DE2 Sustainable Design Engineering

Submission 1.1: Sustainability Analysis of Aircraft Seating

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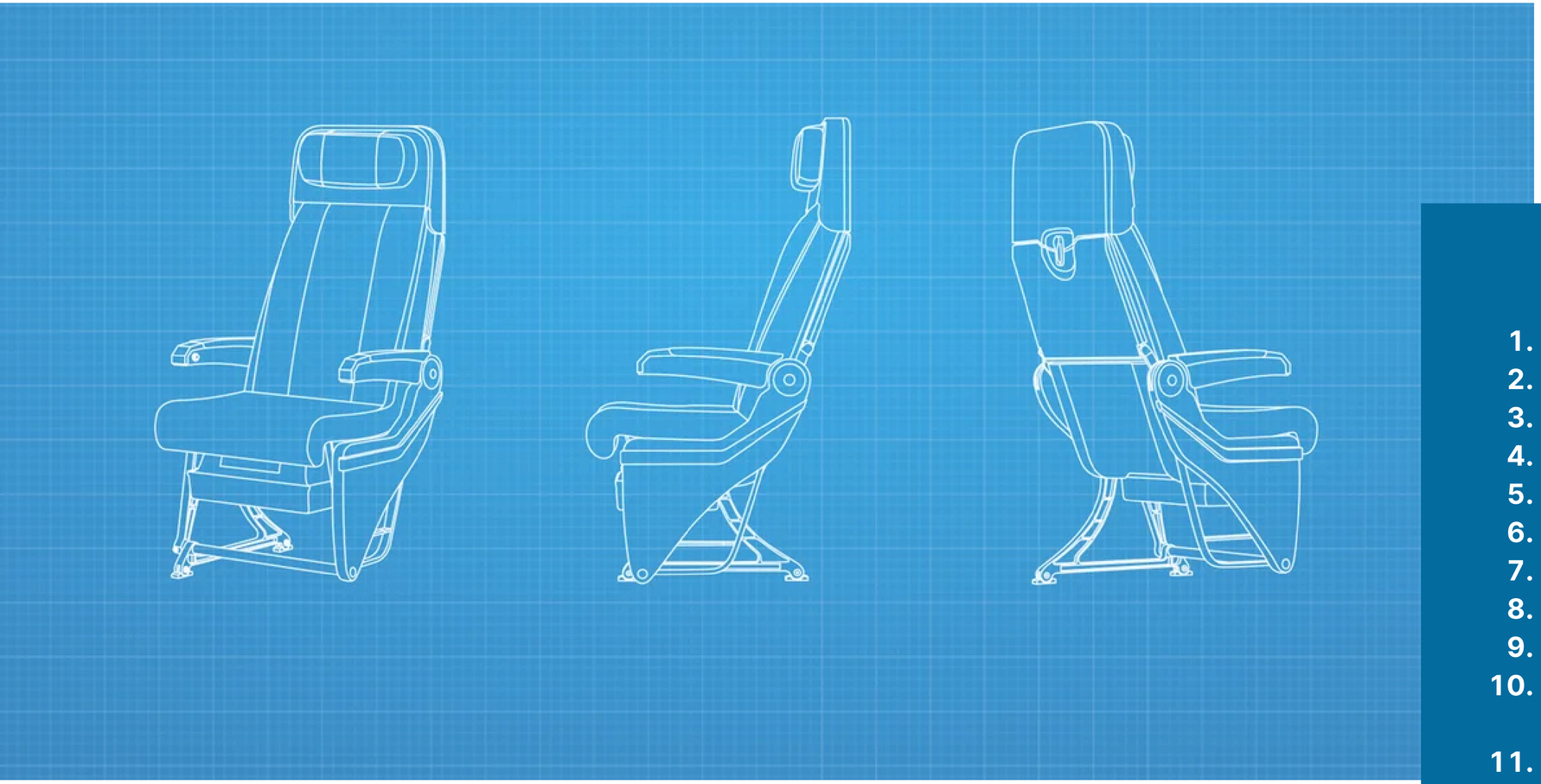

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Market Research

We researched industry trends and timelines to identify how sustainability, circular design, and passenger needs are shaping the future direction of aircraft seating.

2005

In 2005 Industry-wide adoption of **fuel-saving** operational practices begins, such as single-engine taxiing and reduced contingency fuel loads. [1]

2009

In 2009 Industry discussions highlight that aircraft cabin weight accounts for about **10%** of empty weight [2]

2012

In 2012 Airlines begin fleet-wide retrofit of lightweight economy class seats, saving up to **650kg** per aircraft. [65][3]

2018

In 2018 Reports find **47%** of cabin products by weight are not recycled. [2]

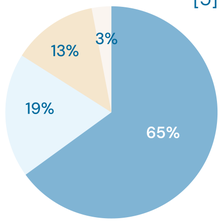
2019

In 2019 Airlines begin **cabin retrofit** campaigns focusing on composite seats, use of **recycled and plant based textiles** and modular seating rails for easier removal and reuse. [4]

2021

In 2021 The global airline sector commits to **Net Zero by 2050**. [5]

65% – Sustainable fuels
19% – Carbon offsets
13% – New technologies
3% – Operational improvements

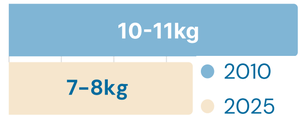


2024

In 2024 Aircraft Interiors Expo highlighted recyclability and circular design as key themes, with exhibitors showcasing **mono-material seat covers** and modular components. [6] [7]

2025

In 2025



Up to **30%** lighter

Newer seats are designed for **easy disassembly**, recycled carbon-fibre frames, and sustainable foams and cushions. [8] [9]

2030

By 2030 ICAO enforces tightened aircraft CO_2 standards; **older, less efficient cabins phased out**. All new aircraft deliveries must comply with revised ICAO fuel efficiency metric. [10] [11]

2035

By 2035 Short-haul aircraft interiors are expected to meet end-of-life circularity standards, with **≥90% recyclability** through design-for-disassembly, QR-coded materials, and OEM take-back schemes. [12] [13]

Growing Market

Research into global aviation trends shows a sector **expanding rapidly,** with passenger numbers reaching 4.4 billion in 2023, double those of the early 2000s. [14] [15]

2000s	2023
2.2 billion	4.4 billion

Although aircraft are now up to **80% more efficient** per seat-kilometre than early jet models, this progress has **not kept pace with rising demand**, leading to continued growth in emissions. [16] [17]

This highlights the need for **system-wide solutions**. Aircraft interiors, including **seat design and cabin materials**, now play a key role in **reducing weight, improving efficiency,** and supporting the industry's broader climate goals, including the target of Net Zero by 2050.

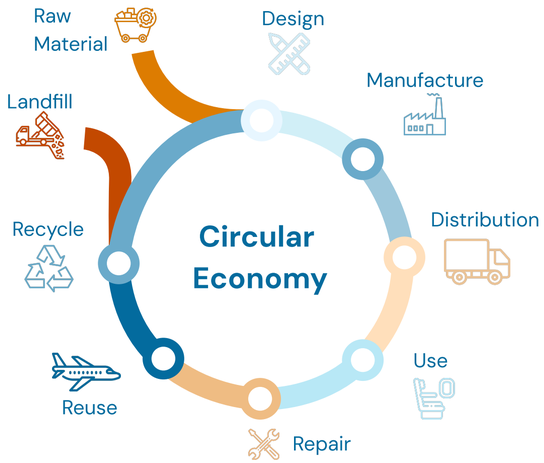
Evolving Seat Life Cycle and Business Models

Most aircraft seat systems still follow a **linear model** - designed, sold, and scrapped after their service life. However, the industry is gradually transitioning to circular models that **prioritise refurbishment**, reuse, and material recovery to extend product life and reduce waste. [2]

Current Lifecycle Model

Manufacture → Use → Dispose

New Lifecycle Model



Circular Business Models

A circular business model focuses on the **economic flow,** showing how value, ownership, and responsibility are managed to keep products in use and **generate sustainable profit.** [18]

Leasing – The manufacturer **retains ownership** while airlines pay per use, encouraging **repairable** and **recyclable** designs but reducing **assets as collateral** for airlines.

Maintenance & Refurbishment Contracts – OEMs offer **mid-life repairs** and services, creating ongoing revenue.

Component Reuse & Modular Design – **Standardised parts** are reused, **simplifying certification** and reducing waste.

Take-Back & Recycling Schemes – OEMs recover end-of-life seats for dismantling and material recycling, **closing the resource loop.**

Data-Driven Tracking – Digital product passports record materials and maintenance, **improving traceability** and refurbishment efficiency.

Insights and Opportunities

The dynamic trend in aircraft seat design reveals more than just weight reduction, it reflects a deeper industry shift. As seats have evolved from **12–14 kg in the early 2000s** to a projected **6.5 kg by 2030**, the focus has moved from basic efficiency to a broader commitment to carbon reduction, circular design, and full lifecycle sustainability. [19]

Shifting industry priorities over time reveal a deepening commitment to sustainability. From a focus on **fuel efficiency and cost (2005–2015)**, to **cabin weight and passenger comfort (2015–2020)**, the post-2020 era marks a clear pivot toward circular design, net-zero goals, modular interiors, and compatibility with sustainable aviation fuels. [17]

Market Research

We benchmarked Safran, Recaro, and Collins Aerospace to identify how leading manufacturers balance comfort, weight, and sustainability, and to uncover opportunities for more circular, adaptable designs.





