole new recycling market. To not lose track of it, there is the need for a summarizing update on aircraft end-of-life strategies, the state-of-the-art aircraft recycling and the next generation aircraft models. These new models are built with a high amount of composite materials (> 50 %) to reduce weight and hence, save fuel as well as emissions during operation. Composite materials, nevertheless, are highly challenging to deal with during design, manufacturing and recycling. The topic of composite recycling in context with the aviation industry completes the summarization on the aircraft end-of-life.

1.1 The obsolete aircrafts and its impact on the environment

In recent years, a number of scientific papers have been published examining the effectiveness of recycling programs, as well as the environmental, ethical, economic, technical and technological aspects of the issue.

Winston Porter. German chemist Michael. Braungardt and American economist Michael J. McDonagh have developed economic concepts for the efficiency of recycling and recycling in production from the standpoint of reversible logistics and product life cycle (LC) management [3].

Since the 80's of the twentieth century. The problem of handling aircraft vehicles is growing relevance due to the accumulation of large quantity of written-off aircraft, storage which is associated with additional costs for conservation and lease of space.

At the end of the shelf life potentially dangerous types of aircraft sharply increases the risk of emergencies that complicates the process of further proper treatment of them. In the world market, according to forecasts Airbus, for the period from 2009 to 2028 will be sent for write-off up to 8453 aircraft units.

Based on a Boeing report [4], the potential market for aircraft recycling will be about 6 thousand units. From 1990 to 1999, the average amount was written off it has 170 commercial airliners, according to ICF International. In the following decade, this number has increased to 400 aircraft per year, by 2023, according to forecasts on average 750 planes will be written off annually, in the future - up to 1000. In the US for civilian aircraft, whose term operation has come to an end, the last refuge is the airport "Mojave" (Fig. 1.1), located in the desert eastern part of the US state of California. Airliners have been brought here for several decades and kept in the hot desert until further separation and processing.
The collection of decommissioned fighter jets is located in Arizona at Davis Monte Air Base (Fig. 1.2) (English Davis-Monthan Air Force Base). The landfill is serviced by a 309 support group and restoration of air force equipment (military Air Force) USA (309th Aerospace Maintenance and Regeneration Group (309 AMARG). In addition to combat aircraft units (355 fighter jet) and headquarters (12th US Air Force Command), on the basis of "Davis Monte" is preserved for conservation, probably the largest fleet of aircraft in the world - more than 4400 units, forty spaceships were also stored.

Fig. 1.1 The largest cemetery of commercial aircraft in the United States, airfield in the Mojave Desert (Air and Space Port), California, USA

Fig.1.2. Davis Monte Air Force Base is located within Tucson, Arizona.

So, what does usually happen to an aircraft when the owner decides to not operate it anymore? For a long time, the common practice of handling such an aircraft was to store it on so called airplane scrap yards until further decisions were made. These scrap yards offered enough space at favorable conditions such as the storage price as well as airplane conserving climate conditions (hot and dry). The stored airplanes were kept functional by authorized personnel if the airworthy aircraft was worth more than its parts. The owner would have then either brought it back into service when operating conditions, e.g. the fuel price, were convenient, or sold it, often to countries with laxer regulations. If these methods were economically unprofitable the aircraft was stored unmaintained for an undefined time. Usually valuable parts such as engines, landing gears, avionics and electronic motors were removed carefully to be sold afterwards [5]. The remaining parts of the airplane that could not be removed and sold were disposed by landfill, which meant to simply store them in places where enough space was available. This landfilling led to thousands of aircraft stored, more than four thousand solely at the Aerospace Maintenance and Regeneration Center in Tucson, Arizona, as shown in Figure 1.2.

The process of landfilling combined with poor traceability and disposal conditions of end-of life aircraft incurred the interest on the end-of-life phase of aircraft [6]. According to, there even have been incidents of nonseries disposal of aircraft parts into the sea which caused social outrage. To in turn improve the image of aviation, airlines and manufacturers felt the urge to replace common practices by sustainable methods.

1.2 The airplanes after life

The end-of-life represents the last phase in the lifecycle of a product. The original product has lived its useful life and is now going to be reused, recycled or disposed. The aircraft end-of life, hence, describes processes executed after an aircraft has retired from service. This includes the stowage of the aircraft, as done for many years, and any other process, such as disassembly or recycling around 16,000 commercial passenger and cargo aircraft have been retired worldwide in the past 35 years. Meanwhile, up to 700 jets each year are getting closer to the end of their lifespan. But where do these planes go after retirement?

Unlike cars, the lifespan of an aircraft is not determined by the distance flown during the years of active operations. And, even though age seems like a compelling way to define whether an aircraft remains suitable for flying, it is not the most accurate index. Many major aerospace manufacturers, including Boeing, Airbus, Bombardier, Dassault, Embraer and Gulfstream, usually measure the life expectancy of a plane based on various indicators, including performed takeoff and landing cycles, flight hours, flight frequency and maintenance hours.

For instance, regardless of the actual age of the plane, an Airbus A320 narrow-body aircraft can endure up to 60,000 cycles, while a Boeing 747 wide-body plane performs around 35,000 cycles, or up to 165,000 of flight hours, before its retirement. However, it takes up to 30 years for the plane to reach that particular amount of takeoff and landing cycles [7].

When it comes to lifespan, cycles are related to aircraft pressurization in-flight as differences in pressure levels have an impact on the efficiency of a number of aircraft components, such as fuselage, wings, doors, windows, surface fasteners and rivets. Although a plane is designed to withstand differential pressure, it leads to aircraft skin defects as a consequence of deterioration over time.

The International Air Transport Association (IATA) estimates that around 16,000 commercial passenger and cargo planes have been retired worldwide in the past 35 years. Meanwhile, every year up to 700 jets are getting closer to the end of their lifespan.

According to the IATA, the global pandemic has prompted airlines worldwide to bring forward early retirement programs of older and less efficient planes, especially wide-body passenger aircraft. But the aircraft decommissioning process has to be properly managed in order to prevent environmental and flight safety-related risks, according to the IATA.

A similar estimation has been made by the UK-based aerospace strategy consultancy NAVEO, which projects that with an average yearly fleet retirement rate varying between 1.7% and 3.4%, at least 11,000 passenger and cargo planes will be officially retired from service over the next ten years.

In its recent research, NAVEO found that in 2021 the average rate of aircraft retirements worldwide stood at 1.5%. Between January 2022 and March 2022, approximately 65 planes had been sent for scrapping. The consultancy says that if the current prices of aviation fuel remain high, the rate of retirements may grow above typical levels.

The company calculated that the average age of the 738 planes which were retired in 2020 was around 23.12 years, while the age of the 429 planes retired in 2021 reached around 23.09 years.

According to NAVEO's data, the top four aircraft models most often sent for scrapping between 2020 and 2021 in the wide-body category were the Boeing 777-300ERs (with an average age of 13.8 years) and Airbus A380s (around 11 years). In the short-body category, it was the McDonnell Douglas MD-80s (30.8 years) and the Boeing 737 Classics (28.9 years).

Other types of planes frequently sent for scrapping aircraft included the Boeing 737NGs, the 737-600/700s as well as the larger version - the 737-800s - and the Airbus A320/A321 family planes.

Once an airline decides to retire a jet, it doesn't mean that the aircraft is permanently grounded. In some cases, air carriers put planes in long-term storage and reactivate them later when market conditions improve. Typically, when the costs of running an older plane are high but it is still valuable as an aircraft, an airline chooses either to reactivate a jet or sell it to a smaller air carrier.

However, when the value of aircraft parts and components are higher than the plane itself, airlines retire the plane for good. And when a jet is retired indefinitely, it is usually sent to an aircraft boneyard (or graveyard). Boneyards are often located in deserts as dry weather conditions help to limit corrosion. In these facilities, the valuable parts of an aircraft are removed for reuse or resale before the rest of it is scrapped.

Planes have a number of used serviceable materials (USMs) that are derived from scrapped or disassembled jets. Airlines operating fleets that are near to retirement usually use USMs to change components of the same aircraft model in the rest of the fleet to reduce costs. It is usually cheaper to do this than purchase new ratable parts.

For example, used aircraft engines are in high demand in the secondhand parts market as their turbines contain rotating blades and other components such as disks – elements that the aircraft operator must regularly exchange in order to comply with the manufacturer’s aircraft safety regulations. The value of a used plane turbofan engine can reach around $2 million. But it is up to 50% cheaper for an airline to purchase this kind of engine compared to the cost of a brand new component.

1.3 The aircraft recycling potential

The disposal and recycling of aerospace materials is an important issue in the whole of-life management of aircraft. The use of sustainable materials is becoming more important as the aerospace industry moves towards a ‘cradle-to-beyond the grave’ approach in the management of aircraft. Until recently, the selection of materials for aircraft structures and engines was based on cost considerations and performance requirements. Materials are selected on economic considerations such as the costs of purchase, manufacturing, assembly, and in-service maintenance. Materials are also selected on performance requirements such as stiffness, strength, toughness, fatigue life, corrosion resistance, maximum operating temperature and so forth. The majority of the aerospace industry has previously given little consideration to the materials beyond the end-of-life of the aircraft. In the past, end-of-life meant the day the aircraft was taken out-of-service, never to fly again. The meaning of end-of-life for aerospace materials has recently changed in an important way. There is a growing understanding in the aerospace industry that end-of-life no longer means when the aircraft is taken out of-service, but extends beyond this point to include the management of the aircraft after end-of-life (or ‘beyond the grave’). Governments, environmental organizations, and the wider public are placing greater demands on the responsible management of products beyond the end-of-life when made using nonrenewable resources. There are growing expectations that products produced in large quantities can be recycled so their materials can be reused rather than being disposed via landfill. Recycling reduces the demand for the production of new metals, which involves mining, extraction and refinement processes; all of which are environmentally harmful. Recycling may also reduce the need for new composite materials, which are produced using nonrenewable petroleum products and use energy-intensive manufacturing processes. The other benefit of recycling is the reduced demand on landfill and other hard waste disposal methods.

Until recently, the recycling of aircraft materials was not a major consideration for the aerospace industry. For decades, the majority of private, civil and military aircraft ended their days in graveyard sites, such as the Mojave Desert in California which stores many thousands of retired aircraft and helicopters Aircraft are too large to bury as landfill, and are left in remote locations such as the Mojave Desert where the dry environment slows the destruction of the airframe, engines and avionics systems. Some of these old aircraft are used for ground training purposes, others are cannibalized for spare parts, and others are dismantled for recycling.

The aircraft recycling rate is currently about 60% [8], with the remainder representing aircraft that are left to decay. However, the pressure on these graveyard sites intensifies as greater numbers of passenger aircraft reach their end-of-life in coming years. Figure 24.2 show the retirement of aircraft per year between the years 1990 and 2012; over this period the number of retirements per year has increased by more than 500%. The number of retirements per year typically accounts for 1–3% of the entire fleet. Airbus estimates about 6400 airliners will retire before 2026. The majority of aircraft in graveyard sites are constructed mostly of aluminum alloy. Most of the fuselage and wings of old civil and military aircraft are made using aluminum, which can be sold as scrap for recycling.

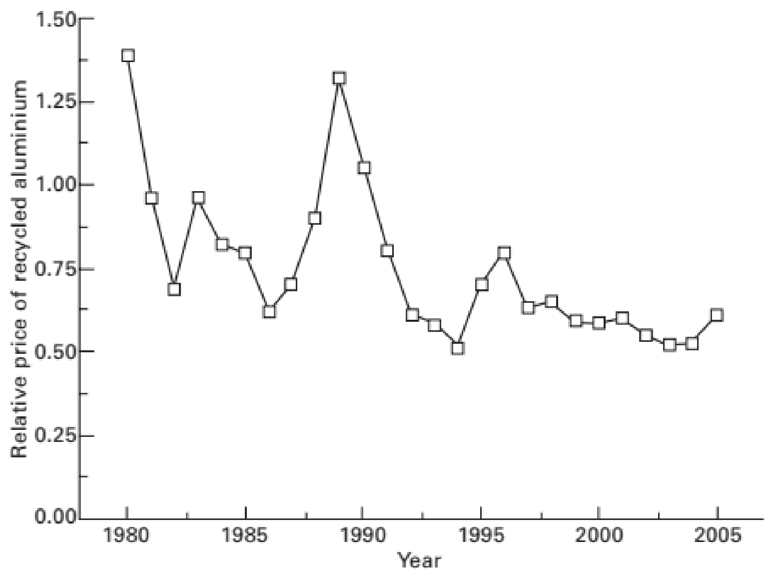


Fig 1.3 Passenger aircraft retirements, 1990-2012. [16]

With the greater use of composite materials in aircraft over the past ten to twenty years it is expected that the recycling of carbon fiber–epoxy will become increasingly important. Growing global concerns about the environmental impact of retired aircraft as well as economic efficiencies are beginning to drive the aerospace industry Aircraft

Recycling Market size was valued at over USD 4.07 billion in 2020 and is expected to grow of 8.5% from 2021 to 2027. An increase in dismantling and recycling activities in the commercial aircraft industry will create several growth opportunities for the industry.

Fig 1.4. Aircrafts recycling market.

Aircraft recycling is the process of harvesting materials and parts from end-of-life aircrafts. The process includes scrapping and disassembling the aircraft and re-purpose the components as scrap or spare parts. The first step of aircraft recycling mainly involves dismantling aircraft components, followed by the sorting out of all the materials like aluminum, copper, alloy, etc. from the aircraft. The sorted components and materials are then. Treated and cleaned to avoid rusting and damage to the critical components of the aircraft.

The growing number of retired and worn-out aircraft is driving the market for aircraft recycling worldwide. According to the Aircraft Fleet Recycling Association, more than 12,000 aircraft can be recycled in the coming years [9]. Reclaiming retired aircraft parts by environmental-friendly techniques and maintaining the value of the recycled materials have become a significant need. Recycled aircraft parts and their applications in different aircraft will further reduce the consumption of natural resources, conserve energy, and aid in landfill allocations. When recycled aircraft components are compared with virgin materials, such as aluminum, steel, copper, titanium, etc., the cost of recycled materials is significantly lower. Moreover, recycling aircraft also reduces soil, air and water contamination and helps in meeting energy demand. Recycling aircraft further provides other benefits such as reducing landfill requirements and consumption of various natural sources.

Rising awareness for aircraft recycling among airliners is fueling the aircraft recycling market growth. The rapidly growing aviation sector in India, China, and Japan is compelling the aviation sector to adopt recycled aircraft parts, which are not only economical but also minimize the environmental impact. Maintenance, Repair, and Overhaul (MRO) [10] providers are investing significantly in recycling aircraft to meet the growing need for aircraft parts.

However, difficulty in the recycling of advanced materials used in the manufacturing of new-age aircrafts such as carbon fiber might hinder the market expansion in the coming years. These materials ends-up in the landfill owing to the lack of large-scale recycling solutions.

Narrow-body segment dominated more than 60% of the market share in 2020. Narrow-body aircraft are widely used by various airlines as they carry more passengers in a cost-effective nature. Additionally, a large number of narrow-body aircraft fleets retire every year, creating opportunities for aircraft recyclers to harvest aircraft parts. Airlines are increasingly adopting recycled aircraft parts due to their low cost.

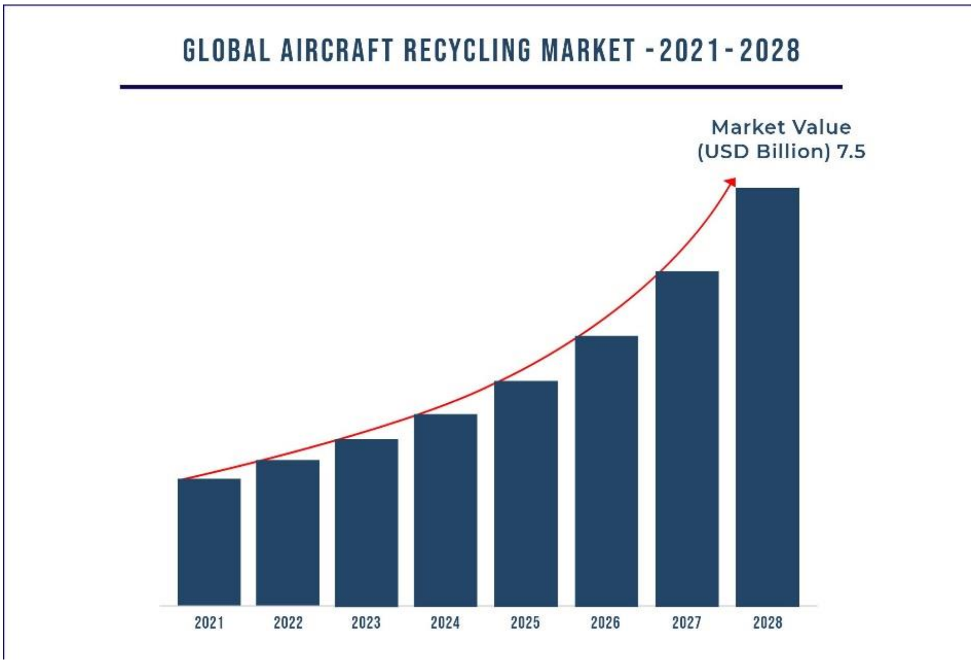


Fig 1.5. Global aircrafts recycling market

Engines segment in the aircraft recycling market is projected to witness an 8% growth rate through 2027 led by growing fleet expansion plans of various airliners and aircraft operators mainly in the emerging economies. The use of second-hand aircraft is growing, especially in low-income countries, on account of low cost and easy availability. With few modifications, the aircraft can easily be operated before its disposal. Increasing air travel around the world is further impelling airlines to maintain a healthy fleet size, thereby driving the demand for recycled engines in the industry.

The North America aircraft recycling market captured 50% of revenue share in 2020 driven by the presence of various major players in the region and the rising demand for MRO for civilian aircraft in the U.S. For instance, in April 2020, Aircraft Solutions USA announced that it will be investing USD 100 million to create a new aircraft recycling center. The growing demand for recycled aircraft parts from various airliners and aircraft operators around the world is further enhancing the market value. Increasing number of ageing aircraft in the region will augment the aircraft recycling activities in the region. In addition, favorable government policies toward aircraft recycling and already established infrastructures that carry the dismantling and recycling of aircraft will influence the market revenue during the forecast period.

Growing adoption of advanced manufacturing technologies by various industry players Market leaders are accepting industry automation and advanced robotics in aircraft dismantling and recycling, increasing the quality and reliability of the products.

Various industry participants are improving their recycling capabilities to maintain their competitive edge in the market. Furthermore, various companies are forming joint ventures and strategic partnerships to boost their revenues and increase their geographical presence.

Companies present in the market include Aircraft End-of-Life Solutions, Aircraft Part Out Company, Air Salvage International, Apple Aviation, Aviation International Recycling, Tarmac Aerosave, Total Technic, Vallair, ADI- Aircraft Demolition & Recycling, ARC Aerospace Industries, ComAv Technical Services, KLM UK Engineering, Sycamore Aviation, Universal Asset Management Inc., and VAS Aero Services [11].