	Short Haul Features	Long Haul Features
SAFRAN	• Slim backrest, optimised for **tight seat pitches** • Optional **USB** and tablet/PED holders • **Recline** functionality available depending on airline configuration • Fire-retardant PU or **hybrid foams** • Woven fabric, wool/nylon blends, leather, or PU synthetic leather dress covers [20] [21]	• Articulating seat pan (the bottom moves slightly when reclining for comfort) • Space for integrated In-Flight Entertainment (IFE) screens • **Adjustable headrests**, and more personal storage • **Thicker cushions, multi-layer foams** (e.g., HR PU with viscoelastic inserts) and higher-hand fabrics/PU for durability on long sectors [22]
RECARO	• Slim-profile back with optional pre-recline (seat fixed in a slightly reclined position) • **Tablet holder** and optional USB ports • Designed to fit **tight cabin** layouts. • FR PU foam cushions + fire blocker • **Woven fabric**, wool blends, leather, or PU synthetic leather dress-covers [23]	• **6-way adjustable headrest**, footrest, larger tray table, and IFE screen up to 13 inches. • **Sculpted back** gives extra shin and knee space without needing more pitch. • Cushions typically move to **multi-density stacks** (HR PU + memory-style inserts by suppliers) with higher-durability dress-covers [24]
Collins Aerospace	• USB charging and **tablet/PED holder** • **Flexible seat base** for comfort • Simple structure makes **maintenance fast** • FR PU foams + fire blocker • Woven fabrics, PU or leather dress-covers [25]	• Up to **5 inch recline**, integrated screens • Optional **cradle-style seat** motion (seat base slides forward as you recline) • Back & bottom comfort system on Pinnacle-line seats (a compliant cushion beneath the dress cover) • Long-haul trims tend toward **higher-spec multi-layer foams** and durable coverings [26]

Priorities For Short Haul vs Long Haul

Benchmarking revealed a clear **trade-off between efficiency and comfort** across short and long-haul seating. Short-haul seats **prioritise lightweight**, low-maintenance efficiency, while long-haul seats accept **added weight to enhance comfort** and features. This highlights potential for more adaptive or modular designs that **balance comfort with sustainability**.

Sustainability Analysis

SAFRAN [27] [28]

Lightweight design: Z-Series seats rank among the lightest, with the Z200 **saving ~12,000 tonnes CO_2** over 10 years on SunExpress fleets.

Modular design: Components like cushions and power modules are easily replaced, extending seat life and reducing waste.

Emissions targets: Safran targets **–30%** GHG by 2025, **–50%** by 2030, and net-zero by 2050 (Scopes 1 & 2, vs 2018).

RECARO [29] [30] [31]

Lightweight efficiency: The **8–9 kg** short-haul seat cuts aircraft fuel burn and CO_2 emissions, helping airlines reduce operating costs and environmental impact.

Sustainable materials: The R-Sphere concept uses recycled and **bio-based materials** like cork and cactus leather, reducing reliance on virgin plastics and improving material circularity.

Modularity and efficiency: Using replaceable parts and shared components **simplifies maintenance, extends seat lifespan**, and reduces both waste and operational costs.

Collins Aerospace [32] [33]

Circular design: Through its "refresh and reuse" program, airlines can replace only covers, cushions, or power modules while reusing **65–90%** of the seat frame, cutting material waste and production emissions.

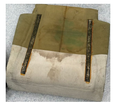
Durability focus: Seats are built for **long product life**, reducing replacement frequency and overall carbon footprint.

Material strategy: Collins prioritises **reuse and upgrade** of certified components instead of full replacements, promoting resource efficiency.

SAFRAN and RECARO **lack verified LCA and end-of-life data**, while Collins offers limited transparency, making it hard to assess true impact and showing a **need for better lifecycle reporting**.

Material and Manufacturing Trends

Common Materials



Cushions: Fire-retardant PU foams (sometimes with memory layers) provide comfort and **low weight** but are **difficult to recycle** because they are chemically bonded to fire-blocking textiles, **required by regulations.** [34]

Structure: Aluminium frames are strong, light and recyclable. Injection moulded PC or ABS are used for the seat shells and trays which can be easily replaced. [35]





Dress covers: Wool-nylon blends or PU leather are durable and easy to clean but use layered fabrics and coatings that cannot be separated for recycling. [36]

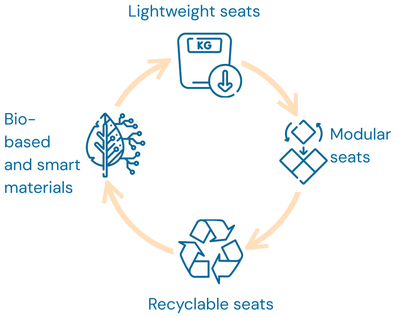
Manufacturing Methods

Bonding: Adhesives efficiently join foams and fabrics but make disassembly and material separation extremely difficult as they are permanent joints. [2]

Assembly: Mechanical fasteners allow for repair and part replacement but add slight weight and complicate assembly. Dress covers are usually attached with Velcro. [2]

Moulding: Ideal for trims and panels but combines polymers and coatings that cannot be reprocessed together. [37]

Emerging Technologies and their Trajectories



1. **Lightweight seats** cut fuel use and emissions, forming the basis of sustainable design. [38]
2. **Modular structures** extend lifespan by allowing easy part replacement. [39]
3. **Recyclable seats** encourage mono-material use and simpler disassembly.
4. **Bio-based and smart materials** further reduce embodied carbon and enhance durability and comfort. [40]

This evolution reflects how sustainability is no longer an add-on but a **core innovation driver**, shaping how materials, maintenance, and passenger comfort are approached across the industry. [2]

Insights and Opportunities

Achieving circularity will require rethinking how seats are assembled, **shifting from bonded multi-material layers to modular systems** designed for disassembly and material recovery.

Lightweight design alone no longer defines sustainability; future progress depends on designing for full lifecycles - materials that can be repaired, separated, and reintroduced into production.

Pillars of Sustainability

We analysed sustainability through social, environmental, and economic pillars to understand how inclusivity, material impact, and lifecycle cost interact, revealing where current seat designs fail to balance comfort, safety, and circularity.

Social Sustainability

[41][42][43][44][45][46][47][48][49]

Social sustainability in aviation means ensuring equitable, safe, and dignified travel for all passengers, regardless of age, body type, or ability. It goes beyond comfort to address inclusivity, accessibility, and human well-being.

Who is the Airline Seat Built For?

Aircraft seats are largely designed around the **50th-percentile Western male**, whose average height, weight, and reach became the industry benchmark because it simplified certification and mass production.



Height: **175cm**
Weight: **75–80kg**
Shoulder Breadth: **46cm**
Hip Breadth (sitting): **36cm**
Thigh Length: **44 cm**

These values underpin legacy design tools and crash-test dummies, so both **safety testing and comfort standards** still reflect the same **average male body.**

Who is Excluded and How?

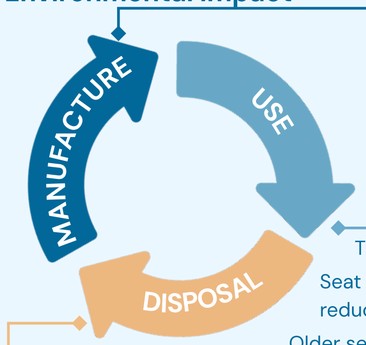
Children: No universal child-restraint anchors making **seats unsafe**
Shorter adults: Feet dangle, tray and IFE out of reach, armrests too high
Reduced mobility: High-force latches, **difficult transfers**, lack of handholds
Blind people: Hard to locate seat numbers, latches, and safety info
Deaf people: Safety briefings and alerts rely on audio
Tall people: Limited legroom and headrest height, knee contact
Larger people: Narrow seats and short belts, **compression and discomfort**



Seats **meet regulations, not people**. They are certified for safety, not designed for the range of bodies and abilities found in real passengers, highlighting the **gap between compliance and true social sustainability** and leaving many unable to sit comfortably, reach controls, or travel with dignity.

Environmental Impact

[2][17][50]



Manufacture

Seats rely heavily on **virgin materials** (e.g., aluminium, nylon, polyurethane foam) which increase carbon footprint.

Energy-intensive production (cutting, moulding, coating) generates **significant CO_2 emissions** and leaves behind **material offcuts and scrap** waste that are difficult to reuse or recycle.

Global supply chains and multi-country sourcing increase transport emissions.

Use

The **largest contributor** to environmental impact comes from **aircraft fuel use**.

Seat **weight** directly affects **fuel consumption**, so lighter designs can significantly reduce lifetime CO_2 emissions.

Older seats are not designed for repair or upgrade, which limits their lifespan.

Disposal

Seats are securely fixed with **rivets and brackets**, making removal **labour-intensive**.

Mixed-material construction, such as foam bonded to metal or plastic, makes **recycling difficult**.

Toxic additives, adhesives, and fire-retardant coatings prevent easy decomposition or reuse, meaning most seats end up in landfill.

Although most emissions come from the **use phase**, reducing manufacturing waste and material intensity still **significantly amplifies environmental gains** across the seat's entire lifecycle.

Economic Sustainability

[51][17][52][2]

Primary Stakeholder Goals

The airline's goal is to **lower total cost** per passenger-kilometre while protecting or growing revenue through higher occupancy, reliability, and passenger satisfaction.

Secondary Stakeholder Goals

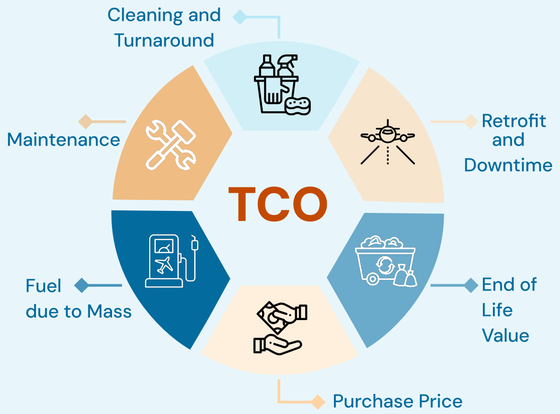
Seat OEMs (such as Recaro, Safran)	Design seats that are cheaper to produce, lighter, modular and attractive to airlines
Seat MROs (Maintenance, Repair & Overhaul)	Seats that are easy to service and re-certify quickly to minimise downtime
Passengers	Benefit indirectly - lower cost supports cheaper fares

Each **stakeholder's** drive for **longevity** and efficiency highlights that true economic sustainability comes from designs that retain value and performance over time.

Total Cost of Ownership (TCO)

[53][54][55][56][57]

TCO captures the entire financial footprint of a seat over its lifespan.



Holistic decision-making: A **low purchase price** may seem **cost-effective**, but if the seat is heavy, hard to service, or quick to wear out, it **increases long-term operating costs** and environmental impact.
Resource efficiency: Seats **designed for lighter weight**, easy repair, and modular replacement reduce fuel use, downtime, and waste - improving both cost and sustainability.

Interactions Between 3 Pillars

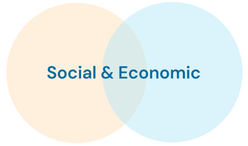
The three pillars do not act in isolation; they constantly trade off and reinforce one another across the seat's life cycle.



Designing for diverse bodies can add weight and material use, but inclusive, longer-lasting seats also reduce waste and improve resource efficiency.