Conclusion to the part 1

Today the world and national economy faces the urgent problem of processing transport waste. As the trend of writing off resources aircraft is gaining strength, the industry is coming to the need to create standards for recycling and reuse of materials and components.

However, difficulty in the recycling of advanced materials used in the manufacturing of new-age aircrafts such as carbon fiber might hinder the market expansion in the coming years. These materials ends-up in the landfill owing to the lack of large-scale recycling solutions.

The disposal and recycling of aerospace materials is an important issue in the whole of-life management of aircraft. The use of sustainable materials is becoming more important as the aerospace industry moves towards a 'cradle-to-beyond the grave' approach in the management of aircraft. Until recently, the selection of materials for aircraft structures and engines was based on cost considerations and performance requirements. Materials are selected on economic considerations such as the costs of purchase, manufacturing, assembly, and in-service maintenance. Materials are also selected on performance requirements such as stiffness, strength, toughness, fatigue life, corrosion resistance, maximum operating temperature and so forth. The majority of the aerospace industry has previously given little consideration to the materials beyond the end-of-life of the aircraft.

One of the problems you may face in future in the processing of aircraft, is because modern Boeing-787 and family aircraft Airbus-A350 XWB is no longer made mainly of aluminum, and used in their manufacture of various alternative compounds (carbon composite materials, titanium and steel alloys, etc.), which naturally complicates the process disposal. Of course, the application of aircraft recycling, recycling and recycling of aircraft requires highly qualified personnel, necessary equipment, energy costs, territories and special equipment, but without economic support and subsidies from the state to implement it to enterprises alone will be impossible. Therefore, in our opinion, one of the possible solutions to this problem is the introduction of state recycling programs.

PART 2

A NEW ERA OF AVIATION TECHNOLOGY AND NEW CHALLENGES

2.1 Aviation's environmental impact

One of the most active sources of air pollution is transportation and air travel is not the best idea from an environmental point of view. The environmental impact of aviation occurs because aircraft engines emit heat, noise, particles, and gases that contribute to climate change and global blackout. Aircraft emit particles and gases such as carbon dioxide (CO_2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead and black carbon that interact with each other and with the atmosphere.

A passenger flying from Berlin to New York and back in economy class emits 1.5-2 tons of CO_2. According to the International Energy Agency (IEA) [12], the average German resident was responsible for nearly 8.9 tons of CO_2 per year when all sources of pollution were taken into account. In the U.S., the figure is about 15 tons per person. According to a World Bank study, airline passengers traveling in first class are responsible for about three times the CO_2 emissions compared to economy class passengers, because the seats in first class take up more space. Globally, aviation accounts for about three percent of climate-damaging emissions, according to the European Environment Agency.

Despite reductions in emissions from automobiles and the more fuel-efficient and less polluting turbofan and turboprop engines, the rapid growth of air travel in recent years has contributed to the overall pollution associated with aviation. From 1992 to 2005, passenger traffic increased by 5.2% per year. And in the European Union, greenhouse gas emissions from aviation increased 87% between 1990 and 2006.

A comprehensive study shows that despite expected innovations in efficiency for airframe, engines, aerodynamics and flight, there is no end, even many decades, to the rapid growth of CO_2 emissions from air travel and air travel due to the projected continued growth of air travel. This is because international aviation emissions escaped international regulation until the ICAO triennial conference in October 2016, aligned with the CORSIA offset system, and because there are no taxes on aviation fuel worldwide, lower fares become more frequent than otherwise, giving a competitive advantage over other modes of transportation. If market caps are not enacted, this growth in aviation emissions will result in emissions in the sector accounting for all or nearly all of the annual global CO2 budget by mid-century if climate change is held to a temperature increase of 2° C or less [13].

It is estimated that by 2040, even with an optimistic projection of improved fuel efficiency technologies, aviation's CO2 emissions could reach nearly 1,500 megatons per year (Fig 2.1) and although today aviation is significantly (about 15 times) inferior to automobile transport in terms of the amount of pollutants emitted into the air, it has a daily impact on the ecology of the upper troposphere and lower stratosphere. Unlike other modes of transportation, aviation covers vast distances, affecting air quality locally, regionally, and globally. At the same time, the impact of aviation on the atmosphere can be divided into acoustic and chemical.

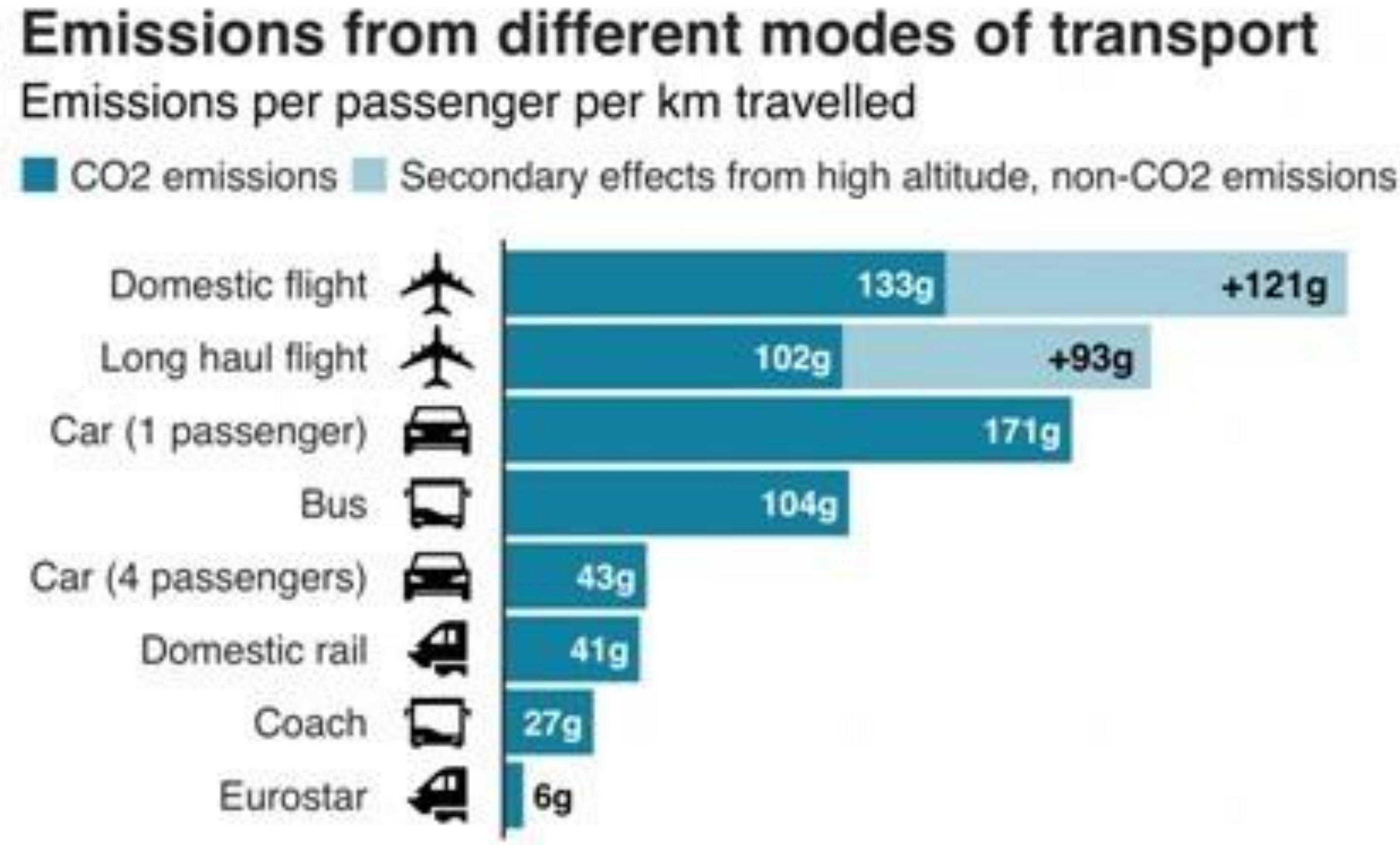


Fig. 2.1 Emissions from different modes of transport passenger per km

Interest in airport air pollution began to grow since the early 1970s, when commercial transportation using turboprop aircraft increased dramatically. Chemical air pollution at airports is represented by such aviation emissions such as carbon oxides (CO, CO2), nitrogen (NOx), sulfur (SOx), hydrocarbons (HC), and suspended particles from engine operation and combustion of aviation fuel (Fig. 2.2)

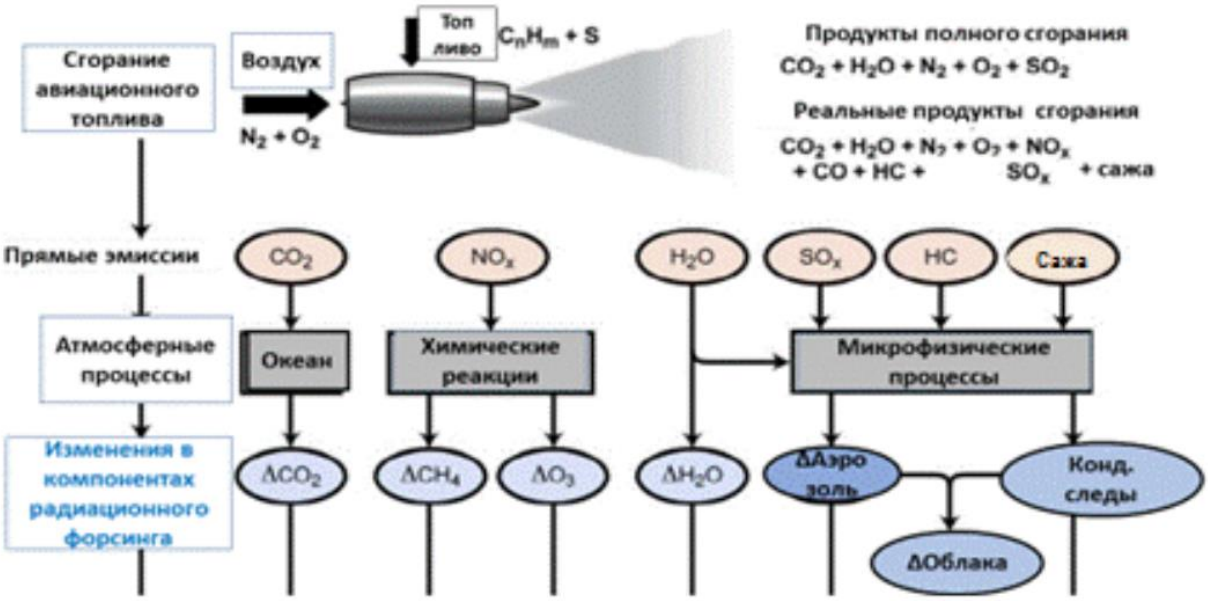


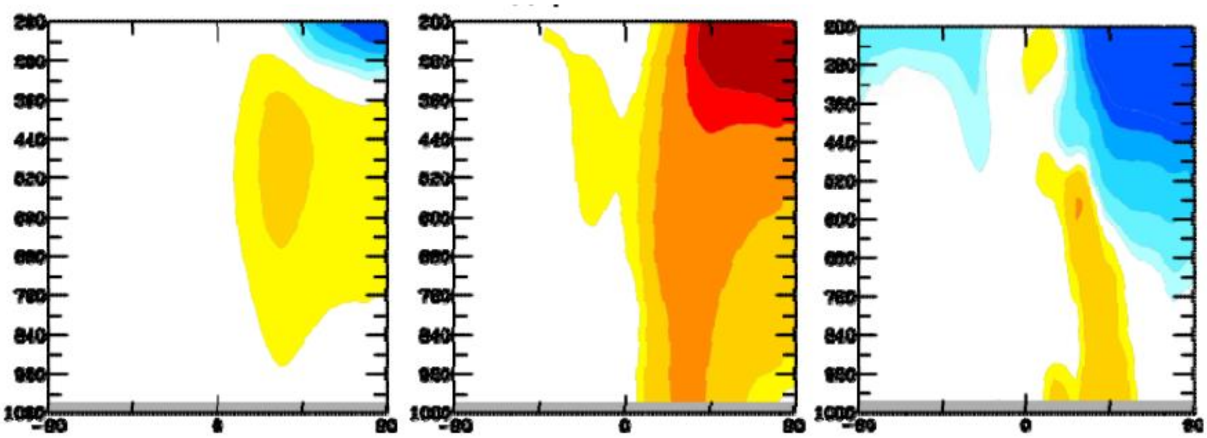
Fig. 2.2 Impact of aviation emissions on the environment [14].

Aviation-related emission sources have the potential to spread and cause air quality degradation in nearby communities. These emissions pose a potential risk to public health and the environment because they can cause an increase in ground-level ozone concentrations and lead to acid rain. National and international air quality monitoring programs routinely require authorized aviation and government agencies to conduct air quality monitoring near airports. Particular attention is also the impact of aviation on the environment related to with water quality, waste disposal, energy consumption, and impacts on local ecology near airports (particularly relevant prevention of fuel leaks)

Among the products of aviation fuel combustion, greenhouse gases, whose emissions can contribute to global warming, are of particular concern. There are essentially only two options available to airlines have essentially only two options to reduce them. The first is to increase fuel efficiency (i.e. specific fuel consumption). The second is to use alternative fuels: synthetic natural fuels, natural gas or biomass. Natural fuel does not contain sulfur and aromatic hydrocarbons, which significantly reduces emissions of fugitive aerosols and cloud nuclei condensation, thus attenuating the impact on the radiation balance. In addition, model experiments have shown that the use of fuel cleaned of sulfur leads to a significant ecological "recovery" of the troposphere in terms of ozone, sulfate and nitrate concentrations (Fig. 2.3).

OZONE	SULFATES	NITRATES

Standard fuel



Sulfurized fuel

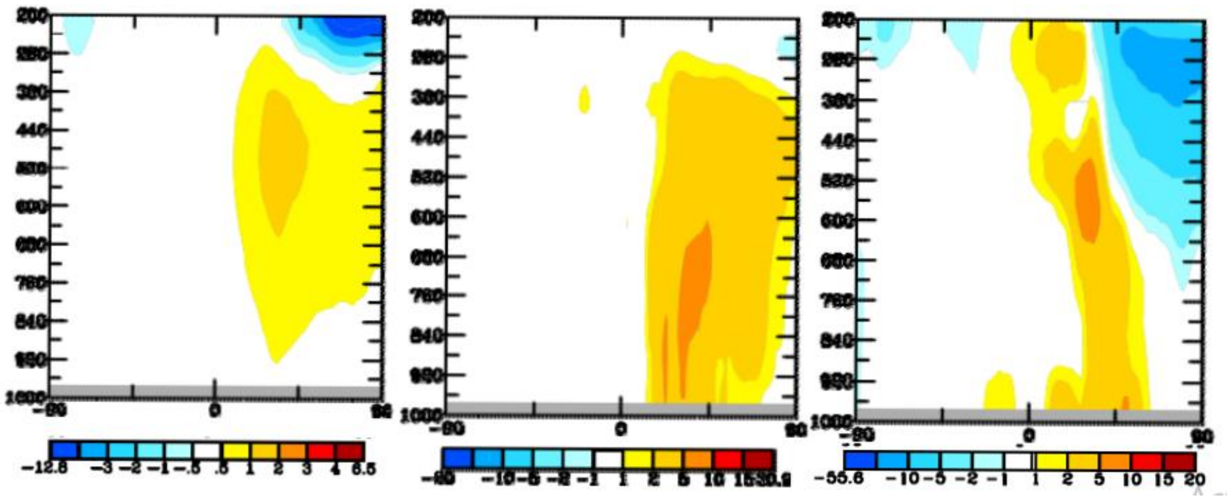


Figure 2.3 Effect of aviation emissions on annual and average ozone concentrations (in %) of ozone, sulfates, and nitrates for standard and sulfated fuel. Vertical axis is. Pressure in hPa, horizontal - latitude in degrees.

Aviation noise is the most important factor of negative attitudes to aviation of the population in the areas adjacent to the airport. Under its impact affects a relatively large number of people living in the vicinity, as well as airport employees and passengers. Aviation noise has a negative influence on people's health (the most frequent ones are hearing impairment, stress and concentration problems). ICAO's policy on aviation noise involves the development of measures to mitigate acoustic pollution: the introduction of noise reduction technologies, ground planning (e.g., nighttime flight bans), Tightening noise standards for the existing aircraft fleet and developing standards for new aircraft models. At the same time, due to the introduction of strict aviation noise standards, Russia lost the opportunity to operate domestically produced aircraft for international flights, which was a huge blow to the domestic aircraft industry. Currently, fundamentally new aircraft designs and engine concepts are being developed [15], manufacturers strive their products meet the highest requirements of environmental standards.

Standards and recommended practices for aircraft noise are outlined in the first volume of Appendix 16. It articulates permissible noise levels and methods of their measurement for aircraft of various (The year of manufacture, number and type of engines are taken into account, values of the maximum certified take-off weight).

Table 1. Estimated long-term prospects for reducing of aviation noise by 2030.

Category of aircraft	**Long-term goals, EPNdb**
Regional jet aircraft 40 t (rated) 50 t (maximum)	 21,5±4 17±4
Short/medium range twin-engine aircraft Turbofan: 78 tons (rated) 98 tons (max) With bi-rotating turbofan engines 78t (nominal) 98 tons (max)	30±4 26,5±4 13,5+2/-6 10,5+2/-6
Twin-engine mainline aircraft 230 t (nominal) 290 t (maximum)	 28±4 24,5±4
Four-engine mainline aircraft 440 t (rated) 550 t (maximum)	 27±4 20,5±4

The Group of Independent Experts formed by CAEP in order to develop noise reduction technologies. Of independent experts, created by CAEP, has formulated medium term (until 2020) and long term (until 2030) goals for noise reduction technologies. 2020) and long-term (until 2030) technological goals. They represent standards that will be mandatory in 2030 for four categories of aircraft (Table 1). The goals are shown as in the form of values of noise level reductions relative to nominal and maximum takeoff weight limits. The level noise level is measured in units of EPNdb - effectively perceived noise level in decibels. Considering that in 2014 these levels, depending on the type of aircraft were 89106 EPNdB, it becomes obvious how radically ICAO is going to combat acoustic pollution of the atmosphere.

Although aviation is a relatively "clean" mode of transportation in comparison to others, its effects on the climate and the environment can become tangible over time due to the ever-increasing air traffic, leading to increased pollution in the upper layers of the troposphere. Although current estimates of such impacts are currently very uncertain, the International Civil Aviation Organization Civil Aviation Organization is taking steps to reduce the negative of the impact of aviation on the environment. To that end, new standards are being developed to tighten the requirements for aircraft operating aircraft on aviation noise and emissions, and the list of aviation emissions is being expanded. List of aviation emissions for which the certification aircraft engines. As the main tool for regulating the negative impact of aviation on the atmosphere, the ICAO's Committee on Environmental Protection proposes the Global market-based measures. Although not all ICAO members support this idea, the need to introduce new technologies into the aviation industry such as all-electric or hybrid aircraft, to reduce the environmental impact of air transport of air transport on the environment is evident.

2.2 Examples of today's electric planes

When the airline industry talks about reducing its carbon footprint, the future of electric planes is always on the horizon. It should be – airline flights globally are expected to double in the next 20 years, yet the industry is far behind other forms of transportation in making the transition to a carbon free future.

If that trend continues, then aviation is going to become one of the top polluters in all industry sectors. Aviation will become the final dinosaur, that does not clean up, if don't act right now.

For jumbo jets, the future of fully electric flight is a few decades away. If a jumbo jet were to use today's batteries, 1.2 million pounds of batteries would be required just to generate the power of the jet engine it would be replacing. This weight would effectively need an additional eight jet planes just to carry that weight!

Understandably, overcoming these limitations of battery technology is a big focus for electric plane development right now. Both private companies and governments around the world are starting with what has worked so far.

Swiss company Solar Impulse, threw down the gauntlet in 2010 by successfully building an electric plane that could run on solar power (fig 2) and by demonstrating its prowess with a 26-hour flight. Advancements keep continuing, as a wide range of companies have shown interest in electric planes.

In 2017, Slovenian aircraft manufacturer Pipistrel introduced one of the first all-electric airplanes – including an electric propulsion system– that has been certified for use in flying schools (Fig 2.4).

Fig 2.4 HB-SIA The first all-day-and-night flight on solar energy

In 2019, seaplane airline company Harbour Air announced completion of the world's first successful all-electric commercial aircraft flight. Its ePlane, a six-passenger DHC-2 de Havilland Beaver (Fig 2.5), which uses a 750-horsepower magni500 propulsion system, flew for about a half hour over the Canadian Fraser River.

Fig 2.5 DHC-2 de Havilland Beaver, first successful all-electric commercial aircraft

NASA has also been focusing on trying to develop an all-electric plane. It has spent the last decade working on the battery and design for a two-seater plane, the X-57, as a way to help develop the needed technology. The X-57 is designed to have a range of about 100 miles and a cruising speed of 172mph. The plane is currently in a high-voltage ground testing phase. Achieving liftoff will require about 200 kilowatts of battery power, enough to power more than 100 average American homes, according to Brent Cobleigh, project manager for Flight Demonstrations and Capabilities at Armstrong.

The 850-pound lithium-ion battery pack needed to power the plane required ensuring safety while minimizing weight. This inspired new welding techniques, lightweight packaging and an alternative method of extracting heat from the battery's surface. For bigger planes, the challenge grows – airline manufacturer Boeing has already estimated that they are still several decades away from getting a 777-sized plane up in the air with just electricity.

The modern jet engine has the highest power density of any machine - this is why jet engines are used in any aircraft. In order to still maximize the benefit of these jet engines, a two-pronged approach to introducing electricity to aviation has emerged.

Short haul, commuter flights for small numbers of passengers are much closer to going electric, especially if battery technologies become somewhat lighter. Smaller all-electric or hybrid regional planes might be available sometime in the 2030s, according to Boeing.

Boeing has also released an electric passenger air vehicle that can be fully autonomous, with a range of up to 50 miles. It was designed for Uber Air (Fig 2.6), as flying taxi service that Uber says could be ready by 2023.

For jet planes, the industry is now looking for ways to integrate more electricity into certain functions of the plane while retaining the design of the jet-fueled engines.

One of the design advantages is that even small electric motors are still powerful, meaning that several motors could be placed on the wing of a plane. Electric flight control systems, for example, have already replaced mechanical flight control systems in some planes, which are the components beneath an aircraft’s surface allowing it to fly.

Companies are also researching ways to introduce more electricity into the engine itself, replacing the gear box that drives the hydraulic pump, fuel pump and oil pump with electrical systems.

Fig 2.6. Boeing is coming closer to making its flying taxis for Uber

The Alice business jet, developed by the Israeli company Eviation, was tested at an airport near Seattle.

Equipped with batteries, the plane can travel 965 kilometers on a single charge. The 12-meter airliner seats 9 passengers and reaches a speed of 450 kilometers per hour. Eviation CEO Omer Bar-Yohai says the Alice is only a few weeks away from its first flight. The company hopes that electric planes carrying 20-40 passengers will become a reality in 7-10 years.

The prototype plane, which debuted in 2019 (Fig 2.7), has been undergoing testing since last December. Eviation has developed three versions of the Alice: a "commuter" variant, an executive business jet and a cargo plane. The commuter configuration being tested holds nine passengers and two pilots, as well as about 400 kilograms of cargo. The executive version has six passenger seats.

Fig 2.7 Alice first passenger electric plane at Paris Air Show, 2019

Rolls-Royce has run tests on the Spirit of Innovation electric plane, which is set to become the world's fastest electrically-powered airplane. The world record is expected to be set this spring. The Spirit of Innovation is expected to break the 300 mph (482 km/h) mark, one-third faster than the previous record.

The current world speed record for electric aircraft was set by the Siemens Extra 330LE in 2017 at 210 mph (338 km/h). The Siemens Extra 330LE's propulsion system had a power output of 260 kW. Rolls-Royce's Spirit of Innovation has a 400 kW (500 hp) powerplant. This is expected to enable it to reach speeds of over 300 mph and set a new world record.

To power the electric motor (Fig 2.8) , the plane has a battery of 6,000 cells, making it the most power-consuming element ever installed on an electric plane. Developers hope that in the future the design techniques and technical solutions that Rolls-Royce will test in the Spirit of Innovation can be used in a wide range of solutions, including air cabs.

This is the first time the aircraft will move using power from an advanced battery and propulsion system that is groundbreaking in terms of electrical technology, this system and the capabilities being developed will help position Rolls-Royce as a technological leader offering power systems for the urban air mobility market.

Fig 2.8. The Rolls-Royce electric 400 kW (500 hp) power plant

No exhaust fumes, almost no noise and high efficiency. These are the advantages of electric mobility. Aviation also wants to use them. At the moment, it is not known when large passenger planes will be flying on electric batteries. However, the process of training pilots will soon be completed.

Electric planes have many advantages over gasoline-powered conventional airplanes. this means that the demand for electric planes will increase in the near future, technology will also continue to grow, as the demand increases so do the technological advances, we can already see that lithium-ion batteries started to develop and this will not stop the progress and the demand for modern electric vehicles and airplanes will also increase.

2.3 Comparison of Conventional and Electric Passenger Short-Range Aircraft

2.3.1 Flights - Life Cycle Sustainability Assessment

Due to the growing demand for flights, the aviation sector will become one of the main emitters of harmful emissions such as carbon dioxide (CO2) and nitrogen oxides (NOx) in the long term. Short haul flights are particularly critical due to the high consumption of kerosene per passenger-kilometer flown. To counter this development, Flightpath 2050's strategy aims to reduce CO2 emissions by 75% [17] and NOx emissions by 90% by 2050. To achieve these ambitious emission reduction targets, radical technological changes are needed. A promising strategy for short-haul flights is the introduction of battery-electric propulsion systems that will replace traditional jet engines. In addition, sustainable aviation fuel (SAF) can replace fossil kerosene as an energy carrier without reconfiguring the powertrain and provide further reduction potential. However, both solutions can be associated with negative environmental and socio-economic consequences throughout the entire life cycle. Therefore, the purpose of this article is to analyze the potential of switching to a new transmission and alternative energy carriers to increase the resilience of the air transport system. The Life Cycle Sustainability Assessment is conducted to analyze the environmental and socio-economic impacts of using an electric powertrain and SAF compared to a traditional fossil kerosene powered powertrain. The evaluation results show that especially the electric transmission offers a huge potential for reducing emissions. In addition, the results also show that SAFs can reduce the environmental impact of conventional aircraft in the short term. Therefore, both solutions will be required to meet the short-term and long-term environmental impact goals of Flightpath 2050.

2.3.2 Increase in demand for flights and changes in the aviation sector

Due to the growing demand for flights from the aviation sector constantly evolving. While this growth desirable from an economic point of view, bringing this to a new environmental challenge for the air transport system (ATS). The combustion of fossil kerosene causes a large amount of harmful emissions in production, such as carbon dioxide (CO2) and nitrogen oxides (NOx), which are returned climate and health. In 2019, the aviation sector 2.6% of the territory of Europe CO2 [18]. This is especially emissions at high altitudes more serious impact on the environment than ground-based emissions [19]. Current Research Predicts Human Air Traffic Volume Attendance at 3.6% per year, which is taken to double air travel for about 16 years. Taking into account the increase in fuel consumption. Efficiency of approximately 25% for a new generation of aircraft this application to the morning aviation emissions on 2050 that ATS comes from sources of CO2 and NOx in the expected future [20].

To counteract this rise, the aviation sector has set itself set retention reduction targets set in Flightpath strategy 2050 [21]. Strategy foresees death aircraft emissions by 75% for CO2, 90% for NOx and 65% noise by 2050 relative to new present on base year 2000. Various programs have been tried in this area in recent years to regain the achievement of reduction goals [22]. However, these programs are mainly aimed to compensate for the concentration, which is not enough in the long term. Innate progress towards a healthy and sustainable life requires more radical technological innovations.

A promising solution for short-haul flights in the future is Electric aircraft associated with low or no emissions when using phase. Alternatives already available today are capable renewable fuels, also known as sustainable aviation fuels (SAF). Kerosene-based biomass or hydrogen can significantly reduce harmful emissions due to the benefits in their production. However, both solutions can cause negative environmental and socioeconomic consequences along with their life cycles. This is virtually unmentioned in the scientific literature, and studies Comparison of conventional and electric aircraft for short-haul flights considering different fuel options are few. Thus, this article aims to analyze and compare electric aircraft and conventional aircraft powered by fossil kerosene and SAF to determine the potential for a promising solution for short-haul flights and thereby contribute to the

ATS's sustainable development. Using a holistic life cycle Sustainability Assessment (LCSA), the environmental and socioeconomic implications are reflected in a well-awakened approach. Well-to-wake includes the energy supply chain, transmission supply chain, and flight operation as the utilization phase. After analyzing a total of nine energy carriers as presented in Table 2, recommendations for action are derived for both the long-term and short-term development of the aviation sector.

2.3.3. Assessment method and fundamentals of the study

The assessment is based on the life cycle assessment method Stability assessment method, and its procedure is borrowed from ISO 14040/14044 standards. Basic explanation

LCSA can be found in the relevant literature since electric transmission is a technology that is still under development, the approach is applied based on the idea of a promising LCA [23], transferred to a promising LCSA.

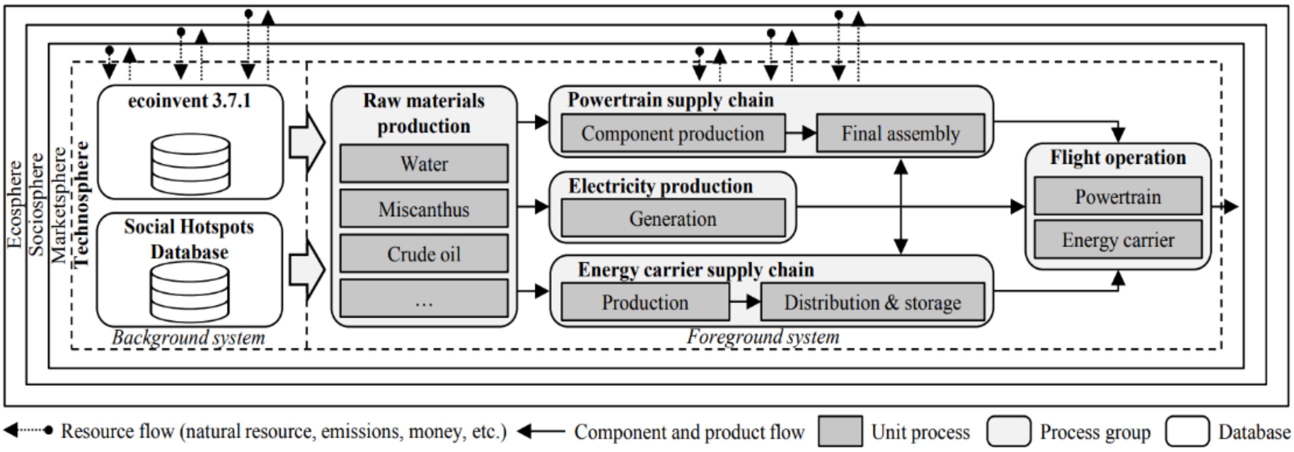


Fig 2.9. Foreground and background system with corresponding boundaries including component, product, and resource flows

This study analyzes and compares the use of traditional and electric propulsion systems for short-haul aircraft. For this, two types of supply chains are considered. On the site On the one hand, the supply chain of the power plant, from extraction of raw materials through production to use. On the at the stage of use, it intersects with the supply chain of energy carriers necessary for the operation of the power unit. Energy carrier required for the operation of the transmission. It includes production, distribution, storage and use of energy carriers. Supply chains supply chains and necessary materials are modeled in the foreground system. They are linked to the Eco invent database and the database social hotspot database (SHDB) in the background system Overview of the considered systems and the corresponding boundaries are shown in (Fig 2.9).

The functional unit for analysis is 100 passengers. Kilometers traveled (pkm) on a short-haul flight per 1000 km from cargo of 100 passengers, including luggage. The impact assessment carried out is based on three types of Life Cycle Impact Assessment (LCIA) methods, one for each of the three dimensions of sustainability. Here Climate change impact category (CC) selected due to high the amount of climate-damaging CO2 from fuel combustion, fossil resource depletion (FRD) is chosen because of the fossil sources needed to generate electricity and fossil character of conventional kerosene and agricultural land occupation (ALO) is chosen due to the required agricultural land for growing bio-raw materials. Economic evaluation based on life cycle cost (LC) related to the energy supply chain, power transmission supply chain and flight operations [24]. Social Impact assessment based on impact assessment method ShDB. Corruption Risk Impact Categories (RoC) and risk of poverty (RoP) are chosen because of socially critical conditions in the country of origin of raw materials necessary for energy carriers and power units.

2.3.4. Conventional and electric powertrain

The traditional transmission analyzed in this study is based on an Airbus A318-100 aircraft. This transmission was chosen because A318-100 can carry about 100 passengers and is a typical short-haul aircraft. The main composition consists two jet engines, fuel tanks in the hull and on the wings, pipes and power electronics for engine control. Pipelines, as well as power electronics for motor control. On the site Powertrain production is based on the Airbus production network with the production of components in England, Germany, Czech Republic, Spain, and final assembly in France [25].

Battery-electric propulsion configuration taken from the reference aircraft defined within the cluster of excellence "SE²A - Sustainable and Energy Efficient Aviation". This short-haul aircraft can carry up to 100 passengers for a distance of up to 1,000 kilometers. Power point consists of two propellers driven by electric motors, battery energy storage system, power electronics and cooling system. Cooling system. Due to technical limitations regarding the maximum takeoff and landing weight, high specific battery energy is critical, which is why a lithium-sulfur solid-state battery was chosen in this study. Selected for this study. Component production carried out in Germany, Japan and France. For each raw material, the country with the highest share of world production according to the US Geological Survey. Survey is taken as the place of origin. Relevant transport routes are taken into account.

2.3.5. Kerosene, sustainable aviation fuel, and electricity

Each power unit requires certain energy carriers for flight operation. Fossil kerosene is currently used for this purpose. Conventional power units. Its supply chain starts from extraction of crude oil, which is processed into kerosene by mixing with various additives. It is assumed that raw oil is produced in Russia and refined in Germany.

In addition to fossil kerosene, there are three promising SNPs. considered in this study. These fuels are produced by converting X to liquid, more precisely by converting biomass to liquid (BtL) and power-liquid (PtL). The starting point processes is the production of hydrogen, which is further processed into kerosene by Fischer-Tropsch synthesis (FTS). In FTS, SNF is produced in a variety of ways. Pressure and using CO2, which is captured from atmosphere or as waste from other industries [26]. As for BtL, the focus is on 2nd generation biokerosene. Miscanthus is the raw material for biokerosene. Grown in Germany and processed into biogas. Biogas processed to biomethane by adding various additives, and then converted into hydrogen using steam reforming of methane (SMR). AT biokerosene is produced in the next production step using FTS. Production takes place in Germany. As for PtL, two production routes are being explored. The first path involves the SMR process, but uses natural gas and water instead of biomethane for hydrogen production. In another way hydrogen production produced by electrolysis. For this, a polymer electrolyte is used. Membrane electrolysis (MEM) is used to produce hydrogen in energy-intensive stage of production from water (55 kWh electricity consumption per 1 kg of hydrogen), which additionally processed into synthetic kerosene via FTS. All synthetic Kerosene production takes place in Germany. There are two scenarios for each SAF production: 1.) Using the current electricity balance in Germany, and the use of mixed electricity produced from 100% renewable sources. Energy sources (RES) expected for Germany in 2050. These two electrical mixtures are also considered as energy supports for the electric drive. In total, nine different energy carriers are analyzed using fossil kerosene.

2.3.6. Mission profile and flight operation

For analysis, a reference flight over a distance of 1,000 km with a load of 100 passengers. This corresponds to a flight from Frankfurt, Germany to Barcelona, Spain, which is potentially possible for an electric aircraft. The flight lasts 135 minutes, while the take-off/rise time is 35 minutes and cruise/landing 100 minutes. According to the Lufthansa Group, such a flight consumes 7.1 liters of kerosene (specific energy 68 kWh) per 100 pkm [27], which is the energy consumption within the framework of this research. The nature of fuel combustion and the resulting indicators taken from the scientific literature [34]. Energy consumption of a comparable electric flight estimated at 17 kWh per 100 pkm. Energy requirement for electric aircraft accounts for about 25% of energy consumption conventional aircraft due to higher efficiency. This difference in efficiency similar to the difference in the automotive industry [28]. In addition to the impact associated with energy consumption, other impacts associated with the production of power units should should be considered on a proportional basis. They are calculated based on based on flight duration relative to total service life service life of the power unit.

2.3.7. Impact assessment results

Review of observation results Table 2. Results of the study showing that electric transmission offers environmentally friendly and socio-economic benefits over conventional power unit running on fossil kerosene, relatively the functional unit has traveled 100 pkm. Current nature in Germany, ecological impacts can be reduced by 63% to 71%. For ALO only usually worsening by 59%, which is associated with the current composition of the electric power mixture. If energy is generated from 100% RE even better results can be achieved. Compared to conventional powertrain benchmark runs on fossil kerosene, morbidity 91% (SS) and 92% (FDP), as well as the influence of ALO can be decreased by 48%. In general, there is only one ecological impact category where a high level can be achieved through using SAF. Regarding CC, the use of Ker (PEM-RE) can reduce environmental impact by 95% due to high savings in production due to the use of electricity, called 100% on RE. With regard to socio-economic impacts, outcomes solution. Here, a reduction from 6% to 91% can be achieved by electric drive compared to the standard. However, there is no difference between the current supply blend or 100% RE based electrical blend used for flight Operation. This is due to the assumption that electricity applies in Germany, and the price of electricity is the same in both infections. Also, no SAF, what's more advantageous compared to the consumed power unit with respect to category of socio-economic impact. The results of the evaluation also showed that some SNFs subject to negative environmental and socio-economic consequences.