Lightweight, modular seats reduce fuel use and cost, but lower-quality materials can shorten lifespan and increase emissions.



Seats that support all passengers improve brand value and economic sustainability, but added accessibility features can raise certification complexity and costs.



True sustainability balances comfort, inclusivity, cost, and lifespan, creating seats that unite environmental, economic, and social value.

Insights and Opportunities

Current seats meet adult safety standards but **lack universal child-restraint fittings or guidance**. Creating integrated, certifiable child-restraint solutions would close a major social sustainability and safety gap.

Features for passengers with disabilities are **inconsistent** and often **added after design**. Building accessibility in from the start would make air travel more inclusive while also improving usability for all passengers.

Lighter seats cut emissions while better ergonomics boost brand value, creating an opportunity to design solutions that benefit every stakeholder at once.

User Research

We analysed how passengers interact with seats to identify comfort pain points, behavioural patterns, and wear factors.

How Users Interact with Airline Seats

Seat Recline [58][59]

Reclining is controversial: **~50%** of flyers **avoid** reclining to be courteous.

Recline use is more common on long-haul flights, where polite practice is to adjust the seat gently after meal service.

IFE [61]

Seatback screens are still widely used on long-haul, but **94–97%** also use **personal devices.**

Many passengers prefer **onboard Wi-Fi** and using their **own devices** to stream, message, or browse during the flight.

Headrest [64][60]

Passengers adjust headrests to **support their necks** and prevent their heads from tilting during rest.

Many also fold the side wings inward for **added comfort** or to create a sense of **privacy.**

Tray Tables [62]

Tray tables have **multiple purposes**, functioning as dining surfaces, desks, entertainment stands, and makeshift headrests for sleep.

Many passengers **disinfect** tray tables before use.

Seat Pocket [62]

Seat Pockets are commonly used for **small items** like snacks, books, and phones.

However, they are often considered **unhygienic,** as pockets can contain rubbish, nappies, and used tissues.

Footrest [64][63]

They are most used by **shorter passengers**, who use them to reduce leg pressure and **improve circulation** during long flights.

Taller passengers often leave them folded and can find them **restrictive.**

What Differs Between Different User Groups



Business travellers view flights as an **extension of their workday**, using seat features for productivity by turning tray tables into desks, power outlets for work, and reading lights for document review.[66][67]



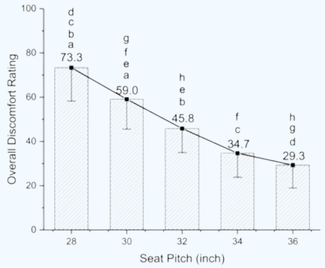
Young international travellers use seat features for **entertainment and comfort**, often relying on personal devices and reclining fully without always considering passengers behind them.



Mothers with young children prioritise their **child's comfort** over their own, adapting seat features for **care and entertainment**. Tray tables are used as play areas, seat pockets store essentials, and screens or devices help distract and soothe within limited space. [68][69][70][71][72]

Impacts that the Seat have on the Passenger

A 2018 survey of **246 passengers** found legroom, cushion comfort, and foot space to be the top priorities for improving comfort, ranking above features like recline or armrests. [73][74]



A 2016 survey of **40** adults found **discomfort** more than **doubled** as **seat pitch decreased**, showing that restricted leg space limits movement and circulation, leading to faster fatigue and reduced comfort. [75]

Studies show that **tray tables** sit too low, forcing passengers to **strain their necks**; raising them by around **5–7cm** or allowing adjustable heights would better support posture and reduce discomfort. [76]

Sleeping upright leads to **back and neck strain**, making it difficult to rest without head support. Allowing a recline helps **ease pressure on the spine**, but airline seats are constrained by cabin space and **safety regulations.** [77][78]

Overlap

How spacious a seat feels depends on both its **size and neighbouring passengers**. When others recline or encroach on shared areas, **comfort drops** as **movement becomes restricted**. Improving visual openness or defining personal boundaries can make the same space feel bigger and more comfortable.

Fabric texture, stitching, and colour affect how **clean a seat appears**. Deep seams trap debris, and dark colours hide both wear and dirt. Passengers feel more **comfortable** when seats **look clean** or can be easily wiped down themselves.

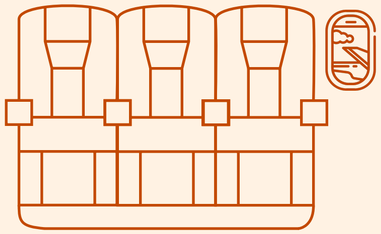
Impacts that the Surroundings have on the Passenger

Infant cries reach **120 dB** against a **75 dB** cabin baseline, creating sharp noise that **trigger stress.** As cabin noise increases, comfort falls, so nearby crying can **significantly reduce it.** [81][80][79][73]

Seat Preferences → **32%** **2%** **66%**

Aisle Seat: Chosen for **freedom of movement** but have higher exposure to traffic, carts, and bumps.

Middle seat: Rates **lowest for comfort** due to shoulder crowding and limited control over armrests or movement.



Window Seat: Offers **light control** and **privacy** with fewer disturbances. However, passengers move less which **reduces circulation** and may lead to **stiffness, swelling** and discomfort. [82][83][84]

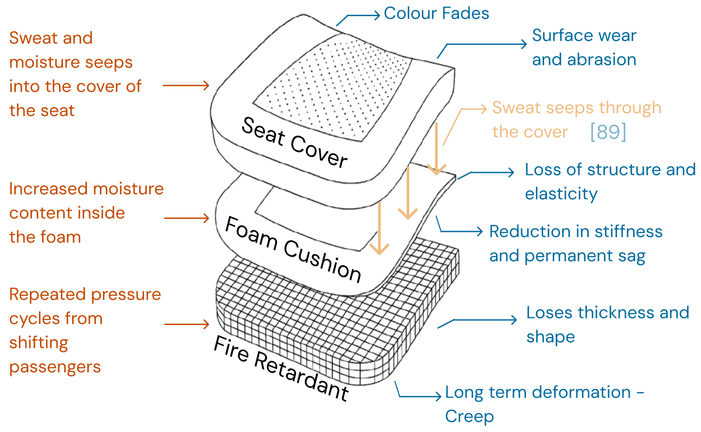
[86]
[85] A study in 2015 found tray tables can have **over 2,000 CFU/cm²**, making cleanliness of high-touch areas a key factor in **passenger comfort and trust**.

Impacts the User has on the Seat

Frequent movement and posture changes increase **strain on seat fabrics** and seams, especially at high-load areas like the **front edge** and **lumbar zone.** [87]

Repeated use of armrests and tray tables **wears down hinges** and latches over time, leading to **looseness** and maintenance issues. [88]

Passenger Use → Seat Wear



Insights and Opportunities

Comfort depends more on supportive geometry and perceived space than on fixed dimensions, revealing a **need for seat designs that adapt beyond narrow anthropometric ranges**.

Comfort and durability are closely linked. Reducing posture shifting through features like improved lumbar contouring or breathable surfaces helps extend the seat's lifespan by lowering mechanical strain and moisture build up in high-stress areas. This creates an opportunity to introduce contoured, breathable seat zones that further enhance comfort and longevity.

Personas

We gathered user data through **web scraping** and **secondary research** to create personas representing **key passenger groups**, helping identify distinct needs, stress points, and design priorities across different travel contexts.

[90] [91]



Consultant Connor - 45

Occupation: Business Man

"I treat the plane as a mobile office or recovery pod before meetings"

Flying Frequency

2-3 per month short haul
4-5 per year long haul

Importance of Flight Cost

Company pays so cost is not a factor

Importance of Comfort

Must be able to work or sleep on flight

Needs	Pain Points
• Reliable power/USB, stable tray for laptop, quiet(er) environment • Extra legroom if possible, recline that does not fight the person behind, adjustable headrest/ lumbar • Seat selection to secure aisle/ window preference.	• No outlets or weak tray tables effecting ability to work • Light/noise spill from neighbours (reading lights, chatter, babies crying) disrupting sleep before meetings • Being jammed between two large neighbours

[92]



Study Abroad Sofia - 21

Occupation: Student

"Give me food, a charger, and a cheap seat and I'll make the rest work"

Flying Frequency

1 per year short haul
3 per year long haul

Importance of Flight Cost

Student budget, cost is everything

Importance of Comfort

Comfort matters, but cost comes first

Needs	Pain Points
• Affordable comfort hacks: decent recline, adjustable headrest, good legroom • Power/USB and a spot for phone/tablet or a good IFE • Generous carry-on or sensible baggage rules	• Additional prices for on flight food or comfort items • Stiff cushions and backrests causing back and neck fatigue • No power outlets or place for tablet or phone

[93][94][95][96][97][98]



Toddler Tamer Tia - 32 (With child age 3)

Occupation: Full time mum

"A good flight is when my toddler naps and nobody is judgemental"

Flying Frequency

2 per year short haul
2 per year long haul

Importance of Flight Cost

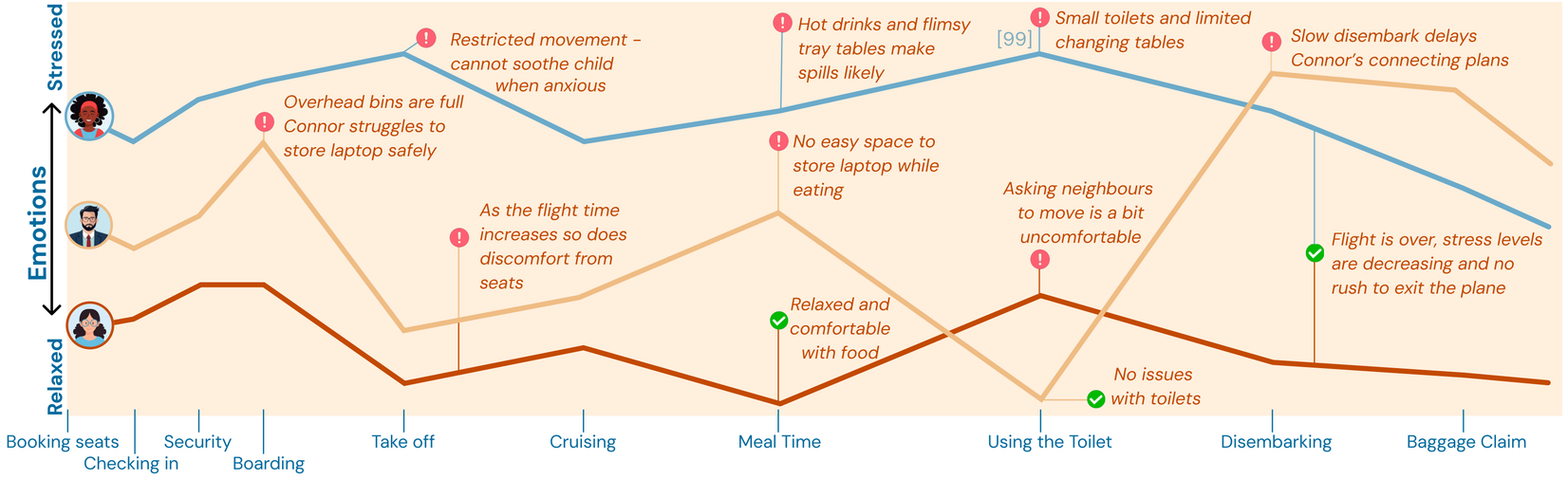
Cost is important but comfort matters most