When collecting biokerosene (Ker (bio) and Ker (bio-RE)) is always beneficial in terms of social impact, LC is 160% higher compared to Ker (fossil). AT in terms of environmental observation, biokerosene return options Beauty potential from 30% to 73% in relation to CC and FRD. However, they are covered by sixteen times more severe consequences [29]. Regarding ALO due to the use of land for raw materials. Results for synthetic fuels that are based on balance of electricity, only with the help of Ker (SMR) transmission to emissions caused by social impacts and CC.

Table 2. Environmental and socio-economic assessment results of the eleven use cases for the functional unit of 100 pkm traveled

Dim.	Impact category	Unit	Per 100 passenger kilometers traveled								
			Ker (fossil)	Ker (bio)	Ker (bio-RE)	Ker (PEM)	Ker (PEM-RE)	Ker (SMR)	Ker (SMR-RE)	Elec	Elec-RE
Env.	CC	kg CO_2-eq.	29.91	20.83	17.36	105.77	1.35	25.92	24.69	11.10	2.44
	FRD	kg Oil-eq.	10.57	3.74	2.82	35.88	8.06	17.97	17.64	3.07	0.76
	ALO	m^2 per year	0.30	5.18	5.05	5.12	1.27	0.53	0.49	0.47	0.15
Econ.	LC	US-Dollar	5.91	15.37	15.37	43.82	43.82	13.08	13.08	5.56	5.56
Social	RoC	Medium risk hour eq.	13.57	2.49	2.49	8.69	8.69	1.86	1.86	1.28	1.28
	RoP	Medium Risk hour eq.	1.36	0.57	0.57	1.84	1.84	0.44	0.44	0.28	0.28

This is due to the high energy demand Ker (PEM) and, which takes responsibility for the high negative environmental and economic consequences. Use of mixed energy based on 100% RES can reduce the impact on the environment as a whole, while the socio-economic consequences return the same. Here Ker (PEM-RE) offers a reduction potential of 95% relative to CC and 24% regarding FRD. Ker (SMR-RE) gives an almost complete picture environmental impact, since a small amount required for the process. Economic In the long term LC is anyway higher than for fossils kerosene (from 121% to 641%).

2.3.8. Analysis of environmental and socio-economic impacts

On (Fig. 2.9) provides more detailed information about environmental and socio-economic consequences, destroying assessing the impact on the energy supply chain, including power generation, transmission supply chain, and final stage of use. For a conventional transmission using fuel, the results show that the energy supply chain is mainly responsible for impacts for five of the six impact categories analyzed. Especially regarding the environmental impact of FRD and ALO SNF, 90% to 99% of all impacts can be attributed to this stage. In the case of biokerosene, growing production of raw materials and kerosene using SMR in the first place responsible. As for synthetic fuels obtained with PEM, the impact is associated with the energy-intensive production of hydrogen [30], while for SMR the upstream natural gas chain responsible. As for fossil kerosene, an energy carrier the supply chain is responsible for 52% (ALO) and 92% (FRD). It is related to the extraction of crude oil and the production of oil. Similar results take place with respect to the socio-economic impacts, where 70% to 97% of the total impact is due to energy supply chain. With regard to LC, energy-intensive manufacturing processes such as hydrogen production, FCS and kerosene production are the main driving forces impact. In the case of social consequences, this also applies, but it should be noted that social impacts are generally low, which because Germany is mainly used as a production site, where the risk of socially unfavorable situations is not very pronounced. The exception is RoC in the case of fossils kerosene, which is usually associated with the extraction of crude oil and transportation through several countries. As for CC, however, the impact for each fuel mainly due to the use stage, when about 3.15 kg CO2 released during combustion. Ker (PEM) is exception. Here, the high energy demand during PEM is main driver. The results also show that SNFs are generated by RE are associated with exposures CC less than zero in their supply chain. This is because more CO2 is captured than released during production. The exception here is Ker (SMR RE), as hydrogen production is based on fossil sources. As for the electric transmission, the results show that the current structure of electricity generation is mainly responsible for environmental impacts. This is due to the high proportion fossil energy sources used in current electricity generation. If the electric mixture is generated by renewable energy, environmental the impact can be greatly reduced, but the combination of electricity Again, it's primarily your fault. It has to do with building renewable energy sources that count in life cyclic inventory datasets.

Similar conclusions can be drawn with regard to socio-economic impact. Electricity generation is mainly responsible for impacts of LC, RoC and RoP. In general, socio-economic the impacts are not different when RES are used for electricity generation. In both cases, generation takes place entirely in Germany under the same conditions.

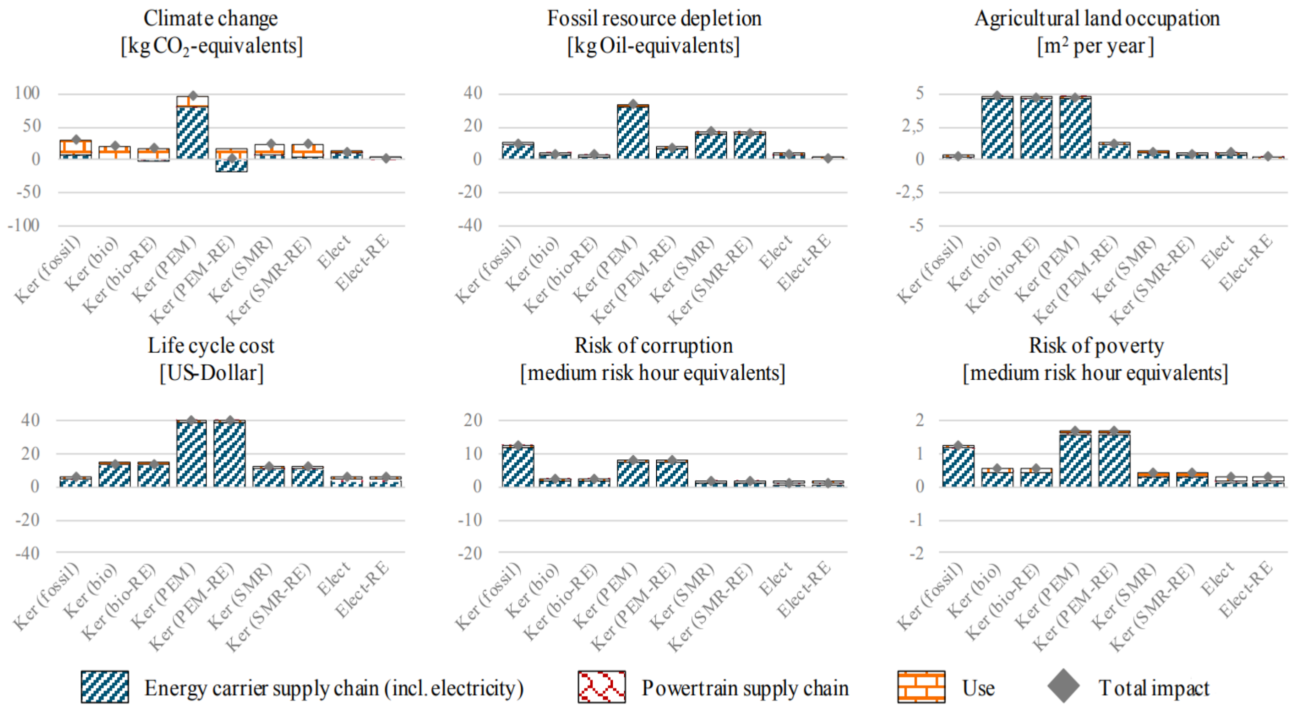


Figure 2.9 Environmental and socio-economic impacts divided between energy carrier supply chain, powertrain supply chain

The sustainability assessment carried out in this article aims potential front transmission and SAF to determine short haul aircraft. Analysis of the state of wakefulness shows that Electric aircraft may seem like a significant reduction environmental and socio-economic consequences. If power necessary for the emergence sources, recovery potential is higher. In the same time, show that synthetic fuels have advantages over fossil fuels kerosene according to the degree of exposure. Peculiarity when it comes to CO2 emission limits, these fuels can be beneficial. However, this only applies if the synthetic fuel occurs with the use of economic energy.

2.3.9. Main components of electric aircraft

Electric aircraft, as well as aircraft powered by fuel, consist of 5 main elements such as the fuselage, wings, landing gear, engine and tail plumage, the main difference between electric aircraft and aircraft that run on fuel is that electric aircraft are powered by electric motors with a resource which is lithium batteries, so we can say that lithium batteries are another major part of modern electric aircraft.

It is also expected that the aircraft industry will make extensive use of ultra-strong and lightweight composite materials. All composite materials consist of a matrix and a rigid reinforcing filler. As a rule, the reinforcing filler in polymer composites is carbon or glass fibers, and the matrix is a polymer material, usually a synthetic resin [31]. The most commonly used thermosetting resins. When heated, they form a three-dimensional polymer network, due to which the matrix becomes rigid and chemically stable. These materials can be used to create lightweight parts that are stronger than metal parts.

Their use is relevant wherever lightness and strength are important, primarily in aviation: fuel consumption directly depends on the weight of the aircraft. In the automotive industry, carbon fiber is used to make sports cars, Formula 1 race cars, luxury cars and electric cars. Everything that moves quickly is now being made from composites.

In the design of an aircraft, composite materials can be used to make the fuselage, wings, tail unit, engine nacelle, and interior details (Fig 2.10). More often, lighter carbon fiber is used for aircraft, and fiberglass is used for unloaded parts and the nose cone. Fiberglass is heavier than carbon fiber and less durable, but it is significantly cheaper. The nose cone of the aircraft is made of fiberglass, since this part must pass radio waves, and carbon fiber conducts current and creates interference.

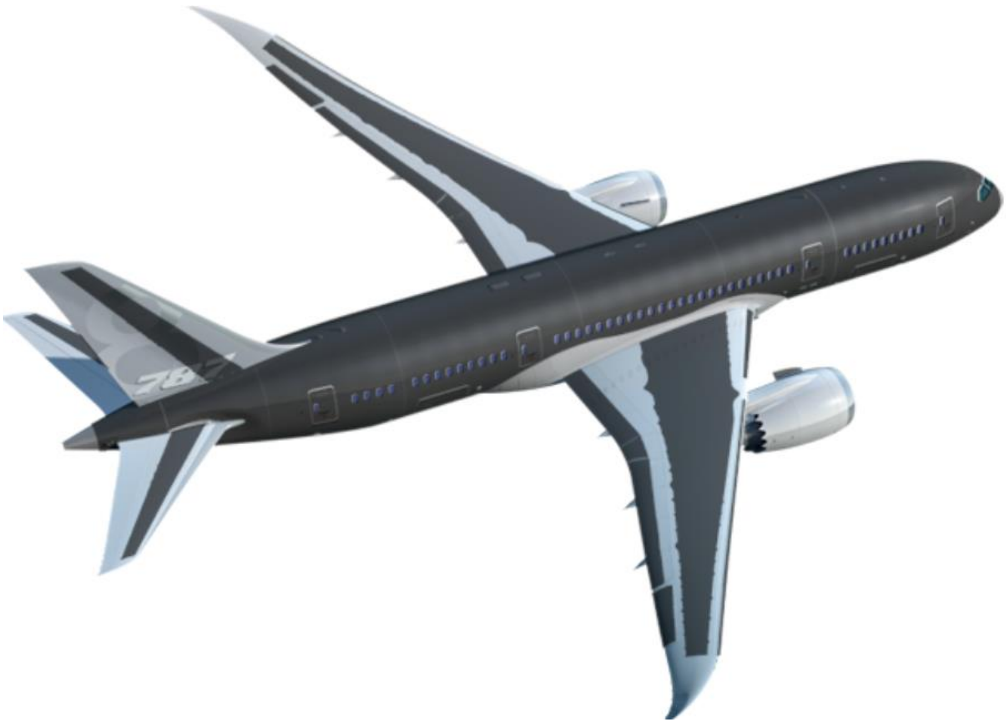


Fig 2.10. Scheme of the Boeing-787 liner. Carbon fiber-reinforced plastic parts are highlighted in dark gray

In the third part of the graduation project, methods for processing and disposing of electric aircraft will be considered, since in the near future electric aircraft will stop being as popular as cars that move on electric power, since electric aircraft have the most advantages compared to conventional aircraft for us, in a number of which includes practically zero emissions and low noise.

Conclusion to the part 2

The environmental impact of aviation occurs because aircraft engines emit heat, noise, particles, and gases that contribute to climate change and global blackout. Aircraft emit particles and gases such as carbon dioxide (CO2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead and black carbon that interact with each other and with the atmosphere.

When the airline industry talks about reducing its carbon footprint, the future of electric planes is always on the horizon. It should be – airline flights globally are expected to double in the next 20 years, yet the industry is far behind other forms of transportation in making the transition to a carbon free future.

For jumbo jets, the future of fully electric flight is a few decades away. If a jumbo jet were to use today's batteries, 1.2 million pounds of batteries would be required just to generate the power of the jet engine it would be replacing [32]. This weight would effectively need an additional eight jet planes just to carry that weight!

Understandably, overcoming these limitations of battery technology is a big focus for electric plane development right now.

It is also expected that the aircraft industry will make extensive use of ultra-strong and lightweight composite materials. All composite materials consist of a matrix and a rigid reinforcing filler. As a rule, the reinforcing filler in polymer composites is carbon or glass fibers, and the matrix is a polymer material, usually a synthetic resin. The most commonly used thermosetting resins. When heated, they form a three-dimensional polymer network, due to which the matrix becomes rigid and chemically stable. These materials can be used to create lightweight parts that are stronger than metal parts.

Based on the trend, we can say that in the near future electric planes can replace flights with small stationary ones which significantly reduces noise and harmful emissions in densely populated areas.

PART 3
AIRCRAFT RECYCLING

The term "sustainable development" has taken on a new meaning in recent years. Manufacturers are encouraged to improve all stages of the life cycle of their products and influence the impact on the environment.

Accordingly, the topic of waste recycling is becoming more and more studied. In the past, recycling in the case of aircraft did not occur, since the decommissioned aircraft were simply stored at the so-called air bases. The extent of these storage sites today can even be seen using Google Earth. This process should be replaced

Lack of knowledge and complete life cycle management [33] is written from cradle to grave. Today, aircraft such as the B787 and A350 are built with a high percentage of carbon fiber plastic and a high percentage of metal, the next generation will be heavier. This saves weight and fuel, but creates problems at the end of the life cycle when it is necessary to manage the disposal of carbon fiber components and lithium batteries. Aircraft recycling as part of the life cycle assessment (LCA) in the conceptual design of aircraft.

3.1 Previous Research

A synthesis paper was published by Asmatulu 2013 examining the progress, environmental benefits and marketability of recycled aviation materials. Towle 2004 described several projects and technologies for the processing of aviation materials. In terms of legislation, industry analogies, and driving forces, Fieldhouse 2011 has produced a comprehensive document. These studies were able to describe in detail some aspects of the end of life of aircraft, but failed to provide an overview of all important topics. With respect to composite materials, Yang 2012 provided a comprehensive overview of composite recycling issues and technologies. First Approach to Correlating Recycling of Composite Materials with aviation issues was presented by Wong 2017. Both topics - the end of life of aircraft and the recycling of composites - have been developing rapidly over the past 20 years, giving rise to a synthesis study.

The basis of every scientific work should be a well-conducted literature research to ensure a comprehensive knowledge of the field of work. Therefore, the research methodology used in this paper is a literature review. There are several strategies for conducting scientific literature research. However, the goal of literature research is not just to copy existing knowledge. Thus, for a proper study, it is necessary to find the relevant literature. The type of research being planned requires a certain quality of references. Based on the quality of information and accessibility of the source, links can be divided into primary, secondary and tertiary. The criteria for such a division are somewhat different.

Since the topic of aircraft end-of-life is relatively new to the scientific world, and few data have been obtained from analysis and experimentation, it is almost impossible to find the original data. Even other literature such as articles, dissertations and industry reports cannot be found in large numbers. However, the available literature contains sufficient information to allow a broad generalization of aircraft end-of-life data.

Three research methods were used to collect the available literature in this work. The first two methods are described as the concentric circle method and the direct search method. Both methods need a central document, such as a central article. The concentric circles method evaluates the links of the central

3.2 Aircraft life cycle

An aircraft is a complex product, not only from a technological point of view, but also from an economic and logistical point of view. In addition, the aviation sector is sensitive to social hype. For a long time it was thought that flying was dangerous, and now air transport is considered polluting. In the last two decades, the term "green" has become increasingly important. Denoting an environmentally friendly lifestyle. Pressure on industry to "green" and reduce the environmental impact of its products. This pressure is also on aviation, which is usually associated with rather poor environmental sustainability. This pushed the aviation industry to change and improve its social image. Flights. Operators began to request aircraft models with better environmental sustainability, and aircraft manufacturers had to follow their requests. So these manufacturers began to analyze the life cycle of their products and soon found that the end of the aircraft life cycle [34] is a comparatively polluting part. The reason for this was the widespread practice of simply parking out-of-service aircraft and leaving them without any deconstruction. The next two subchapters devoted to the basics of the aircraft life cycle and its storage, in order to better understand the understanding of the desire to overcome past practices.

Each system and product goes through various stages of development or use during its life, from the initial idea of creation to disposal at the end of its life. In most cases, the life cycle of a product is examined when performing a life cycle assessment or life cycle management. The main goal of these methods is to gain insight into properties such as quality, measurability, and outliers. The life cycle, defined by the international standard ISO / IEC / IEEE 15288, is divided into six main stages:

- Design stage.
- Development stage.
- Production stage.
- Stage of use.
- Support phase and.
- Recycling stage.

This division, in general, can be applied to almost every product, and therefore also to the aircraft product. However, the steps defined by the international standard are neither aircraft specific nor specific to a specific use case. To add value, the life cycle of an aircraft can either be simplified to four stages, or broken down into a larger, more detailed number of stages. Schmidt 2013, for example, divides the aircraft life cycle for life cycle costing purposes into four main phases:

- Research and development, planning and conceptual design, preliminary design and system.
- Integration, detailed design.
- Production and acquisition.
- Operation and support.
- Disposal.

In contrast. For a long time, the end-of-life phase of aircraft was not considered important, as only a few aircraft were taken out of service each year. The concept of parking old, unprofitable aircraft originated at that time and led to the fact that aircraft are parked for years before they are dismantled, if not completely dismantled. Another reason for this The concept of aircraft storage is explained by the lack of an aircraft dismantling industry. This stage in the idealized aircraft life cycle shown in (Fig 3.1.)

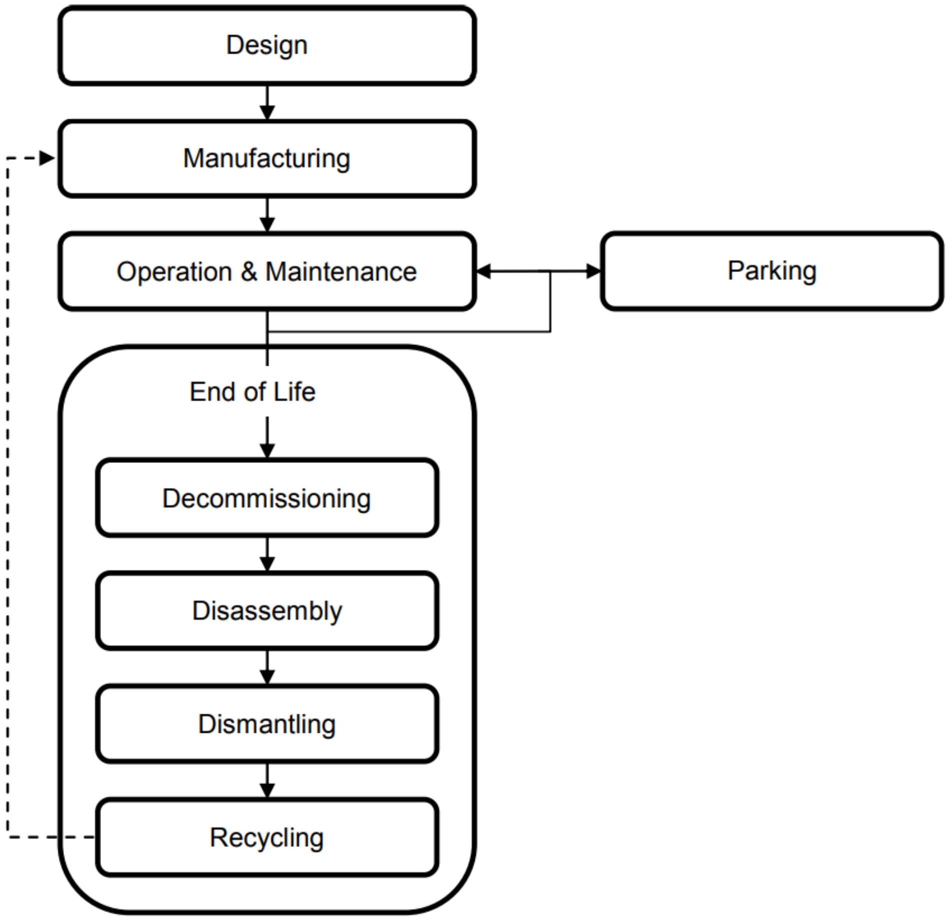


Fig 3.1 Idealized aircraft life cycle.

However, a missing stage in the idealized cycle is mentioned the junkyard stage:

- Disposal or incineration of materials that cannot be recycled.
- Operation and maintenance.
- Removal from service.
- Disassembly.
- Dismantling.
- Production.

- Design.
- Recycling.
- Parking.
- End of life.

In addition to the aforementioned features, the aviation industry is determined by the rules and the general process of aircraft manufacturers to largely interview consumers, airlines in this context, before developing a new aircraft. So one more step and divides the life cycle into the following ten stages:

- Design.
- Definition.
- Development.
- Production.
- Testing.
- Exploitation.
- Support.
- Modernization.
- Decommissioning and if necessary
- Extension of the technical resource.

Unfortunately, basic knowledge about the life cycle of an aircraft does not always lead to any improvements. Thus, aircraft lifecycle management is now emerging to enable airlines to strengthen their competitive edge by maximizing fleet performance. Moreover, knowledge of the aircraft life cycle gives airlines the opportunity to gain a deeper understanding of how their fleet will change in the coming years and what countermeasures should be taken, such as operating old aircraft with low fuel prices. To save flight hours on new, more fuel-efficient aircraft. Aircraft manufacturers such as Boeing and Airbus have joined this trend and have studied the entire life cycle of their aircraft. Recently, for example, Airbus stated that the development of new aircraft will take into account their operation and end-of-life. When designing new aircraft.

3.3 Aircraft storage

What usually happens to an aircraft when the owner decides not to fly it anymore? For a long time, the accepted practice for handling such aircraft was to store them in so-called aircraft junkyards until further decisions were made. These sites offered ample space under favorable conditions such as the price of storage as well as climatic conditions conducive to the preservation of aircraft (hot and dry). Stored aircraft were kept operational by authorized personnel if a serviceable aircraft cost more than its parts. The owner then had to either return it to service when operating conditions, such as the price of fuel, were convenient, or sell it, often to countries with more relaxed regulations. If these methods were economically disadvantageous, the aircraft was stored without service for an indefinite period. Usually valuable parts such as engines, landing gear, avionics and electronic motors were carefully removed to be sold later. The remaining parts of the aircraft, which could not be removed and sold, were disposed of in a landfill, which meant a simple store them in places where there was enough space. This dumping has resulted in thousands of aircraft being stored in warehouses, over four thousand exclusively at the Aerospace Services Center and Regeneration Center in Tucson, Arizona, as shown in (Fig 3.2.)


Fig 3.2 The east side of the Aerospace Services Center and Regeneration Center in Tucson

The waste disposal process, combined with poor traceability and disposal conditions for end-of-life aircraft, has generated interest in the end-of-life phase of aircraft. There have even been cases of frivolous disposal of aircraft parts at sea, which caused public outrage. To improve the image of aviation, airlines and manufacturers have felt the urge to replace conventional practices with environmentally friendly practices.

3.4 Airbus strategy

Airbus began developing various approaches to avoid storing and selling aircraft outside the European Union in 2005. The “Advanced Aircraft End-of-Life Management Process” called PAMELA was launched in collaboration with Suez-Sita, a French waste management company. Company - and the working group LIFE (l'Instrument Financier pour l'Environnement). Moreover, the European Union supported the project, which, on the one hand, was aimed at proving that 85-95% of aircraft can be easily disposed of, reused or restored. On the other hand a new standard for the safe and environmentally friendly management of "Aircraft out of Service" (ELA) was to be created. Finally, the third goal was to launch a European network for further dissemination of the resulting dismantling process.

In early 2006, an end-of-life Airbus A300-B2 arrived at Tarbes Airport, marking the start of the pilot phase of the dismantling project. The A300 was the world's first full-scale demonstration and was completely disassembled, while the results and effectiveness of the methods used were recorded. According to Airbus 2006, the project was supposed to last until 2015, but was already completed in 2007. However, PAMELA has successfully developed a three-step approach, the so-called 3D approach. On (Fig 3.3) shows a general view of the process.

During decommissioning, aircraft are parked, inspected, decontaminated and cleaned. All liquid materials and hazardous substances are drained and either disposed of or stockpiled. for reuse. The second step starts with planning the disassembly process. All possible parts, such as APU (auxiliary power unit), avionics and landing gear, are disassembled, checked and cleaned. If necessary, repairs are carried out before the assembly of the part is completed. Documentation and sale of these spare parts.

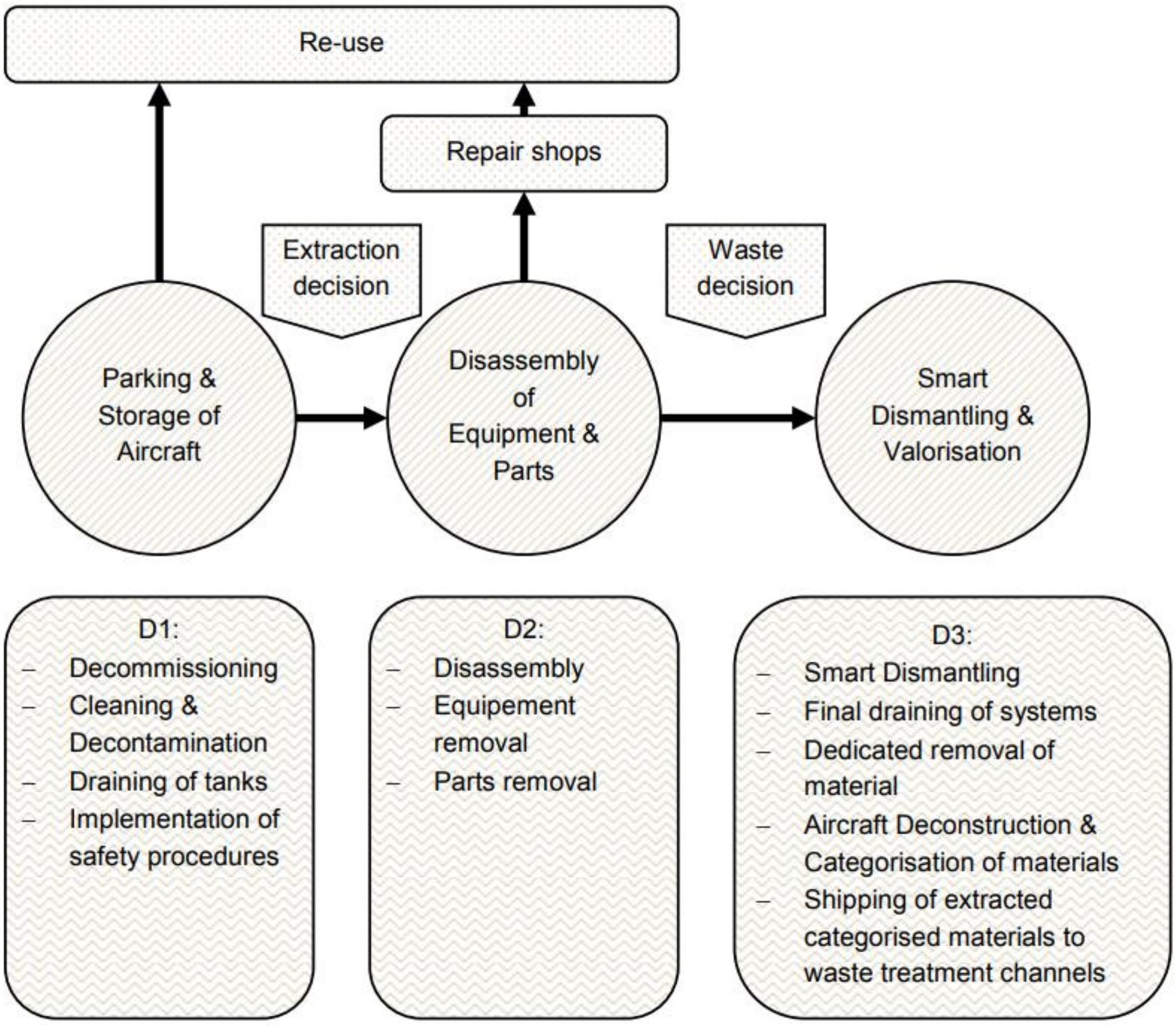


Fig 3.3 PAMELA's 3D Approach Airbus recycling strategy

Parts that are not fit for flight are destroyed immediately after disassembly. If the owner then decides to move on to the third step, disassembly, the aircraft is no longer required by aviation law, but must be handled in accordance with all applicable waste disposal regulations. PAMELA has tested different approaches to the dismantling order and methods to improve this step. After dismantling, the received materials are grouped, sorted and sent to the recovery channels. In the end, recycled metal can be returned into the corresponding one.

As a result, the project has shown that it is possible to achieve a valorization ratio of up to 85% by weight and save up to 90% of the energy and resources of metal material mining. In those days, the A300-B2 arrived with a total mass of 106 tons, which was reduced to 88 tons upon decommissioning. The mass of disassembled parts at the second stage reaches 13.5 tons. After the dismantling phase, only 13.5 tons of material, mainly insulation material and sheathing, remained unrecycled and were subject to disposal. In addition to proving a high recycling rate, PAMELA has been able to create a blueprint for how the industry can scrap and recycle any given aircraft in an environmentally sound, safe and cost effective manner.

In May 2007, a new PAMELA project started using the A380 static test frame. The project was called PAMELA A380 and used methods and best practices developed by the previous PAMELA project. By launching the PAMELA A380 a month before the first delivery of this type of aircraft, Airbus came close to already considering the end of the aircraft's life when developing a new type of aircraft. When dealing with the issue of recycling problems associated with larger aircraft, Airbus was able to assess the recovery potential of new alloys and achieved a 98% recovery rate for metal components. Calling it "smart demolition", Airbus addressed both the technical and commercial aspects of recycling in PAMELA projects.

Following the PAMELA project and applying its results, Airbus founded the Tarbes Advanced Recycling and Maintenance Aircraft Company (Tarmac Aerosave) in cooperation with companies such as Snecma Services and Aeroconseil. First operational launch the dismantling of the facility took place in 2009 in Tarbes, France. In 2012, the company achieved the placement of the 100th aircraft in Tarbes. A new factory opened in Teruel, Spain in 2013 and then in Toulouse-Francasal, France in 2017. It took the company almost three months to completely dismantle the aircraft. In January 2020, Tarmac Aerosave has reworked a total of 170 aircraft and 135 engines since their inception in 2007. Tarmac Aerosave's two shareholders besides Airbus are currently the Safran Group and Suez, each owning approximately one-third of the company. In addition, the organization is ISO accredited. 14001, ISO 9001, EN 9110, EN 9120 and certified by EASA/FAA part 145 and EASA part 147.

Tarmac Aerosave started its business by applying the recognition of the PAMELA project and expanded its capabilities to the environmentally and socially sound storage, maintenance and recycling of aircraft and engines. Eventually, the company was also able to increase its recycling rate to over 90%.

3.5 Boeing strategy

Compared to the Airbus fleet, the Boeing fleet is relatively old. While Airbus delivered its first commercial aircraft in 1974, the Boeing 707 debuted in 1957. Thus, most of the stored and currently retired aircraft belong to Boeing by pressuring the company to join the green movement. Boeing has taken a different approach to managing its growing decommissioning stream than Airbus. In partnership with ten European and American companies, Boeing founded the Aircraft Fleet Recycling Association (AFRA) in April 2006. Combines aircraft recycling experience with the best technical standards. AFRA is a self-funded non-profit organization whose members work in the aircraft recycling industry in accordance with the certificate and certain processes.

The mission of the association includes the formation of a global network of members at all stages of the supply chain, from the manufacturer to the processors of materials. Based on the collective experience of its members, a series of Best Practices for the Management of Used Aircraft Parts and Assemblies and the Recycling of Aviation Materials (BMP) was developed, version 4.0 of which became effective on April 18, 2019. The guide describes the handling of parts that are removed from an aircraft or engine during disassembly of a decommissioned asset, as well as the disposal of remanufactured parts and materials through a set of guidelines. For members or companies applying for membership, document is a verifiable standard.

Application for AFRA is open to all businesses and organizations related to aircraft. The applicant will be approved by the board of founding members and undertakes to ensure the following:

- aircraft and parts extracted from them are safe for future use in the aerospace industry,
- Defective parts and components are disposed of responsibly,
- Best practices are shared among AFRA members and all stakeholders

during storage, maintenance and disposal of aircraft, regardless of the manufacturer of this airplane

- during disassembly, the airframe and its components are disposed of in accordance with applicable legislation and best environmental practices.

AFRA currently has 90 members who enjoy benefits such as:

- Participate in shaping the future of end-of-life aircraft components and materials.

Sustainability, as well as in the development of best practice standards,

- Representation in regulatory bodies and the media,
- Opportunities to participate in AFRA committee projects,
- Engage with the industry through newsletters and updates,
- AFRA Electronic Newsletter with Association committee updates, member news,

And lists of upcoming events,

- Training in the value chain and new technologies for dismantling and Processing,
- Recognition of commitment to environmental responsibility and
- Opportunities for networking and sponsorship at AFRA meetings.

In addition, AFRA accreditation increases the cost of remanufactured parts because a higher level of safety is ensured, as well as quality in terms of environmental impact and occupational safety. The current members of AFRA are Boeing, as well as Tarmac Aerosave, Embraer, AELS, American Airlines, Delft University of Technology, Institute of Chemical Technology. technologies, Lufthansa Technik AG, Pratt & Whitney and Magellan Aviation Group, to name but a few (AFRAA). a few examples. about one-third of aircraft scrapped worldwide each year are dismantled and dismantled for parts members of AFRA, illustrating the association's impact on aviation recycling culture. AFRA has also approached the FAA and EASA official aviation authorities to obtain accreditation for their BMP manual. The BMP Manual has been accredited and has taken the first step towards legally responsive management of end-of-life aircraft. According to the missing news, these efforts have not yet been rewarded.

In addition to the successes achieved by the two major aircraft OEMs Boeing and Airbus, others manufacturers, companies and academic institutions have also tried their best to get an idea of final stage of the aircraft life cycle. Consequently, the industry was able to start creating a new the aircraft scrapping market, implying the efforts of Airbus and Boeing. In addition to Airbus and Boeing, there are other aircraft manufacturers such as Bombardier, Embraer, Comac and others. Most other aircraft manufacturers have joined the green movement in one way or another. For example, AFRA-accredited Bombardier began working on a metal recycling project with the Quebec Consortium for Research and Innovation in Aerospace (CRIAQ), other industry players and academic institutions. The first objective of the project was to better understand end-of-life requirements and associated commercially viable recycling technologies. In addition, in 2011 Helene Gagnon, then Vice President of Public Affairs, Communications and Corporate Social Responsibility Bombardier has stated its commitment to building an aircraft that is 100% recyclable. Therefore, the company must look for solutions to recycle the last 25% of its aircraft that are not yet recyclable. The Bombardier Cseries, rebranded as the Airbus A220 in 2018, even received an Environmental Product Declaration, a standardized way to quantify a product's life-cycle environmental impact as the aircraft model was designed for end-of-life.

Even today, when research is ongoing and where the future number of aircraft decommissioned the service is well studied, there is no regulation directly related to the handling of expired service life airplane. State that relatively few retired aircraft are now being used as justification for this missing rule.

Although proper regulation would be the best way to clarify the legal situation with aircraft. Recycling, there are two approaches for better classification.

The first approach uses regulation that indirectly affects the disposal of aircraft. The fact is that there is no regulation regarding the end of the life of the aircraft, this does not mean that the disposal they are not subject to any government regulation at all. Processes indirectly affected by various existing regulations due to the characteristics of some of the materials. Model provisions adopted by the European Parliament and related The Council includes Directive 2002/96/EC on Waste Electrical and Electronic Equipment. (WEEE), Directive 1994/62/EC on "Packaging and packaging waste" (Richtlinie 94/62/EC), Regulation (EC) No 1907/2006 on "Registration, evaluation, Authorization and Restriction of Chemical Substances (REACH)" and the European Directive 2002/95/EC of 2012 "Restriction of the use of certain hazardous substances in Electrical and electronic equipment” (Richtlinie 2002/95/EG). These rules apply the principle of extended producer responsibility. The trend of industrial legislation is clearly this principle, such as the European Directive 2008/98/EC on "Waste and certain Directives" clearly refers to the introduction of "the concept of an "extended responsibility", which "may include the obligation of manufacturers to accept and dispose of goods returned after use. The Directive also reaffirms the principle that primary waste the producer must pay the costs of waste management, which is called the polluter pays principle. BUT the waste hierarchy is also well established, choosing prevention as the best waste disposal, followed by reuse, recycling, recovery and finally disposal. Council Directive 1999/31/EC on "landfill" aims to reduce the organic material sent to landfill. This Thus, the directive again has an indirect effect on the disposal of aircraft. Organic materials include composite material and some fluids. Analyzing the current regulations for the disposal of aircraft companies can tailor their processes to the requirements of governments, which may perhaps one day they will also impose the end of the life of the aircraft.