Importance of Comfort

Must be comfortable and safe for child

Needs	Pain Points
• Sit next to her child and be close to a toilet • Storage within reach for snacks, wipes or toys • Usable recline and adjustable headrest to create nap positions; armrest that lifts to share space • Quick aisle access, tolerant crew, early boarding to settle in	• Cramped seat area makes feeding/soothing messy and exhausting • No changing table in the toilet • Judgemental passengers and anxiety about disturbing others; social pressure magnifies small hiccups • Unsafe seatbelts for child

Journey and Emotions Map



Insights and Opportunities

Current seat configurations assume uniform passenger behaviour, overlooking the vastly different postures, spatial needs, and activities of users. The lack of adaptability exposes a **gap between user diversity and seat design intent.**

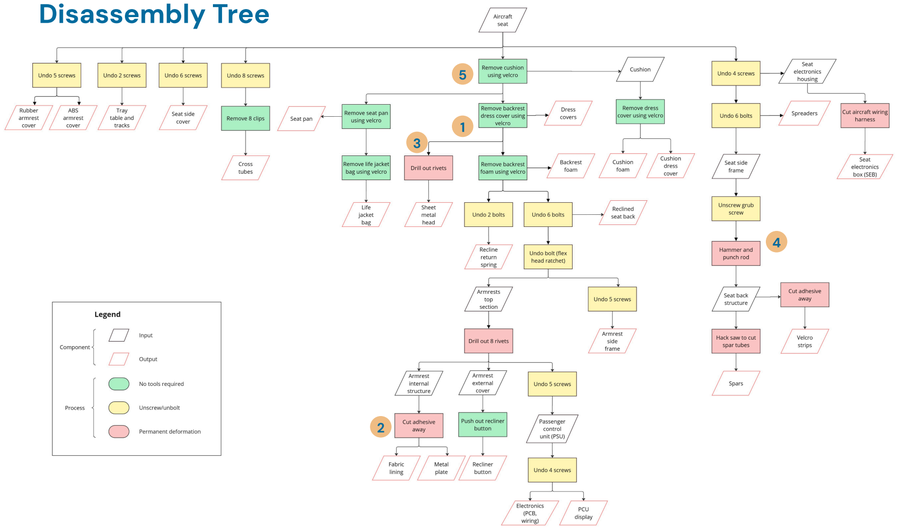
Take-off, meal service, and disembarking are consistently high-stress periods because **passengers lose control of movement precisely when their needs increase**. The system prioritises order and safety over emotional wellbeing, leaving users anxious, constrained, and reactive. Small, well-designed moments of control could improve comfort and reassurance while maintaining full safety compliance.

Teardown Analysis

We conducted a seat teardown to compare material use and disassembly efficiency, revealing how simpler, modular designs can reduce labour, cost, and environmental impact.



Disassembly Tree



This Disassembly Tree for a Standard Economy Seat (also found in Appendix) shows that the design is targeted towards maintenance rather than disassembly:

- Top level components are mostly removed without tools, such as Velcro.
- As the tree expands, more permanent deformation processes are required, such as removing rivets and adhesive bonding.

Standard Economy Seat

9+ Different Materials

6 Hours to Disassemble

5 People to Disassemble

Seat covers attached with Velcro were easy and quick to remove.



Adhesives can be toxic damage materials and are very hard to remove.



Drilling rivets to separate PC and aluminium was extremely difficult.



Pins were particularly hard to remove and took a lot of time and effort.



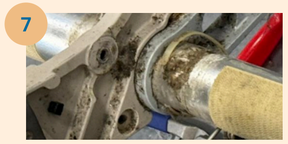
Difficulty



Seat cushion removed quickly and easily with Velcro.



Electronic components were easy to disassemble without tools.



Rusty and dirty materials prevent future reuse and are hazardous to workers.



Bad labelling made sorting and identification difficult and time consuming.

Ultra Slim Seat (Doy Designs)

5+ Different Materials

0.1 Hours to Disassemble

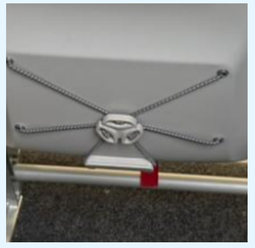
1 Person to Disassemble



Snap-fit cushions replace fastening components, reducing weight, lowering part count, and allowing faster disassembly without tools.



Velcro and sewn-in labels replace adhesives, allowing easier disassembly, cleaner handling, and simpler material identification.



Seat netting is replaced with a bungee cord mechanism, reducing trapped litter, simplifying cleaning, and allowing easy removal.



A single metal extrusion replaces multiple parts, reducing waste, eliminating casting, and providing a more cost-effective, lightweight design.

**The Ultra Slim Seat was not completely disassembled as the frame itself was not taken apart, significantly reducing the difficulty in comparison to the standard seat teardown*

Insights & Opportunities

The teardown highlights opportunities to replace labour-intensive processes: **modular design reduces disassembly time by 99.7% and labour by 80%** (based on our teardown experience). Furthermore, the disassembly tree show that **20–30% of joints are permanent, requiring destructive removal** which significantly increases labour.

Clean disassembly preserves material and economic value by preventing contamination and damage during teardown. Replacing toxic adhesives and rivets with reversible joints would allow foams, fabrics, and electronics to be recovered intact, enabling true circular material loops rather than downcycled waste.

Embedding **digital tags could transform seats into data-driven assets**, enabling predictive maintenance and closing material loops through traceable, lifetime tracking.

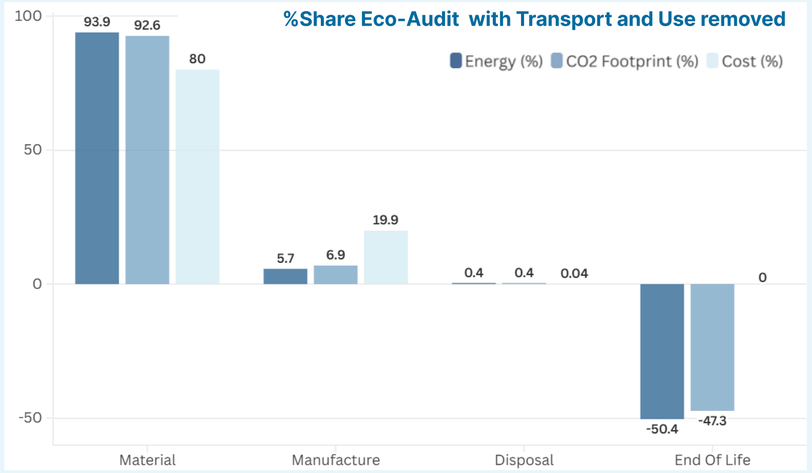
Eco - Audit Analysis

We ran an Eco Audit comparing the standard seat and Doy Design's Ultra Slim seat to evaluate energy use, carbon footprint, and recyclability, revealing how lightweight, mono-material structures improve efficiency across the seat's lifecycle.

Gary Doy (Ultra Slim Seat)

99.8% of energy is from use phase

99.9% of CO2 is from use phase



Assumptions

Materials: ***(2.44e+03 MJ & 149 Kg)***

Based on Gary Doy's Ultra Slim Low Carbon Seat; materials data matched to the closest categories in the Level 3 Ansys Eco Audit tool.

Manufacture: ***(148 MJ & 11.2 Kg)***

- **Aluminium** produced as a single-piece extrusion
- **Polymers** moulded and trimmed as required
- **Fabrics** are a woven wool–nylon blend with dyed and finished yarns for durability and fire resistance.

End of Life Potential: ***(-1.31e+03 MJ & -76.1 Kg)***

- All components assumed recycled via AIRA.

Transport:

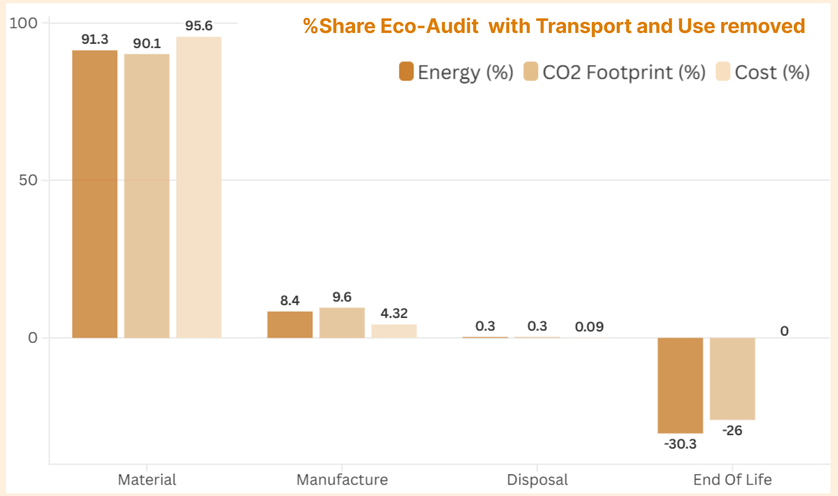
- Excluded due to limited transparency in supply chain

"We used compressed aluminium and a single monocoque structure: fewer parts, fewer fasteners, less waste."
- Gary Doy

Standard Economy Seat

99.8% of energy is from use phase

99.9% of CO2 is from use phase



Assumptions

Materials: ***(3.41e+03 MJ & 223 Kg)***

Based on teardown findings and discussions with Gary Doy and Tony Seville, aligned with common airline seat materials:

- **Aluminium 7075** – primary frame structure
- **Synthetic leather** – seat and backrest covers
- **Polycarbonate (PC) and ABS** – polymer components and trims
- **Polyurethane (PU) foam** – seat and backrest cushioning

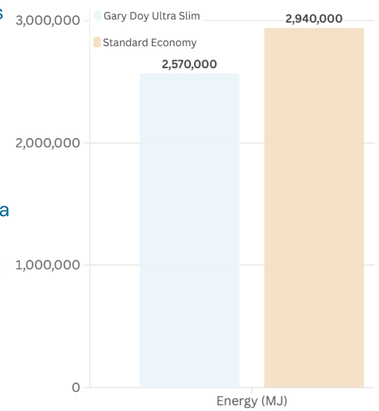
Manufacturing: (315 MJ & 23.7 Kg)

- **Aluminium 7075**: Extruded, CNC-machined, and anodised for strength and corrosion resistance.
- **Synthetic leather**: PU-coated textile, embossed, dyed, and flame-retardant finished.
- **PC & ABS**: Injection-moulded and trimmed for precise fit and finish.
- **PU foam**: Mould-foamed, trimmed, and laminated for comfort and contour.