The second approach tries to find similarities with other transport industries such as trains, shipping or automobiles. Acquires analogies with all three of these vehicles, finding similarities and differences in initial incidents, legal and other requirements, and the implementation of end-of-life processing. Recycling processes in the railway industry offer little information. As in aviation, there is no specific regulation governing the handling of decommissioned trains that does not call for a change in treatment at the end of their service life. Railroad cars are usually classified as waste. Thus, the main difference between the aviation and railway industries lies in the idea of environmentally friendly. A life cycle strategy in which a waste declaration must be made after all reusable parts have been removed. However, the shipping industry has been regulated since the adoption of the "Hong Kong International Convention for Safe and Environmentally Friendly Dismantlement of ships" in 2009. The convention contains, among other things, the obligation to conduct an inventory of hazardous materials when a ship is sent for recycling, as well as guidelines to help implement the convention, covering the entire life cycle of ships from design to recycling. The main problem in the industry is the sheer number of violations of naval regulations, as ships usually break down in shipyards where the rules are much less stringent, such as in India or Bangladesh. These ships, which consist mainly of steel covered with coatings, are then disposed of in the simplest way, without regard to safety and environmental issues (Fig 3.4).

Fig 3.4 Ship scrapping in Bangladesh

Also growing amount of composite materials used, which will be a future challenge and will require more specific regulations.

3.6 Aspects of the situation

When developing a regulation on the handling of expired service life, as well as when considering strategies or processes relating to the same topic, goals and objectives should be highlighted to close the loop. Discuss their various aspects, summarized below. Goals and driving forces can be divided into environmental and economic. The environmental benefits of end-of-life aircraft improvements include reduced end-of-life emissions and energy and natural resource savings. These benefits result in reduced environmental impact and therefore minimization global warming. Saving energy and natural resources despite environmental safety also economic benefits, since high quality recycled material can be sold at a good price, while savings on energy consumption and on the purchase of raw materials. Economical driving forces include labor costs, documentation costs and disposal costs leftover materials that cannot be recycled. All these costs are more environmentally friendly aircraft is recycled. However, the achievable result from sales of removed parts and recycled materials are also increasing (Fig 3.5).

Metal	Energy ($MJ\ kg^{-1}$) Primary from ore	Secondary from scrap	Average energy ratio (ore/scrap)
Magnesium	350–400	8–10	42
Aluminium	200–240	18–20	12
Titanium	600–740	230–280	2.6
Nickel	135–150	34–38	3.9
Steel	32–38	9–11	3.6

Table 24.2 Carbon dioxide generation in the production of metal from ore or scrap

Metal	Carbon dioxide production ($kg\ kg^{-1}$) Primary from ore	Secondary from scrap	Average CO_2 ratio (ore/scrap)
Magnesium	22–25	1.8–2.0	12.5
Aluminium	11–13	1.1–1.2	10.5
Titanium	38–44	14–17	2.6
Nickel	7.9–9.2	2.0–2.3	4.0
Steel	2.0–2.3	0.6	3.6

Fig 3.5 Energy needed to produce metal from ore or scrap

The aircraft recycling industry is complex and involves many different stakeholders, businesses, goals and processes. Process improvement saves energy, emissions, money and also space that would otherwise be used as landfill. The end-of-life stage has gained a lot lately public interest, which put pressure on the previously exclusively economic business, forced to engage in with fluctuations in metal prices. Legislative assistance, such as guaranteeing a stable income, is needed to optimally end the life of an aircraft. But another problem is about to appear, especially in the field of recycled materials, namely composite materials and lithium-ion batteries that are used in modern and future electric aircraft. Moving from wood to steel and aluminum, the composition of the aircraft structure has changed. Changed a lot over the decades. In recent years, the following change has already begun: partial replacement of aluminum alloys with composite materials. Driven by Purpose lower operating costs and emissions, aircraft OEMs are using a lighter, stronger composite material. On Fig 3.6 shown the total weight of larger commercial aircraft as a percentage of basis in recent years.

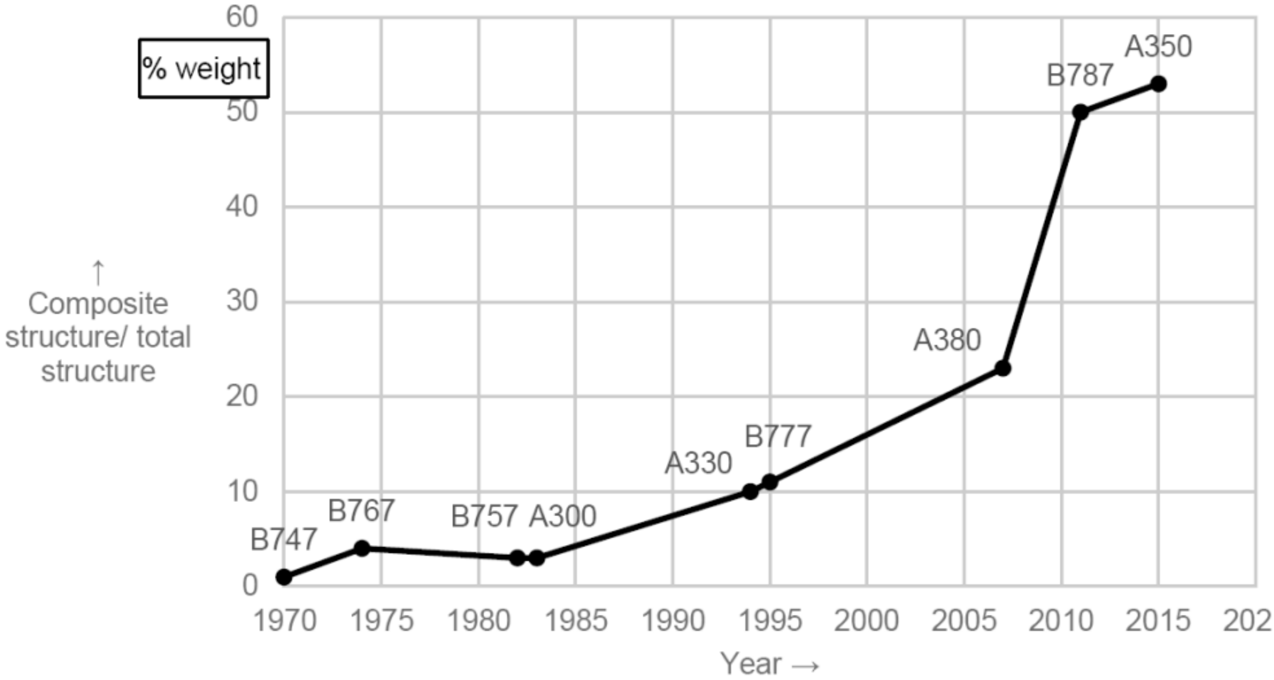


Fig 3.6 Use of composites in aircraft

3.7 Mechanical recycling

In the first phase of mechanical recycling, the composite waste is shredded into smaller pieces, also called recyclates. Subsequently, the different fragments are sorted. Low-speed cutting or grinding mills grind the material down to 50-100 mm. If the composite waste is homogeneous and does not contain metallic components, high-speed shredding is used to reduce the size from 50 μm to 10 mm. Thus, recyclates are divided into coarse recyclates with higher fiber content and fine recyclates with higher resin content. At present, all research is mainly focused on reinforced polyester fiberglass. This is due to the fact that recyclates and their reuse are used in low-value applications such as concrete filling, for example. An important aspect here is the price - carbon fiber is more expensive than fiberglass. Disruption of the physical integrity of carbon fiber due to mechanical processing can lead to economic and fiber loss. From the beginning of the development of this process, it had serious drawbacks, although studies by some authors have shown an improvement in the flexural strength of concrete after the addition of recycled fiberglass filler. However, other studies have shown that the use of recycled fiberglass as fillers is not economical because of the availability of other fillers, such as calcium carbonate or silica, as alternatives. Some scientists and engineers have succeeded in separating 70% of the glass fibers with a conventional hammer mill. The remaining 30% is then ground up and used as a filler for thermoplastics. A study by other scientists describes how aerospace waste was crushed with a hammer mill followed by grinding. The recyclates were compressed into flat trays and subjected to mechanical tests, which showed a reduction in mechanical properties of at least 50-60% compared to the original composite. As the particle size of the carbon fiber recyclate decreases, its mechanical properties increase. One important aspect of a more streamlined proposal for mechanical processing of both fiberglass and carbon fiber reinforced plastics is that a higher recirculation rate is more energy efficient, but still achieves a plateau at a certain processing rate. In addition, the composite matrix has been shown to be used as a fuel substitute, thus saving on the use of other (fossil) fuels

3.8 Thermal processing

Processes that use or produce high temperatures are called thermal processes. Three different types of operations exist for composite waste:

- Burning or burning only for energy,
- Incineration to recycle fibers and fillers to generate energy and
- Pyrolysis with regeneration of both fiber and fuel.

Since some European directives distinguish between "recycling" and "recovery", the first type of thermal processing, leading exclusively to energy recovery, cannot be considered as recycling process and therefore will not be explained further. The term incineration in this case must be separated from conventional waste incineration, as this type of recycling leaves behind recyclable material, while incineration leaves no reusable material behind.

Oxidation is a type of thermal process that involves the combustion of a matrix in a hot and oxygen-rich flow. The so-called "fluidized bed" technology is one such process and on the one hand, restores the fibers, and on the other hand, an organic resin matrix and the heat of combustion is used for energy recovery. This technology can be used for polyester and epoxy resin composites using both glass and carbon fibers. Composite scrap first mechanically broken into manageable pieces, which are then fed into the fluidized bed reactor. The reactor operates with a sand bed, which is heated and fluidized by a hot air stream. Which ensures fast and uniform heating. Epoxy resin composites require temperatures up to 550°C, while polyester resin composites only require 450°C. Although glass fibers lose 50% of their tensile strength at 450°C, carbon fibers have higher heat resistance and are less susceptible to degradation. Thermal stability and subject to less degradation even at 550 °C hot air flow decomposes the matrix and burns the pyrolytic charcoal. The pure fibers are then removed from the fluidized bed by a stream of hot air before being separated from the air in a cyclone. Heavier components, such as metal components, are not blown up with the airflow, and the resin from the matrix is completely oxidized in the afterburner, which generates energy. Received the resulting fibers have a fluffy shape and a length of up to 10 mm.

Pyrolysis uses temperatures between 300 and 800 °C in the absence of oxygen to decompose. Polymers. The resin matrix is broken down into lower molecular weight organic compounds, which can later be used as a raw material for composites or other chemical processes. Due to the pyrolysis process and subsequent ashing or oxidation in air, long fibers and it is possible to obtain fillers with a high modulus and a clean surface. The process can be used to polymer-matrix composites with both glass and carbon fibers. Various types of reactors can be used, although fluidized bed reactors and rotary kilns are more suitable. Result products are a mixture of solid, condensed liquid and gaseous components with different proportions and composition of materials. As mentioned earlier, pyrolysis technology is often combined with an incineration process to remove residual materials from the surface of the fibers.

3.9 Chemical processing

Chemical processing is also carried out to extract fibers from the composite material and especially suitable for carbon fiber composites with thermosetting matrix. Carbon fibers provide high thermal and chemical stability and, therefore, prevent mechanical failure and the destruction of bonds from processing process. In this recycling process, the matrix is chemically polymerized or is removed using dissolution chemicals and thereby exposes the fiber. As reactive fluids, liquids such as catalytic solutions, benzyl alcohol, and supercritical fluids (SCFs) can be used. Liquids whose temperature and pressure are just above their critical point are called supercritical, combining the characteristics of liquid and gaseous states. Application SCF is a relatively new approach that promises no chemical degradation of carbon fibers. and recovery of beneficial chemicals from the matrix. Chemical processing is also called solvolysis. Water and alcohol are environmentally friendly and can be separated from the dissolved solution by evaporation or distillation. solvolysis, however, tends to be energy intensive, leaving the push for research into more economical fits.

3.10 Lithium-Ion battery recycling

Many disposal problems arise from the design of the facility and the strategy adopted for disassembly and recovery. The number of individual phases in devices such as lithium-ion batteries, coupled with their distribution in complex designs with inert separators, complicates the task of separating into separate pure phases. The current method of recycling lithium-ion batteries uses pyrometallurgy, or grinding followed by hydrometallurgy. These methods result in low value product streams or have a high cost and low product recovery. Accordingly, savings from the use of recycled material compared to never used material range from -5% to +20%.66, 110.

Lithium ion batteries are currently being developed, manufactured and sold without recycling. With the inevitable increase in the production of electric vehicles in the coming years, it is vital to implement a scalable and suitable recycling scheme. Ideally, the creation of a scheme whereby EoL batteries are returned to manufacturers could start a standardization whereby lithium-ion batteries are destined for recycling.

The development of appropriate legislation will incentivize manufacturers to recycle their EoL lithium-ion batteries in a safe and cost-effective way. Addressing issues such as extended producer responsibility will undoubtedly help create circular partnerships. It is clear that cell and packaging design is vital to achieving an efficient and easy recycling process. It has recently been shown that separating electrode materials instead of shredding can result in savings of up to 70% compared to never used material, a strong economic and environmental argument in favor of segregation. Battery design to facilitate separation. The first is moduleless packages with cells that are easy to separate and open. Automation of this process, especially with the use of robotics, is of considerable interest. The second area is the use of adhesives and binders, which are important for both macroscopic disassembly (facilitating the separation and opening of cells) and microscopic delamination of electrodes (separation of active material from current collectors). The development of reversible adhesives in electrode construction, or perhaps even adhesive-free electrodes, will make it easier to peel and remove the active material. Improved package labeling would also allow different battery chemistries to be separated prior to processing and reduce the risk of cross-contamination.

The ideal battery for recycling would be in a pack configuration with solid bars instead of flexible cables, where large cells could be easily separated from the bulky structure. Cells can be autonomously dismantled and divided into anodes, cathodes and polymer separators. This will be facilitated by small changes in the geometry of the electrode and connector that do not affect the characteristics of the electrode. The active materials on the electrodes can be exfoliated and recovered using a binder that can be dispersed with aqueous solutions.

Recyclable design often includes minor changes to the structure of a product, but can help create a circular economy if it returns raw materials to the manufacturing process at a significantly lower cost compared to primary sources. During product development, there will be an initial phase where performance improvement is paramount, and this is replaced by cost considerations as the product starts to gain significant market share. Only at this point can environmental concerns affect product design.

Conclusion to the part 3

As it was said before with the increase in the growth of electric aircraft in the aviation market, the share of composite and lithium-ion batteries will also increase, demand will increase, the price will decrease, and with the increase in the number of batteries and composite materials, the question and demand for their processing and disposal

Unfortunately, in our society, not everything is done as we would like and there is nothing ideal, well, there are problems on which you can find an engineering and technological solution and the problem of disposal and recycling of electric aircraft belongs to this category.

Today, the situation with aircraft that develop their own cycle is not very good, there are various effective methods for their disposal, unfortunately there are no various right-handed drivers and authorities that could monitor this, therefore, airline companies are in a position to effectively dispose of their aircraft. Just for canning, although there are economic and environmental benefits in this.

After analyzing the market and methods of the giant aircraft manufacturers as well as monitoring the right directives in various aviation regulatory authorities, the following projects and ideas were proposed to improve the above problems:

- Create and adopt a directive where the manufacturer undertakes to accept the aircraft after decommissioning for further recycling process.

Aviation companies do not consider it necessary to spend money on recycling, they prefer to simply drive the aircraft to the cemetery, most often the aircraft are subjected to partial recycling, where various units are removed from the aircraft for sale for spare parts.

- The issue of recycling must be taken into account at the product design stage.

Today, recycling is not a priority, the focus is on technical characteristics, and this also applies to the development of new electric aircraft and the design of new energy sources for these aircraft.

- Adopt international standards for marking batteries and composite materials, according to which it was possible to clearly define the composition of the device and material.

Unfortunately, there is no global standard for marking these aircraft parts.

PART 4
LABOR PROTECTION

The recycling of an aircraft is a complex procedure containing of several hazardous steps. First, it must be prepared for recycling (all fluids drained, all useful and non-recyclable components removed, and then the airframe should be cut to pieces and sent for recycling). The worker who prepares an aircraft for recycling must make all necessary preparations have proper tools to perform the job, and be cautious of the dangers listed in this article.

4.1 Harmful and Hazardous Working Factors

Due to huge size of a passenger aircraft and economic factors, the retired aircraft are disassembled outdoors on the so-called "boneyards". So, the workplace, being outside of any building or hangar, is subjected to environmental factors.

The first potentially hazardous working factor will be the microclimate. Microclimate is a set of atmospheric conditions, such as humidity, temperature, speed of wind, barometric pressure, dew, frost, heat balance, and evaporation. The employee must be aware of and strictly follow Occupational Safety and Health Act of 1970. The employer, according to this OSHA standard, must assure safe and healthful working environment for his workers, and provide research, information, education, and training in the field of occupational safety and health, protect their employees from hazards. There are 4 groups of OSHA standards: General Industry, Construction, Maritime, and Agriculture. The employer must follow the standards applicable to the type of work performed.

When the aircraft arrives at the boneyard, all fluids are drained. So the next working factor is working with hazardous materials and concentration of pollutants. In case of electric aircraft it may be coolant for batteries or electric engines, and brake fluid.

According to the Engine Coolant and Antifreeze Bittering Agent Act of 2005, the engine coolant and antifreeze should contain a bittering agent. The purpose of the engine coolant and antifreeze bittering agent is to reduce the number of antifreeze poisonings in children and animals through the addition of denatonium benzoate to ethylene glycol-based engine coolant and antifreeze products. Ethylene glycol is a toxic, clear, colourless, and sweet tasting liquid that is used as the primary compound in the majority of engine coolant and antifreeze products. Because of the nature of this chemical joint, improper disposal or accidental ingestion, contact with ethylene glycol-based antifreeze poses an unnecessary health risk.

Denatonium Benzoate (Bitrex) used in these coolants. According to the California Institute of Technology's Centre for Science and Engineering of Materials, denatonium benzoate is the most bitter substance known. It is harmless by itself, but since it is added to coolant, it must never make contact with skin or mucous membrane.

Brake fluid is regulated because it contains harmful contaminants, such as brake cleaning solvent. The regulations require safe management and disposal of used oil, which protects not only the worker, but the nature as well.

In 1987, EPA issued a memorandum that defined "used oil" to include brake fluid Therefore, the used oil regulations apply to use brake fluid that is recycled as used oil. This is regulated by TERC Used Oil section.

On the other hand, if used brake fluid is going to be disposed of, then it is not regulated under the used oil standards, but rather, it is regulated like other potentially hazardous wastes by the TERC Hazardous Waste section.

Then the electric aircraft battery must be removed. The battery has a lot of hazardous materials and is sensitive to damage. This poses safety risks to the personnel. There are several regulations that must be followed when handling used batteries. The UK and EU regulations are used in this article as an example, but it is similar for most countries. The main ones are The Batteries Directive, The Hazardous Waste Regulations, European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) and the Carriage of Dangerous Goods Regulations. The battery is usually declared waste for the aircraft use, when an aircraft is at scrap yard. But it can also be reused for other applications, such as powering homes or be a charging station on some companies' plants. But if there is no use to it at all, it should be recycled.

Handling heavy loads because disassembling and recycling an aircraft is connected with moving some heavy loads by hand, it is regulated by the Manual Handling Operations

Regulations legislation, 1992. The Manual Handling Operations Regulations legislation was updated and improved in 2002. According to it, employers must ensure that employees work as safely as possible. There are some other regulations that can be applicable to this factor: the Provision and Use of Work Equipment Regulations 1998 (PUWER) and the Lifting Operations and Lifting Equipment Regulations 1998 (LOLER).

As there are no extremely flammable liquids on-board of the electric plane, in opposition to jet engine powered aircraft, the electrical instrument may be used. So the risks linked to the use of powered tools must be taken into account by the employer. Under the Occupational Safety and Health Act of 1970, employers are responsible for providing a safe and healthful workplace for their employees. Here are some of the standards that must be followed: 2000 edition of the National Fire Protection Association's (NFPA) Electrical Safety Requirements for Employee Workplaces (NFPA 70E), and the 2002 edition of the National Electrical Code (NEC).

4.2 Analysis of Working Conditions and Development of Protective Measures

4.2.1 Microclimatic factor

Microclimatic parameters of the working place are mostly determined by temperature, relative humidity and airflow. These values affect the well-being (comfort) or ill-being (discomfort) of a worker. The extreme weather conditions may pose risks to worker s health and life.

(1) For example, extreme winds may knock the worker off the airplane or drop a heavy part from aircraft on him. Working at heights, for example, on the wing or fuselage of an aircraft, is especially risky in high winds, because there is nowhere for the worker to hide, and strong gusts can throw worker off balance. The more the distance to the ground, the more are chances for death or serious injury. 30% of fatal falls happen from a height of less than 2 metres, 50% - from high below 3 meters. To avoid such unfortunate events, the next safety precautions must be made:

The worker must check the forecast before the day of planned work, and check it from time to time during work. The work at elevations must not be scheduled on days where high winds are expected.

It is mandatory to wear a harness when working on big heights (1.5m and above) and you should ensure that you are connected to an anchor point at all times. Also it is best to follow the so-called “3-point rule”, when possible. You must always have 3 fulcrum points, for example, stand on ground with 2 legs and hold to aircraft with 1 hand, or when moving one leg from the ground, hold to aircraft with 2 hands.

Ensure that the equipment used for aircraft disassembly, or for access to higher points on aircraft, such as ladders and scaffolds, are mounted correctly and will not fall in case of high wind.

All equipment present on an aircraft must be taken off according to Aircraft Maintenance Manual or similar document. Always check if outer panels, flaps, slats, portions of wing are properly held by ropes, cables or other equipment recommended in manual when you disassemble the aircraft. The high winds can disrupt the balance of the part that is taken off. If you do not obey, the injuries to you and other personnel can occur, and the equipment that is still good to use can be damaged.

Of course, you can perform other types of work when there are high winds. But be sure to follow these recommendations:

Never work on elevations in such conditions. The high winds can disrupt your balance and lead to injury or death.

Ensure that tools are packed away safely and that any loose materials are safely secured. The wind can pick up a piece of scrap material or a panel and carry it far from aircraft, injuring workers who happen to be nearby.

Be sure to wear proper uniform. You should always wear the protective helmet, durable and non-slippery footwear, clothes that can protect you from spillage of dangerous chemicals or other harmful conditions. The employer should have clear instructions about which uniform you must wear, and in most cases will provide you with it.

Do not pick up large-area panels in high winds, because it can act as a sail and blow you away. This can lead to injuries to personnel or damage to equipment.

(2) The high and low temperatures may also affect working conditions, so they must be taken into account. Although illness from exposure to heat can be easily prevented, every year, thousands become sick from excessive heat exposure, and there are even some fatal

cases. According to OSHA, most outdoor fatalities, 50% to 70%, occur in the first few days of working in warm or hot environments. This happens because the body needs to build a tolerance to the heat gradually over time. The process of building tolerance is called heat acclimatization. The employer must carefully plan the work so that unprepared workers will not be in danger. The sufficient amount of water must be provided, alongside with some place with shade and lower temperature for workers to rest. The employee must be aware of his condition and report immediately if feeling sick, and stop the work.

The risk factors for heat illness include heavy physical activity, warm or hot environmental conditions, lack of acclimatization, and wearing clothing that holds in body heat.

Hazardous heat exposure can happen during any season, not only in the summer. Workers who have not spent time recently in warm or hot environments will need some time to acclimatize to the heat. During their first few days in warm or hot environments, these things must be done:

- Workers should drink a lot of water to stay hydrated
- Changes to workload and schedules must be made. For example, the supervisors should tell workers to slow down physical activity, like reducing the speed of work or scheduling work for the morning or shorter shifts with frequent rest breaks in the shade.
- At a minimum, all supervisors and workers should receive training about heat-related symptoms and first aid.

OSHA recommends rest, water, and shade to prevent the heat-related illness. It can also be used to treat the heat-related illness, but if it does not end, the ambulance must be called for the sick worker.

Cold conditions (especially in winter) also present hazards, such as slippery surfaces, strong winds and sheer cold. Employers must prevent any harm to workers health and life. OSHA and National Oceanic and Atmospheric Administration (NOAA) have some recommendations regarding this issue:

To prevent slips, trips, and falls, employers should clear snow and ice from walking surfaces, and spread de-icer on used surfaces. If it is necessary to walk on ice and snow, the workers should wear footwear that has good traction and insulation. This can be provided by employer or employee himself. It is better to use insulated and water-resistant boots or rubber over-shoes with good rubber treads.

Take short steps and walk at a slower pace to react quickly to changes in traction. Employer must provide fall protection and training when it is necessary for the worker to work on the elevated heights.

The ladders and other means of reaching higher parts of an aircraft should not be covered in snow and/or ice. It is employer s responsibility to maintain the equipment in safe condition, and the workers should always check if the ladder is safe to use, and report any problems to the supervisor.

4.2.2. Risks posed by recycling of electric battery

If it was decided that the battery of an aircraft cannot be reused in a safe and meaningful way, or if the owner decided that it should meet its end, the battery must be recycled. There are the fire and explosion safety risk in the processing or disassembly operation of batteries. There are fundamental hazards with which the worker has to deal when dismantling the battery and preparing it for recycling. Here are the most common hazards:

- Mechanical
- Electrical and the intrinsic potential energy in the battery, electrocution, short circuits and release of energy leading to fire and explosion
- Stored energy, thermal runaway and overheating
- Physical, manual handling issues with the mass of the battery
- Chemical risk factor
- Respiratory hazards, including potentially liberation of HF, (highly reactive) hydrogen fluoride
- Carcinogenic materials, present in electrode materials and electrolytes.

The employer must plan and arrange the workplace to be safe in the event of a serious incident. The personnel must be trained to perform the first aid, and the specially-trained professional person must be present to do the first aid in extreme cases.

Before starting the work, the employer must consider:

- The number of units to be processed
- The number of workers to be recruited and trained
- Time they will be required to work for
- Levels of competency and experience required

The worker must always inspect the battery for any damage before starting the work. If a battery is damaged, the worker must not work with it and inform the supervisor. There exist an option to dismantle and recycle such batteries remotely, to ensure no one will be hurt. But since it is much more expensive, the undamaged batteries are recycled by human workers.

Employer must pay attention to planning the work and the workplace ergonomics. The worker should not dismantle batteries in the centre of a building or work area but in a secluded part of the structure where, if a fire breaks-out, the damage may be contained or limited. The workplace design must allow people to literally step-back from the work in the event of an incident and must allow them to retreat to a place of safety. The exit must not be on the opposite side of the working place.

The worker must wear protective gear according to standards with working with hazardous materials, and electricity.

4.2.3. Electricity handling factor

Electricity is a serious workplace hazard. Employees can receive electric shock, serious burns, and may fall from aircraft or damage themselves because of it. There even were fatal cases recorded. To ensure that the work can be done safely, the next precautions must be made:

1. The employees must undergo proper training before being allowed to work with the electrical instrument. If the employee has any questions, the supervisor must be

ready to help. Additionally, the information about working with electrical instrument should be placed in the workplace, so that everybody can read it when needed.

2. The employer must take responsibility to maintain the instruments in good and safe condition. If the instrument is damaged, it must be sent for repairs or replaced by a new one. The employee, on the other hand, must perform the visual inspection of the instrument before work. Is the cable damaged? Are there visible wires? Is the casing damaged? The damaged instrument must not be used, and must be reported to supervisor/employer. If the instrument stops working during the shift, or has strange noises or smell, the worker should immediately stop it. Then this instrument should be sent for inspection to be repaired or replaced.

3. The employee must wear safety gear, recommended by safety standards and employer. If worker will not obey, the damage to persons and equipment can occur.

4.3 Fire Safety Rules at the workspace

4.3.1. Dangers and Possible Solutions

Fire safety becomes everyone's job in the workplace. Employers must educate employees about fire hazards in the workplace and what to do in the event of a fire. This plan should specify the responsibilities of key personnel in the event of a fire and a plan for the evacuation of workers on site. In the construction industry, a "fire protection plan" must be drawn up before any demolition work begins. The aircraft is a complex structure in which a huge amount of flammable parts and substances are assembled, when disassembling it is necessary to know what the employee is dealing with in order to prevent possible dangers.

The specialist must be able to:

- work safely at all times, following health and safety regulations and other relevant rules, directives and guidelines
- perform actions to remove elements within your personal authority
- carry out the disassembly and dismantling of components in the specified sequence and in the agreed documentation report all cases where the dismantling activity cannot be fully complied with or in the presence of identified defects that go beyond the regulations
- issue the relevant documentation in accordance with organizational requirements

- dispose of waste in accordance with safety regulations practices and approved procedures
- leave the aircraft and system in a safe and proper condition, disposal of debris from foreign objects after the completion of the activity

4.3.2. Knowledge and understanding

The specialist must know and understand:

- specific security practices and procedures that you need observe when working with aircraft fire protection systems (including any specific legislation, rules/codes of practice for activities, equipment or materials)
- the importance of maintaining aircraft fire protection systems, and impact on extended range twin engines Procedure systems (ETOPS), electrical connections Systems (EWIS), legislation and local procedures
- the need to check that switches, selectors and circuit breakers are in the correct position before applying any form of external energy (for example, electrical, hydraulic, air or vacuum)
- requirements and the importance of understanding and applying human factors as defined by regulatory requirements and
- hazards associated with maintenance work on aircraft fire protection systems, as well as tools and equipment used, and how to minimize them and reduce any risk
- protective equipment that you need to use for both personal protection (PPE) and aircraft protection
- what is dangerous voltage and how to recognize victims of electric shock
- how to reduce the risk of phase damage from the ground (for example, insulated tools, rubber mats and isolation transformers)
- how to extract and use information from aircraft manuals, magazine books, flight logs, diagrams, diagrams and physical layouts, specifications, symbols used in aircraft fire protection systems, and other documents on dismantling works
- terminology used in aircraft fire protection systems and usage system diagrams and related symbols

- various types of pipes and components that make up an aircraft fire protection system (e.g. rigid pipes, hoses, pipes connectors; sealing and supporting devices for pipes; valves; pumps; mechanical and electrical control)
- principles of operation of the aircraft fire protection system processed (e.g. thermal switch, thermocouple, continuous loop, continuous element; fire detection and notification; sources and types of fire extinguishing agent; extinguishing agent control and distribution)
- methods used to remove components from aircraft fire protection systems without damaging components or surrounding structure
- various mechanical fasteners to be removed and replaced, and methods for removing and replacing them (for example, threaded fasteners, special fasteners)
- different types of electrical connectors that are used, methods unlocking, orientation indicators and localization and locking connections eighteen.
- importance of electrostatic discharge (ESD) preventive measures when working with sensitive equipment or devices
- the importance of ensuring that any exposed components, wires or pipe ends are properly closed/protected twenty.
- the need to properly label and store components that require repair or overhaul, and to verify that the replaced components have the correct part/identification markings and accompanying release documentation
- how to make adjustments to components/disassembly to ensure that they work correctly

Conclusion to the part 4

The recycling of an aircraft is a complex procedure containing of several hazardous steps. First, it must be prepared for recycling (all fluids drained, all useful and non-recyclable components removed, and then the airframe should be cut to pieces and sent for recycling). The worker who prepares an aircraft for recycling must make all necessary preparations have proper tools to perform the job, and be cautious of the dangers listed in this article.

Due to huge size of a passenger aircraft and economic factors, the retired aircraft are disassembled outdoors. So the workplace, being outside of any building or hangar, is subjected to environmental factors.

Electricity is a serious workplace hazard. Employees can receive electric shock, serious burns, and may fall from aircraft or damage themselves because of it. There even were fatal cases recorded.

If it was decided that the battery of an aircraft cannot be reused in a safe and meaningful way, or if the owner decided that it should meet its end, the battery must be recycled. There are the fire and explosion safety risk in the processing or disassembly operation of batteries. There are fundamental hazards with which the worker has to deal when dismantling the battery and preparing it for recycling

An aircraft is a very complex structure with billions of components and various materials and the substance in most of them can be very strong igniters such as aviation fuel, oils, electrical system, lithium-ion batteries, composite materials, therefore it is very important that an employee who is engaged in the recycling department of spmolets realized that in case of a fire, he could be in danger in the first place of his life and the life of his employees, as they say in society, safety regulations and fire regulations were written in blood, knowledge of these rules is very important and their observance is even more important.

PART 5
ENVIRONMENTAL PROTECTION

Driven by the need to decarbonize personal vehicles to meet global targets to reduce greenhouse gas emissions and improve air quality in urban centers, the electric vehicle revolution is set to revolutionize the automotive industry. In 2017, electric vehicle sales exceeded one million vehicles per year worldwide for the first time and in close future we will see the electric aircraft in our skis. Making conservative assumptions of an average battery weight of 250 kg and a volume of half a cubic meter, the resulting battery waste will be about 250,000 tons and half a million cubic meters of unrecycled battery waste when these vehicles reach the end of their life. While reuse and current recycling processes may redirect some of this waste to landfill, the cumulative burden of EV waste is significant given the growth trajectory of the EV market. These wastes represent a number of serious global problems; in terms of battery storage before repurposing or final disposal, in the manual testing and disassembly processes required for both, and in the chemical separation processes that recycling entails.

Given that the environmental footprint of electric vehicle production is strongly affected by the mining of raw materials and the production of lithium-ion batteries, the resulting waste streams inevitably place different demands on end-of-life disassembly and recycling systems. In the waste management hierarchy, reuse is considered more preferable than recycling (Fig 5.1). Because industrial lithium-ion batteries (LIBs) have significant value, it has been proposed to cascade their use through an application hierarchy to optimize material usage and lifecycle impact. Energy storage markets are under development as energy regulators in various places move to cleaner energy sources. Energy storage is especially in demand in areas where weak grids need to be strengthened, where the widespread use of renewable energy requires supply to be balanced with demand, where it is possible to trade energy with the grid and in off-grid applications. Battery recycling projects have begun to be developed in places where there is regulation and market harmonization. However, large concentrations of waste – whether it be repairs, remanufacturing, dismantling or final disposal – can create serious problems. For example, a warehoused tire fire in Poway’s, Wales, smoldered for fifteen years from 1989 to 2004. Because the electrode materials in LIB are much more reactive than tire rubber3, without a proactive and economically sound LIB waste management strategy, there are potentially greater hazards associated with the accumulation of end-of-life LIB stocks. Already, the number of reported fires in metal processing plants is increasing due to illegal or accidental concealment of (consumer) LIB under the guise of, for example, lead-acid batteries. Examples of recent major fires include those that occurred at metal recycling facilities in Shoreway, San Carlos, USA, in September 20165, Guernsey in August 2018, and Tacoma, Washington, USA, in September 2018.

According to a number of studies, electric transport will not be able to develop until the problem of recycling and disposal of batteries is solved.

The electrification of transport has become a major challenge for all automakers. But as more and more electric vehicles are produced, a new problem is emerging, which is almost impossible to solve and in comparison with which CO2 emissions from internal combustion engines are nothing more than an annoying nuisance.

Electric vehicle batteries are starting to become a new environmental problem. From the report published in the journal Nature, it becomes clear that its scale cannot be compared with the CO2 emission problem. The researchers concluded that it is urgent to put the disposal and processing of lithium-ion batteries on stream. And there are several reasons for this.

First, it is necessary to use natural resources more economically, which are not unlimited. Lithium batteries for electric vehicles are made from cobalt, a mineral mined primarily in the Congo. The growing demand for it has led to the fact that the mines there today use child labor, and the mining process itself cannot be called environmentally friendly and environmentally friendly.

Secondly, every day more and more batteries need to be disposed of - spent batteries will soon have nowhere to go. So in 2017, more than 1 million electric vehicles were sold worldwide. According to the authors of the study, this is 250,000 tons of batteries, which in 10 years will have to be somehow disabled. For example, Toyota offers to equip solar power

plants with them. But there are more and more electric vehicles, and there may not be a use for so many worn-out batteries. As a result, they will rot in landfills, poisoning nature.
That is, not just recycling is necessary, but complete recycling of batteries, and here we will face a third, more serious problem, the chance to solve which we have already missed. Thousands of batteries will have to be dismantled daily for recycling. At such a scale, it will not be possible to do without automated conveyors. But each automaker installs unique batteries on their cars that differ in structure from others, and in principle it is not so easy to disassemble them into their component parts. The main problem is that there is no standardization, without which hundreds of thousands of tons of batteries will have to be disassembled manually, slowly and inefficiently.

As a result, in order to avoid a battery catastrophe, it is urgent to develop a unique battery consisting of identical blocks, which can be disassembled by robots, and to establish a process for processing materials to create new batteries.