End of Life Potential: ***(-1.13e+03 MJ & 64.7 Kg)***

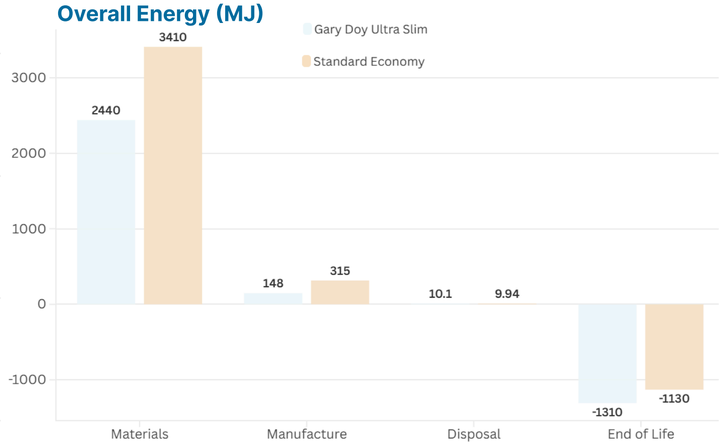
- Aluminium recycled; all other materials assumed non-recyclable and combusted or landfilled.

Use Energy (MJ)



Both seats were modelled with a **5-year** lifespan, operating **355 days** a year over **5,000 km** daily. The Doy Ultra Slim (short-haul) seat uses **~14%** less energy than the Standard Economy (long-haul) seat due to its **lighter structure** and **lower fuel use.**

Overall Energy (MJ)



Cost: Doy's seat costs £183 vs £121 (+£62 upfront). Its lighter weight lowers fuel use, so the **higher initial cost is offset** by savings during operation over its service life.

Materials (2,440 vs 3,410 MJ): Doy's lighter, mono-material extruded frame replaces multiple cast and fastened parts, **reducing the amount of high-energy aluminium** and mixed polymers required, which in turn lowers the seat's overall embodied energy.

Lifespan (5 years vs 2 years): With a longer service life, Doy's seat needs **fewer replacements across the same aircraft lifetime,** meaning its material and manufacturing impacts occur less often, **reducing** total embodied **impact over time.**

Manufacture (148 vs 315 MJ): Streamlined production using extrusion and moulding instead of casting and machining lowers factory energy use, part count, and waste from offcuts or rework, improving overall efficiency.

End-of-Life (-1,310 vs -1,130 MJ): Doy's **mono-material** construction and clear part separation allow full material recovery. Partnering with **AIRA,** the seat is **100% recycled**, maximising energy return and eliminating reliance on virgin materials.

Insights and Opportunities

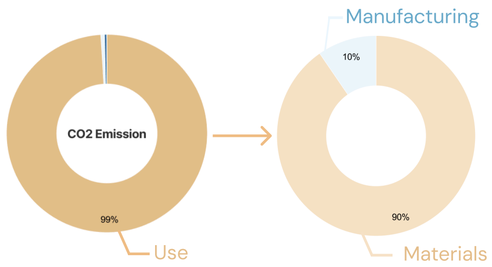
Over 99% of total energy is tied to use phase, showing that every kilogram removed during design has a compounding effect through reduced fuel burn. Lightweighting offers more lifecycle benefit than improving manufacturing efficiency alone.

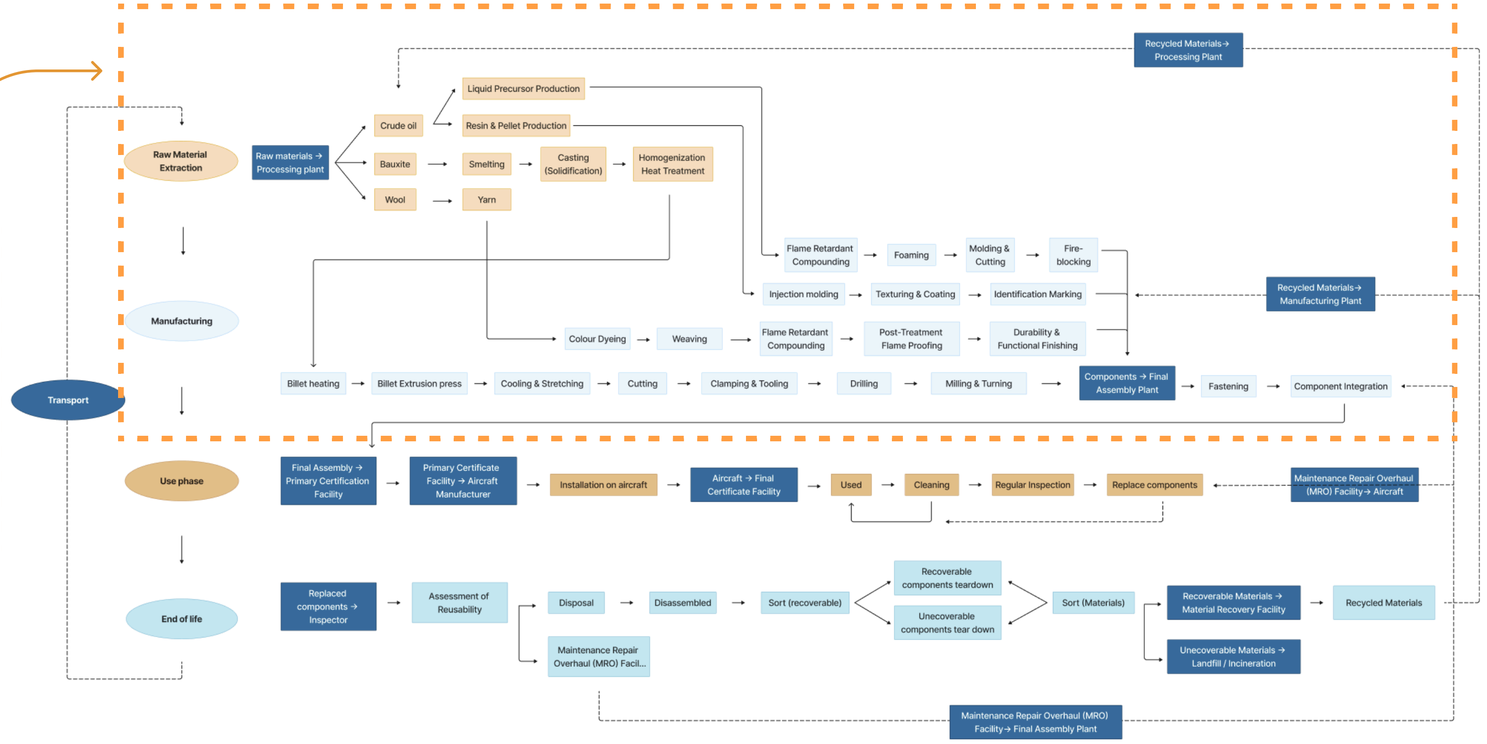
Although manufacturing energy differences are small, Doy's single-piece extruded structure creates larger downstream benefits by reducing assembly labour, fasteners, and tolerance build-up. **Integrating processes delivers greater overall efficiency than minor process improvements alone.**

Life Cycle Assessment

We conducted an LCA using the Eco Audit to quantify energy use, carbon footprint, and end-of-life recovery across the seat's life cycle, identifying **key impact hotspots** to guide material choices and design improvements for the next iteration.

Use dominates total energy and CO_2, making up to 99% of the total impact. Within the embodied phases, **Materials contribute the most**, while Manufacturing is much lower. The End-of-Life potential is relatively small but increases when components are mono-material and clearly identified. **Transport was excluded** from the assessment due to insufficient supply chain data.





Life Cycle Analysis Flow Chart [106]

"The industry talks circularity, but certification locks parts to aircraft tails. That's the real recycling barrier" **- Gary Doy**

Functional Unit

The functional unit is one economy-class aircraft seat was modelled over a **5-year lifetime, 355 service days per year, and about 5,000 km flown daily**, ensuring results reflect material, manufacturing, and design differences rather than flight distance.

Materials CO2 Contribution [100] [101] [102]

The aviation industry relies heavily on **energy-intensive virgin materials** because **strict safety** and certification standards make the use of recycled feedstock difficult, resulting in the **Materials phase** being **much higher** than other life-cycle stages.

- Strict safety and certification standards (EASA, FAA) require **fully traceable, mechanically verified materials,** with each batch certified to aerospace-grade standards, which recycled materials rarely meet.
- Virgin aluminium and polymers are **required** to meet **strength, fire resistance**, and fatigue criteria.
- **FST** (flammability, smoke, toxicity) regulations further **restrict the use** of recycled or mixed polymers. [103]

Transport Emissions [104] [105]

Transport was **excluded from the Eco Audit** because supplier routes and shipping data were unclear, so any figures would have been speculative.

Assuming aluminium from France, EPP foam from the Czech Republic, fabrics from Switzerland, and seatbelts flown from the USA to Issoudun, France, transport adds roughly **2.8 kg CO_2 per seat**. This is **small** compared to total lifecycle emissions but could be significant at scale. **Shorter travel distances** are especially important for bulky, low-density materials like PU foam, which are inefficient to ship long distances.

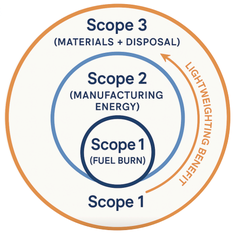
Localising suppliers or avoiding air freight could greatly reduce this impact.

Emissions Scope Overview

Scope 1 – Direct emissions
From **aircraft fuel burn**; seat mass impacts fuel use, so lightweighting cuts CO_2 across flights.

Scope 2 – Indirect emissions
From **purchased energy** used in manufacturing and assembly (e.g., extrusion, moulding, finishing).

Scope 3 – Upstream and downstream emissions
From **material extraction**, refining, logistics, and end-of-life processing. (The bulk of embodied impacts.)



This LCA focuses on **Scope 2–3** embodied emissions, and **mass reduction** improves Scope 1 fuel efficiency for airlines.

Reducing emissions across the seat's life cycle helps **lower pollution** linked to **climate change**, resource extraction, and manufacturing, which can affect **community health** and wellbeing.

Insights and Opportunities

Costs could decrease with more intensive manufacturing if it allows for cheaper materials, due to the materials' outsized cost.

Aviation **regulations limit the use of recycled materials** due to strict strength, traceability, and flammability requirements, making virgin materials necessary despite their higher embodied impact.

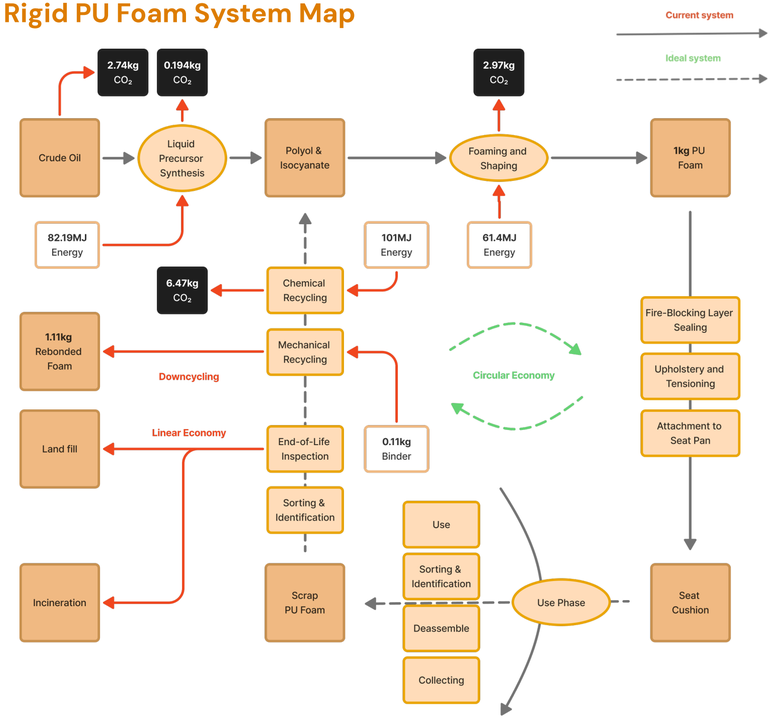
Reliability and consistency remain non-negotiable in aviation, meaning **sustainability progress comes from designing lighter, more efficient structures** rather than substituting certified virgin materials with recycled alternatives.

Since the **profit incentive is aligned with Scope 1 CO2 emissions**, firms will have already searched the market for optimal materials. An innovation is more likely to be cultural/behavioural or an advancement in technology.

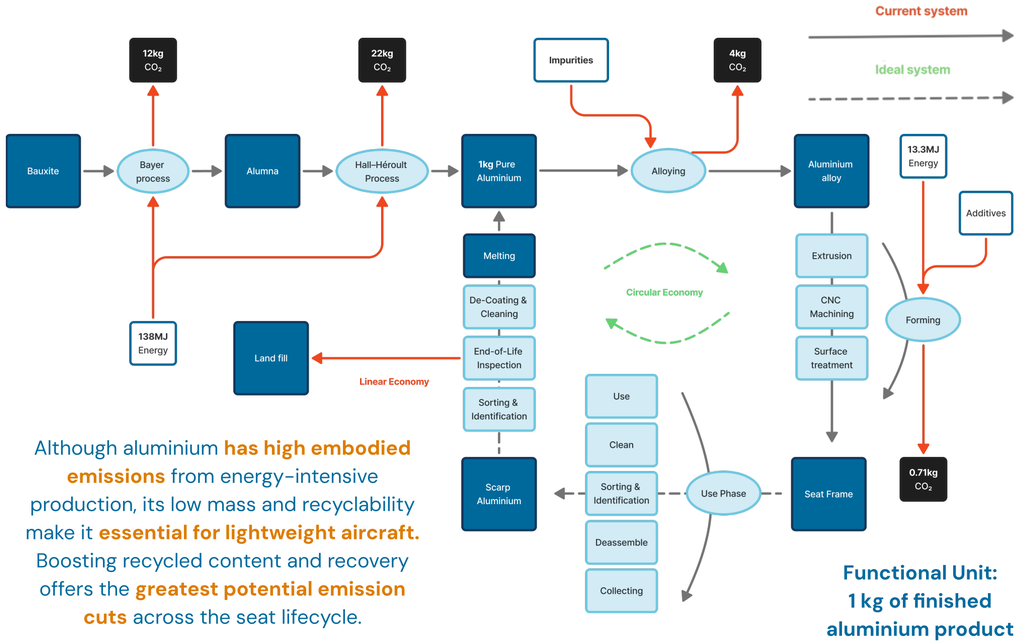
Material Circularity & End-of-Life Schemes

We found that the **CO_2 footprint** was **most sensitive to aluminium and PU foam content**, leading us to explore how material circularity and end-of-life pathways could reduce their impact.

Rigid PU Foam System Map



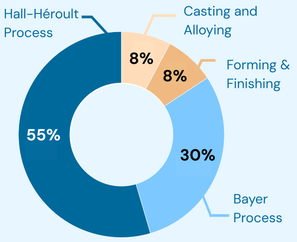
Aluminium System Map



Although aluminium **has high embodied emissions** from energy-intensive production, its low mass and recyclability make it **essential for lightweight aircraft.** Boosting recycled content and recovery offers the **greatest potential emission cuts** across the seat lifecycle.

Functional Unit: 1 kg of finished aluminium product

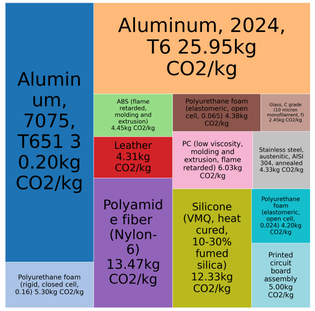
CO2 Emission Per Production Stage of Aluminium



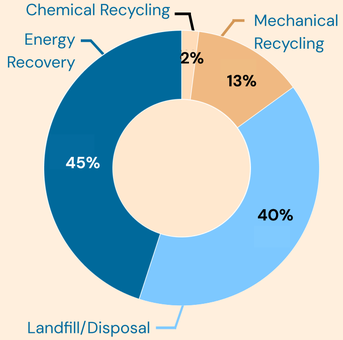
85% of aluminium emissions come from energy-intensive primary production, while recycling uses only about **5%** of that energy [109]. Although 75% of aluminium in use is recycled, only 40% of purchases in Europe are, due to high demand. For aircraft, scrap value rarely offsets dismantling costs—break-even is around USD 4200 per tonne versus ~USD 3900 market value [108].

Specific CO2 Footprint by Material

This mosaic plot shows that some materials have disproportionately high CO_2 impacts. 1 kg of Aluminium 7075 adds 30.2 kg CO_2, while 1 kg of leather adds 4.31 kg.



PU Foam End-Of-Life Pathways



PU foam's **irreversible cross-linking** makes it very hard to recycle. The only viable route, chemical recycling (glycolysis), is energy-intensive and **costs 2–3× more than virgin production.** Unknown impurity levels such as for fire retardants and bio-contaminants alter the foam's properties, making it harder to create the correct controlled environment. As a result, **over 85% of PU foam ends up in landfill** or energy recovery, and only highly-resourced firms can recycle.

Separable layers, fewer adhesives, or reversible thermoplastic foams could make circular recovery far more achievable.

End Of Life Schemes [107]

AIRA-Q **turns teardown waste into feedstock** by coding, sorting, and closing the loop, keeping aviation-grade materials aviation-grade.

***"Separation and traceability are the value - mix grades and you turn aerospace alloy into scrap."* — Tony Seville, AIRA**

By linking every part to a digital material ID, AIRA-Q builds a **traceable "passport"** that allows high-grade alloys to re-enter aerospace supply chains instead of being downcycled into low-value scrap.



Insights and Opportunities

Demand for aluminium outstrips recycled supply by 60%, but airliners don't scrap it because of dismantling costs.

Airlines prefer owning seats as assets to strengthen their portfolio and absorb financial risk. Modular designs could let them resell damaged parts for recovery, enabling carbon credit gains and shared circular value.

Promising **recycling methods (Phosphorolysis, Acidolysis) exist** but lack investment because uncertainty in **material impurities at EoL** complicate centralisation of infrastructure into fewer, larger-scale controlled environments.

Insights & Design Opportunities

In sustainable aircraft seat design, deriving 'How Might We...?' questions ensures ideas address **real passenger needs** while aligning with **environmental goals**. Linking each opportunity to **Eco Design Strategies** like reducing material impact, enabling disassembly, and extending lifespan embeds sustainability into the design process, creating solutions that enhance comfort, reduce weight, and lower environmental impact.