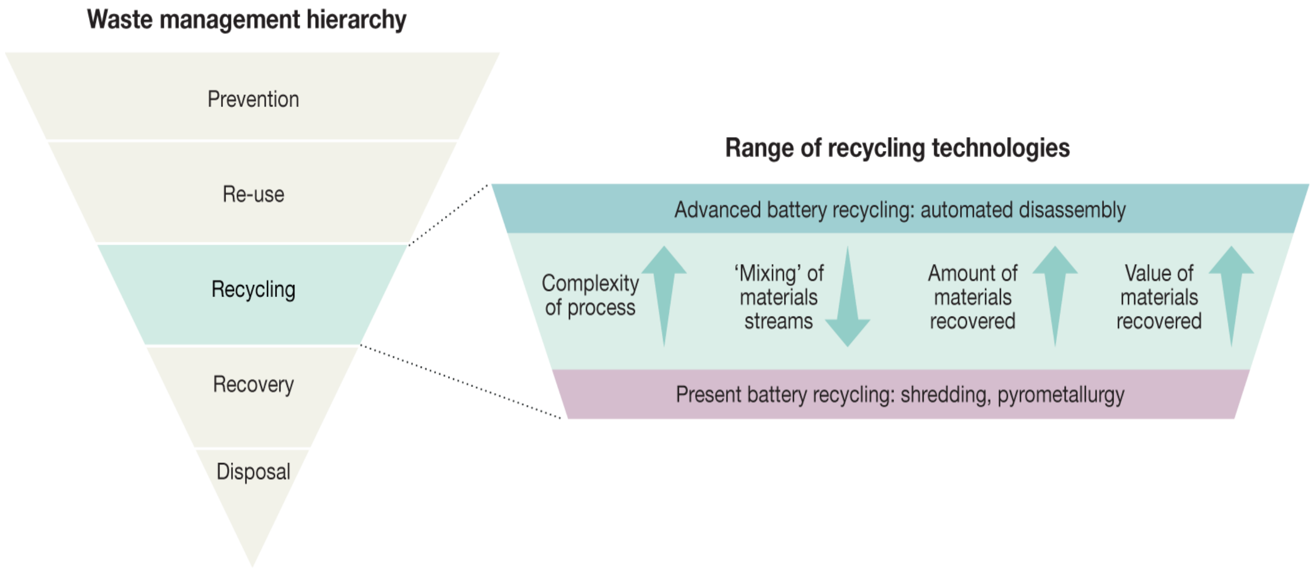


Fig 5.1 Hierarchy of waste management and range of recycling options

Waste can also be a valuable resource. The cells and materials contained in electric vehicle batteries are not available in many countries and access to resources is critical to ensure a stable supply chain. In the future, electric vehicles may prove to be a valuable secondary resource for critical materials, and it has been argued that batteries with a high cobalt content should be immediately recycled to increase cobalt reserves6. With tens of millions of electric vehicles produced each year, conserving the resources used in the production of electric vehicle batteries will certainly be essential to the sustainability of the automotive industry of the future, as will the economical use of materials and energy. 3R system (reduce, reuse, recycle). Here we provide an overview of the state of the art and identify some of the important issues related to LIB EV operation management.

5.1. Social and environmental impact of LIB

If we consider the two main primary production methods, it takes 250 tons of mineral ore spodumene to produce one ton of lithium or 750 tons of mineral-rich brine. Processing large quantities of raw materials can lead to significant environmental impact. Brine production, for example, entails drilling a well in a salt marsh and pumping a mineral-rich solution to the surface. However, this mining depletes groundwater. In Chile's Salar de Atacama, a major center of lithium production, 65% of the region's water is used for mining. This affects farmers in the region, who then have to import water from other regions. The need for water in the processing of lithium obtained in this way is significant: to extract a ton of lithium, 1900 tons of water are required, which is spent on evaporation.

In contrast, only 28 tons of used LIB (about 256 used lithium-ion batteries for electric vehicles) would be needed for secondary production. The net impact of LIB production can be significantly reduced if more materials can be recovered from decommissioned LIB in a form that is as close to usable as possible. However, in a phase of rapid growth in the electric vehicle market, recycling alone cannot come close to replenishing mineral reserves. LIBs are expected to last 15–20 years based on calendar aging predictions (aging due to the time that has passed since manufacture), which is three times longer than lead-acid batteries. Initial concerns about a lack of resources to scale up lithium-ion battery production focused on lithium; however, lithium stocks are unlikely to become an obstacle in the near future.

Of great immediate concern are the cobalt reserves, which are geographically concentrated (mainly in the politically unstable Democratic Republic of the Congo). They have experienced sharp short-term price fluctuations and raise numerous social, ethical and environmental issues in connection with their extraction, including artisanal mines using child labor. Beyond the environmental imperative of recycling, there are serious ethical issues associated with the supply chain of materials, and this social burden is being placed on some of the world's most vulnerable people. Given the global nature of the industry, international coordination will be required to support concerted efforts to recycle lithium-ion batteries and the circular economy in materials.

5.2. Stabilization and passivation of end-of-life batteries

Once the LIB has been designated for processing, the three main processes include stabilization, opening and separation, which can be performed individually or together. LIB stabilization can be achieved with brine or ohmic discharge. However, stabilization during the opening process is currently the preferred method in the industry because it minimizes costs. It consists of grinding or crushing batteries in an inert gas such as nitrogen, carbon dioxide, or a mixture of carbon dioxide and argon. Modern LIB physical processing in Europe and North America includes the Recupy (France), Akkuser49 (Finland), Duesenfeld (Germany) and Retrieve (USA/Canada) processes. Large-scale European processes currently do not use pre-opening stabilization techniques, instead choosing to open in an inert atmosphere of carbon dioxide or argon (less than 4% molecular oxygen). Opening under carbon dioxide allows the formation of a lithium carbonate passivating layer on any exposed lithium metal. The Retriev process differs from European processes in that it uses water spray during the opening phase. Water hydrolyzes any open lithium and acts as a heat sink, preventing heat from escaping during opening.

Discharging through saline solutions or "brine" (previously used sea water) is an alternative method that should render the cells harmless by corrosion and subsequent leaching of water into the cells, which passivates the chemistry of the internal cells. Aqueous solutions of halide salts have been shown to cause significant corrosion at the ends of battery terminals, while alkali metal salts such as sodium phosphate have been shown to cause much less corrosion without water intrusion, allowing cells to be evaluated and reused. This represents a significantly safer method of discharge than using sea water; however, competing electrochemical reactions do occur. Oxygen, hydrogen and other gases such as chlorine (depending on the salts in the brine) will form at the anode and cathode terminals and can potentially be collected, although the dangers and difficulties associated with this should not be underestimated. The time for a full discharge depends on the solubility of the salt and therefore on the conductivity of the solution; an increase in temperature will also shorten the discharge time. After the discharge is completed, the cell components can be separated into streams of different materials for further processing: steel can or aluminum laminate, separator, anode (graphite, copper, conductive additive), binder and cathode (active material, aluminum, carbon black, binder).

The brine dump method is not suitable for high voltage modules and blocks due to the high electrolysis rate and intense outgassing. However, for low-voltage modules and cells (or after the high-voltage battery has been dismantled) where electrolysis can be more closely controlled, this could, in principle, offer a discharge method in which hydrogen and oxygen could be recovered for other applications, increasing the cost-effectiveness of the process. The disadvantage, however, is that contamination of the contents of the cell can complicate subsequent chemical processes or reduce the value of the recycled material streams.

An alternative to using salt solutions is direct ohm discharge of the battery through the carrier circuit. If electricity can be recovered from the discharge, this could partially offset the costs of further processing. By comparison, domestic consumption of a standard UK home is up to 4,600 kWh per year. So a 60kWh battery at 50% charge and 75% health has a potential 22.5kWh to regenerate at end-of-life, powering a UK home for almost 2 hours. At £14.3p/kWh, this equates to £3.22/pack, which may seem like a modest profit that doesn't justify the investment in equipment. However, if it is not recuperated, the discharge energy must be dissipated, and this will increase the load on the cooling system, which will lead to additional costs. In addition, mass recycling of electric vehicle batteries should allow for economies of scale. Similarly, recovered energy can make a useful contribution to the profitability of repurposing for reuse (see Battery Evaluation and Disassembly).

LIB cells can be shredded at various states of charge, and commercially, if discharged modules or cells are to be treated in this manner, discharging prior to shredding increases the cost of the processes. In addition, it remains unclear what exactly the optimal discharge level may be. Depending on the chemistry of the cells and the depth of discharge, over-discharging the cells can cause copper to dissolve in the electrolyte. The presence of this copper is detrimental to material recovery because it can then contaminate all the various material streams, including the cathode and separator. If the voltage is then increased again or “normal” operation is resumed, this can be dangerous as copper can redeposit throughout the cell, increasing the risk of short circuits and thermal failure.

Current LIB processing technologies essentially circumvent these problems by loading end-of-life batteries directly into a shredder or high temperature reactor. Industrial grinding technologies can passivate batteries directly, but extracting battery materials requires a complex set of physical and chemical processes to produce usable material streams. Pyrometallurgical recycling processes (see Stabilization and Passivation of End-of-Life Batteries) on a large scale can accept entire EV modules without further disassembly. However, this solution cannot capture much of the embodied energy that goes into LIB production and leaves a lot of work for chemical separation methods as the battery materials become more and more intimately mixed.

5.3. Processing methods

5.3.1. Pyrometallurgical recovery

Pyrometallurgical metal recovery uses a high-temperature furnace to reduce constituent metal oxides to an alloy of Co, Cu, Fe, and Ni. The high temperatures used mean that the batteries "melt" and this process, which is a natural extension of those used for other types of batteries, is already being used commercially for consumer LIBs. This is particularly advantageous for the recycling of conventional consumer LIBs, which currently tend to focus on imperfectly sorted cell feedstocks (indeed, batteries can be recycled along with other waste types to improve thermodynamics and resulting products), and this versatility is also valuable. Regarding LIB for electric vehicles. Since metal current collectors aid the smelting process, this method has the important advantage that it can be used with whole cells or modules without the need for a preliminary passivation step.

The products of the pyrometallurgical process are the metal alloy fraction, slag and gases. Gaseous products formed at lower temperatures (<150 °C) contain volatile organic compounds from electrolyte and binder components. At higher temperatures, polymers decompose and burn out. The metal alloy can be separated by hydrometallurgical processes (see section "Hydrometallurgical recovery of metals") into its constituent metals, and the slag usually contains the metals aluminum, manganese and lithium, which can be recovered by further hydrometallurgical processing, but alternatively can be used. In other industries such as the cement industry. There is a relatively small safety risk in this process as all cells and modules are subjected to extreme temperatures with a reducing agent to recover the metal - the main contributor here is aluminum from the electrode foil and packaging - so hazards are contained in the processing. In addition, the combustion of electrolytes and plastics is exothermic and reduces the energy required for the process. It follows that the pyrometallurgical process generally does not take into account the disposal of electrolytes and plastics (approximately 40–50 percent of the battery weight) or other components such as lithium salts. Despite environmental disadvantages (such as the generation of toxic gases that must be captured or purified, and the need for hydrometallurgical after treatment), high energy costs, and limited recoverable materials, this process remains frequently used to recover minerals. Valuable transition metals such as cobalt and nickel.

5.3.2. Separation of physical materials

For regeneration after grinding, the recovered materials can be subjected to a variety of physical separation processes that exploit various properties such as particle size, density, ferromagnetism, and hydrophobicity. These processes include sieves, filters, magnets, shaker tables and heavy media used to separate a mixture of lithium rich solution, low density plastic and paper, magnetic sheaths, coated electrodes and electrode powders. The result is usually a concentration of electrode coatings in the fines of the material and a concentration of plastics, housing materials and metal foils in the coarse fractions. Coarse can be subjected to magnetic separation processes to remove magnetic materials such as steel casings and density separation processes to separate plastic from foil. The fine product is called "black mass" and consists of electrode coatings (metal oxides and carbon). Carbon can be separated from metal oxides by froth flotation, which uses the hydrophobicity of carbon to separate it from more hydrophilic metal oxides. An overview of how these processes are being used by several companies is shown in (Fig 5.2), where Recupy (France), Akkuser49 (Finland), Duesenfeld50 (Germany) and Retriev (USA/Canada) processes are mentioned.

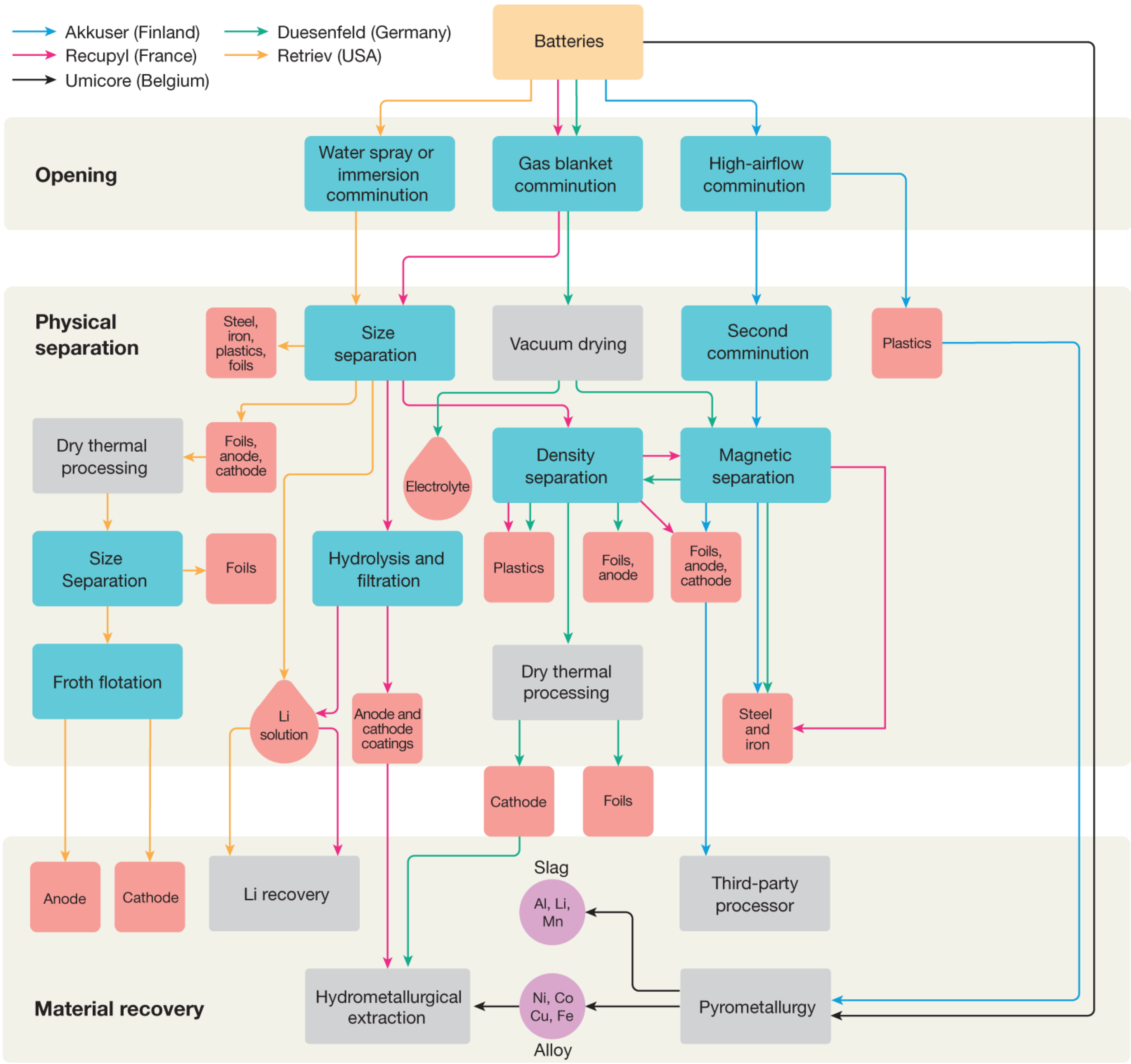


Fig 5.2 A flowchart representing the potential pathways for a LIB circular economy, detailing the applications of recycling, reuse, physical recovery, chemical recovery, and biological recovery.

Conclusion to the part 5

Driven by the need to decarbonize personal vehicles to meet global targets to reduce greenhouse gas emissions and improve air quality in urban centers, the electric vehicle revolution is set to revolutionize the automotive industry

The electrification of transport has become a major challenge for all automakers. But as more and more electric vehicles are produced, a new problem is emerging, which is almost impossible to solve and in comparison with which CO2 emissions from internal combustion engines are nothing more than an annoying nuisance.

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In 2017, electric vehicle sales exceeded one million vehicles per year worldwide for the first time and in close future we will see the electric aircraft in our skis.

Given that the environmental footprint of electric vehicle production is strongly affected by the mining of raw materials and the production of lithium-ion batteries, the resulting waste streams inevitably place different demands on end-of-life disassembly and recycling systems.

First, it is necessary to use natural resources more economically, which are not unlimited. Lithium batteries for electric vehicles are made from cobalt, a mineral mined primarily in the Congo. The growing demand for it has led to the fact that the mines there today use child labor, and the mining process itself cannot be called environmentally friendly and environmentally friendly.

GENERAL CONCLUSION

Today the world and national economy faces the urgent problem of processing transport waste. As the trend of writing off resources aircraft is gaining strength, the industry is coming to the need to create standards for recycling and reuse of materials and components.

However, difficulty in the recycling of advanced materials used in the manufacturing of new-age aircrafts such as carbon fiber might hinder the market expansion in the coming years. These materials ends-up in the landfill owing to the lack of large-scale recycling solutions.

The environmental impact of aviation occurs because aircraft engines emit heat, noise, particles, and gases that contribute to climate change and global blackout. Aircraft emit particles and gases such as carbon dioxide (CO2), water vapor, hydrocarbons, carbon monoxide, nitrogen oxides, sulfur oxides, lead and black carbon that interact with each other to the atmosphere.

When the airline industry talks about reducing its carbon footprint, the future of electric planes is always on the horizon. It should be – airline flights globally are expected to double in the next 20 years, yet the industry is far behind other forms of transportation in making the transition to a carbon free future.

With the increase in the growth of electric aircraft in the aviation market, the share of composite and lithium-ion batteries will also increase, demand will increase, the price will decrease, and with the increase in the number of batteries and composite materials, the question and demand for their processing and disposal

Unfortunately, in our society, not everything is done as we would like and there is nothing ideal, well, there are problems on which you can find an engineering and technological solution and the problem of disposal and recycling of electric aircraft belongs to this category.

Today, the situation with aircraft that develop their own cycle is not very good, there are various effective methods for their disposal, unfortunately there are no various right-handed drivers and authorities that could monitor this, therefore, airline companies are in a position to effectively dispose of their aircraft. Just for canning, although there are economic and environmental benefits in this.

After analyzing the market and methods of the giant aircraft manufacturers as well as monitoring the right directives in various aviation regulatory authorities, the following projects and ideas were proposed to improve the above problems:

- Create and adopt a directive where the manufacturer undertakes to accept the aircraft after decommissioning for further recycling process.

Aviation companies do not consider it necessary to spend money on recycling, they prefer to simply drive the aircraft to the cemetery, and most often the aircraft are subjected to partial recycling, where various units are removed from the aircraft for sale for spare parts.

- The issue of recycling must be taken into account at the product design stage.

Today, recycling is not a priority, the focus is on technical characteristics, and this also applies to the development of new electric aircraft and the design of new energy sources for these aircraft.

- Adopt international standards for marking batteries and composite materials, according to which it was possible to clearly define the composition of the device and material.

Unfortunately there is no global standard for marking these aircraft parts. Therefore, the idea of regulating recycling and integrating design solutions into the design phases can reduce a high percentage of hazardous substances on the environment.

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