Source	Insights	How Might We...?	Design Opportunities
User Research (p5), Personas (p6)	Different personas (business, student, parent) have unique needs: productivity, affordability, child safety. Current designs assume uniform behaviour.	HMW design modular, size-scalable seat components such as boosters, belt guides, and adjustable head or side wings that improve safety and comfort for young children, helping them feel secure and reducing stress for parents during flights? — Mayli	1. Integrate universal child modules with quick, tool-free attachment points for safe and adaptable seating across aircraft. 2. Develop lightweight, size-adjustable inserts that enhance comfort and security for children while maintaining adult usability. 3. Use removable, easy-clean soft goods with traceable components to improve hygiene, turnaround, and circularity.
Pillars of Sustainability (p4) User Research (p5)	Comfort relies more on supportive geometry and perceived space than on fixed dimensions, highlighting the need for seats that adapt to a wider range of body types and passenger needs.	HMW create adaptable seating configurations that accommodate different passenger profiles such as families, children, and business travellers while maintaining comfort, efficiency, and sustainability? — Alex	1. Place universal anthropometric forms with dimensions that fit extreme or minoritised users. 2. Add modular features to a statistically modelled seat frame designed to fit most passengers, to meet the needs of different customer groups. 3. Design carefully crafted part geometries to be inherently movable, allowing the seat to conform to the passenger when they sit and stand.
Eco Audit Seat Analysis (p8), End-of-Life Schemes (p10)	Polyurethane foam and aluminium dominate the seat's weight and carbon footprint, showing that material choices directly influence environmental impact. Prioritising lighter, low-impact alternatives offers an effective ways to cut emissions across a seat's lifecycle.		
PU Foam & Aluminium System Maps (p10)	Recycling pathways already exist for the relevant high-emission materials, but unknown levels of various impurities create investment risk that prevents necessary infrastructure centralisation.	HMW mitigate the environmental effects of heavy, high-impact materials without compromising on seat performance for planes (durability) and Passengers (comfort)? — Emily	1. Design for ergonomic efficiency to reduce material use and improve comfort. 2. Embed blockchain-enabled standardised material identification passports for traceability, increasing resale value and recycling take-up. 3. Develop adaptive assembly systems using smart fastening technologies that enable reversible connections.
Pillars of Sustainability (p4) User Research (p5), Personas (p6)	Take-off, meals, and disembarking are peak stress moments when passengers lose control just as their needs rise. Prioritising safety over comfort leaves them anxious and constrained; small, well-designed moments of control could restore reassurance without compromising safety.		
Business Models (p3), Disassembly Tree (p7)	Disassembly is often slow and labour-intensive, with complex joints and mixed materials turning maintenance and recycling into costly tasks. Simplifying structures and standardising materials can drastically cut time, labour, and waste at end of life.	HMW leverage seat design to mitigate imperfect information and unlock capital for recycling infrastructure without infringing on protection of sensitive/proprietary data? — Hamish	1. Design for ease of carbon offset to efficiently internalise negative CO2 externalities. 2. Embed use data collection into design that protects user privacy. 3. Encode material and manufacture parameters into design to enable distribution to IP owners for recycling, without revealing the IP.
Evolving Lifecycle and Business Models (p1), EoL Schemes (p10)	Smaller manufacturers don't want to share information that would facilitate recycling because they want to protect their IP, but airliners don't want to lease parts because they want the assets as collateral.		

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Appendix: Bill of Materials

Bill of Materials from aircraft seating disassembly and links to the CES EduPack 'Eco Audit' Level 3 Database for analysis.

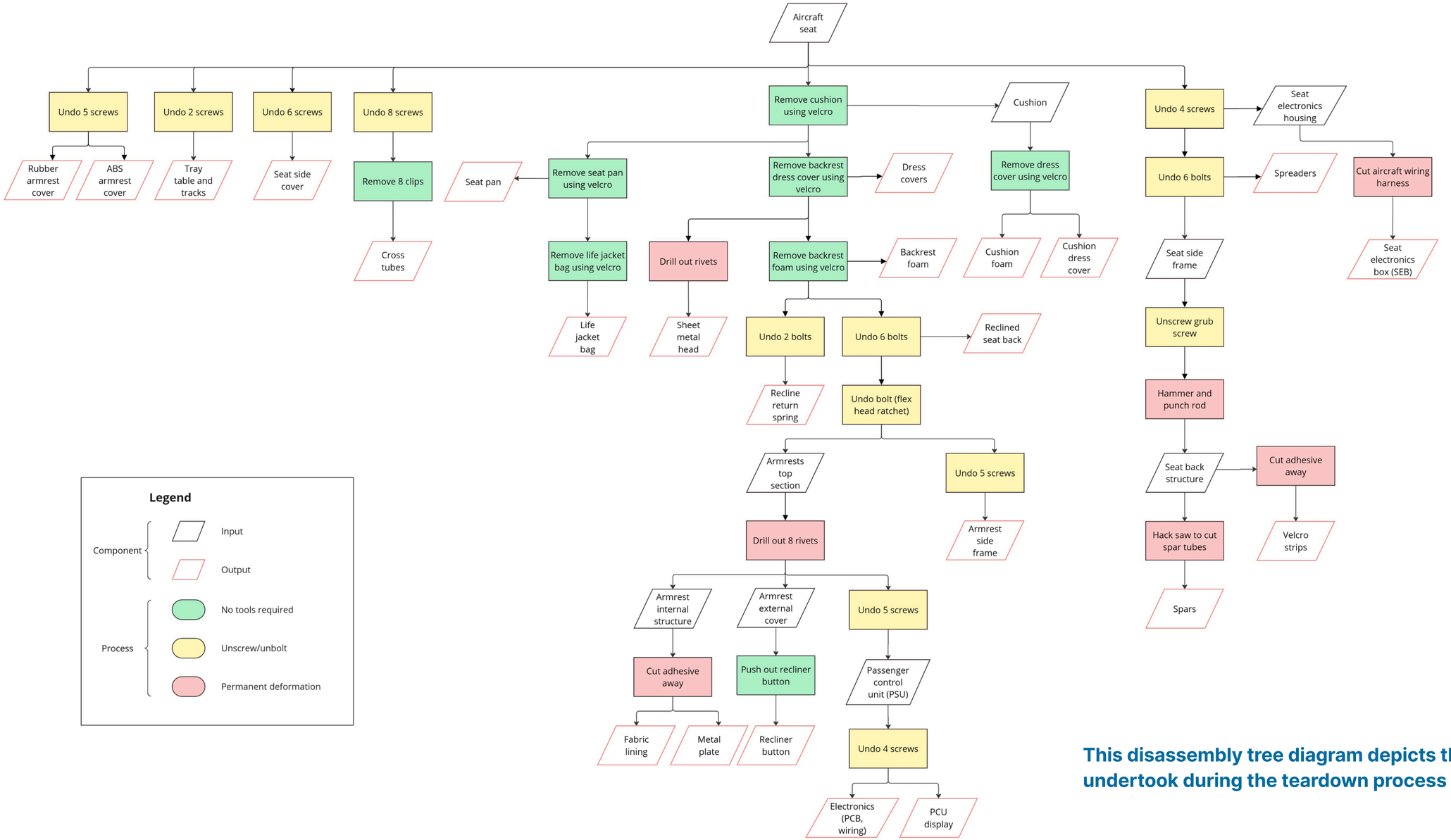
For the full Eco Audit, please see documents below:
Doy Design PF3000: click here
Safran Weber 5751: click here

For the full Bill of Materials, please see this document:
Safran Weber 5751: click here
Doy Design PF3000: provided by module lead (view anyway)

Component	Part mass (kg)	Qty.	Material
US1002-01-BAGGAGE-BAR-RH	0.40	1	Aluminum, 2024, T6
US1003-01-STD-LEG-LH	0.93	1	Aluminum, 7075, T651
US1004-01-STD-LEG-RH	0.93	1	Aluminum, 7075, T651
US1005-01-SEAT-CUSHION-EPP	0.36	3	PP (impact copolymer, flame retarded)
US1006-01-SEAT-CUSHION-COVER	0.29	3	Cotton fiber
DRESS COVER MATERIAL (BF) Aramid	1.44	1	Aramid fiber (Kevlar 29)
DRESS COVER MATERIAL (BF) PU	0.06	1	TPU (Ether, aromatic, Shore A85, flame retarded)
US1007-01-SEAT-CUSHION-FOAM	0.26	3	Polyurethane foam (elastomeric, open cell, 0.028)
US1008-01-MAIN-SPAR	1.26	2	Aluminum, 7075, T651
US1009-01-STD-SEATBACK	0.55	3	Phenolic/E-glass fiber, woven prepreg, QI lay-up
US1010-01-BUNGEE-CLIP	0.01	3	PC (low viscosity, molding and extrusion, flame retarded)
US1011-01-LINKAGE-SPACER	0.00	1	Aluminum, 2024, T6
US1012-01-BUNGEE-CORD	0.00	3	Styrene butadiene rubber (SBR, unreinforced)
US1013-01-BUNGEE-CORD-PLUG	0.00	12	PC (low viscosity, molding and extrusion, flame retarded)
US1014-01-BUNGEE-LWR-HOOK	0.01	3	PC (low viscosity, molding and extrusion, flame retarded)
US1015-01-HANGER	0.45	2	Aluminum, 7075, T651
US1016-01-HANGER-INLINE	0.38	2	Aluminum, 7075, T651
US1017-01-BAGGAGE-BAR-END-CAP	0.00	1	PC (low viscosity, molding and extrusion, flame retarded)
US1018-01-BAGGAGE-BAR-SIDE-LWR	0.58	1	Aluminum, 2024, T6
US1019-01-BAGGAGE-BAR-SIDE	0.07	1	Aluminum, 2024, T6
US1020-01-BAGGAGE-CORNER-JOINT	0.01	1	PC (low viscosity, molding and extrusion, flame retarded)
US1021-01-BAGGAGE-BAR-JOINT	0.01	1	PC (low viscosity, molding and extrusion, flame retarded)
US1022-01-ARMREST-PIVOT-CAP	0.00	2	PC (low viscosity, molding and extrusion, flame retarded)
US1023-01-ARMREST-COVER	0.06	4	PC (low viscosity, molding and extrusion, flame retarded)
US1024-01-ARMREST	0.13	4	PARA (50% glass fiber, flame retarded)
US1028-01-HANGER-COVER-RH	0.12	1	PC (low viscosity, molding and extrusion, flame retarded)
US1029-01-SEAT-ETSO-C39C-PLACARD	0.01	1	Bond/copier paper
US1032-01-SEATBACK-INSERT(PU)	0.05	6	Polyurethane rubber (unfilled)
US1033-01-SEAT-HANGER-FIXING-SLEEVE	0.00	2	Aluminum, 7075, T651
US1034-01-SEAT-HANGER-FIXING-SLEEVE-B	0.01	1	Aluminum, 7075, T651
US1035-01-HANGER-FIXING-STUD-MALE	0.03	6	Aluminum, 7075, T651
US1036-01-HANGER-FIXING-STUD-FEMALE	0.02	2	Aluminum, 7075, T651
US1037-01-SHACKLE-SPACER	0.00	6	Low alloy steel, AISI 4130, air melted, quenched & tempered
US1038-01-ARMREST-PIVOT	0.02	4	Stainless steel, semi-austenitic, 17-7PH, TH1050
US1039-01-STD-SEATBACK-INNER	0.55	3	Phenolic/E-glass fiber, woven prepreg, QI lay-up
US1040-01-SEAT-CUSHION-FIRE-RETARDANT	0.20	1	PARA (unfilled)
US1042-01-SEAT-BACK-STD-COVER	0.40	1	Cotton fiber
US1043-01-ARMREST-STOP-PIN	0.01	8	Stainless steel, semi-austenitic, 17-7PH, TH1050
US1044-01-BAGGAGE-BAR-BUNG	0.00	1	PC (low viscosity, molding and extrusion, flame retarded)
US1035-01-SEAT-FIXING-BUSH	0.00	1	Aluminum, 7075, T651

Component	Part mass (kg)	Qty.	Material
Edge tube	0.71	2	Aluminum, 2024, T6
Edge tube Velcro	0.05	4	Polyamide fiber (Nylon-6)
Life jacket holder	0.41	1	Polyamide fiber (Nylon-6)
Base Rivet	0.00	8	Aluminum, 2024, T6
Seat back Middle panel	0.44	1	Glass, C grade (10 micron monofilament, f)
Seat back panels	1.32	1	ABS (flame retarded, molding and extrusion)
Seat back Panel Upper frame	0.21	1	Aluminum, 2024, T6
Seat back dressing Velcro	0.02	1	Polyamide fiber (Nylon-6)
Seat back dressing Cover	0.39	1	Leather
Seat back Filling	0.13	1	Polyurethane foam (rigid, closed cell, 0.16)
Seat bottom cushion Foam	1.59	1	Polyurethane foam (rigid, closed cell, 0.16)
Seat bottom cushion Velcro	0.05	1	Polyamide fiber (Nylon-6)
Seat front dressing Upper cushion	0.71	1	Polyurethane foam (elastomeric, open cell, 0.065)
Seat back dressing Back cushion	0.10	1	Polyurethane foam (elastomeric, open cell, 0.024)
Seat front dressing Velcro	0.03	1	Polyamide fiber (Nylon-6)
Seat front dressing Cover	0.53	1	Leather
Seat foam back Velcro	0.07	1	Polyamide fiber (Nylon-6)
Seat foam back Foam body	1.37	1	Polyurethane foam (rigid, closed cell, 0.16)
Fasteners	0.13	1	Stainless steel, austenitic, AISI 304, annealed
Seat bottom dressing Foam cushion	0.03	1	Polyurethane foam (rigid, closed cell, 0.16)
Seat bottom dressing Cover	0.39	1	Leather
Seat bottom dressing Velcro	0.01	1	Polyamide fiber (Nylon-6)
Seat back Spring	0.08	1	Stainless steel, austenitic, AISI 304, annealed
Arm rest Back cover	0.59	2	ABS (flame retarded, molding and extrusion)
Arm rest Front frame	0.04	2	Aluminum, 2024, T6
Arm rest Front cover	0.06	2	Silicone (VMQ, heat cured, 10-30% fumed silica)
Arm rest Front filling	0.02	2	Polyurethane foam (rigid, closed cell, 0.16)
Arm rest Frame	2.33	2	Aluminum, 7075, T651
Electronics	0.01	1	Printed circuit board assembly
Arm rest Controll panel	0.29	1	PC (low viscosity, molding and extrusion, flame retarded)
Front leg Beam	0.23	2	Aluminum, 7075, T651
Back leg Beam	0.33	2	Aluminum, 7075, T651

Appendix: Disassembly Tree



This disassembly tree diagram depicts the process we undertook during the teardown process of aircraft seating.

Appendix: Eco-Audit Data Analysis

Weight

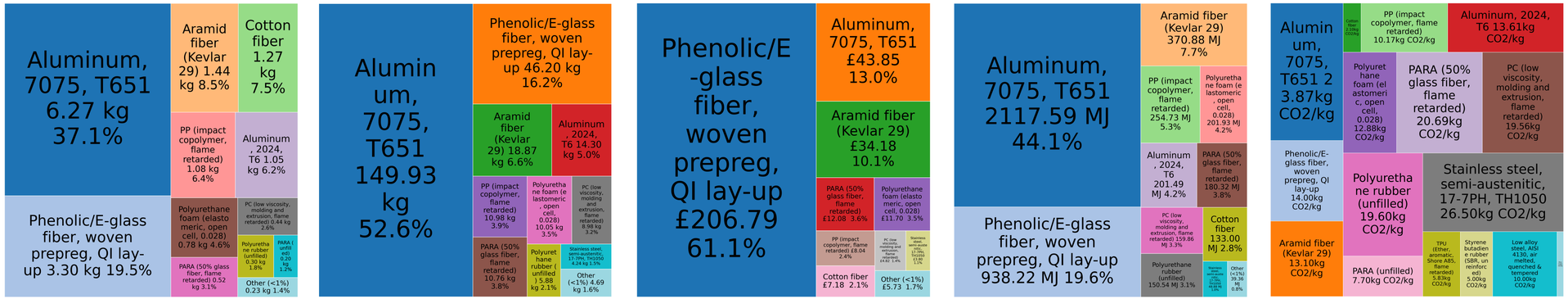
CO2

Cost

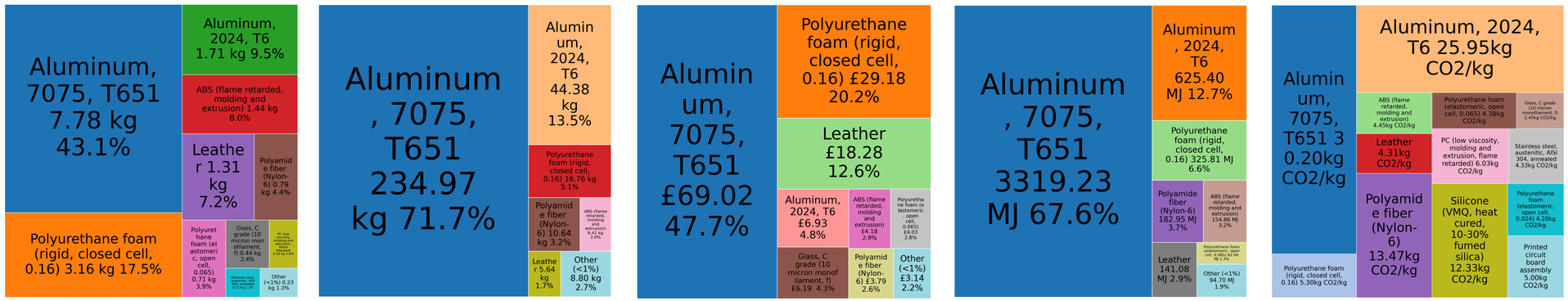
Energy

CO2 per kg

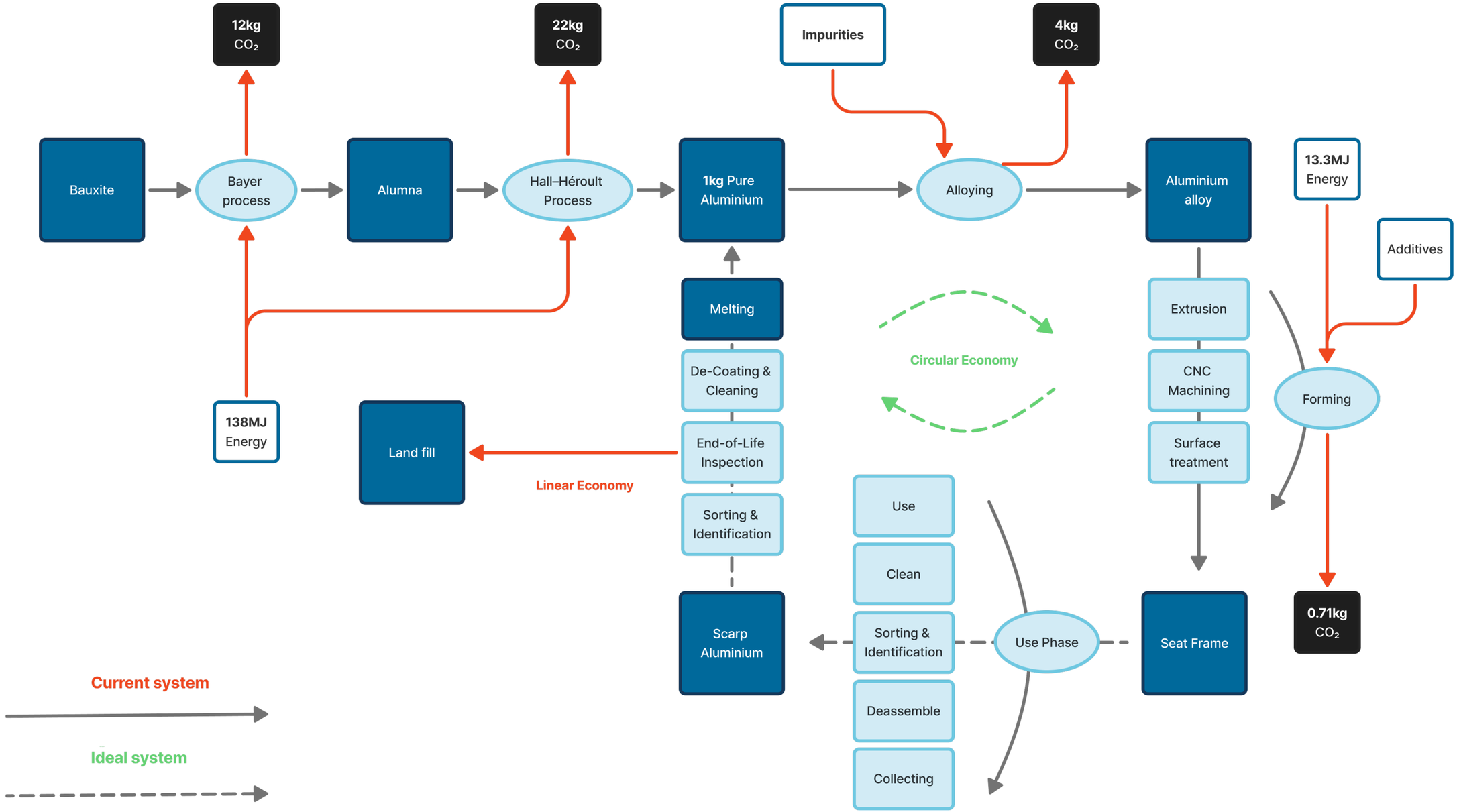
Doy Design PF3000



Safran Weber 5751



Appendix: Aluminium System Map



Appendix: PU Foam Systems Map

