

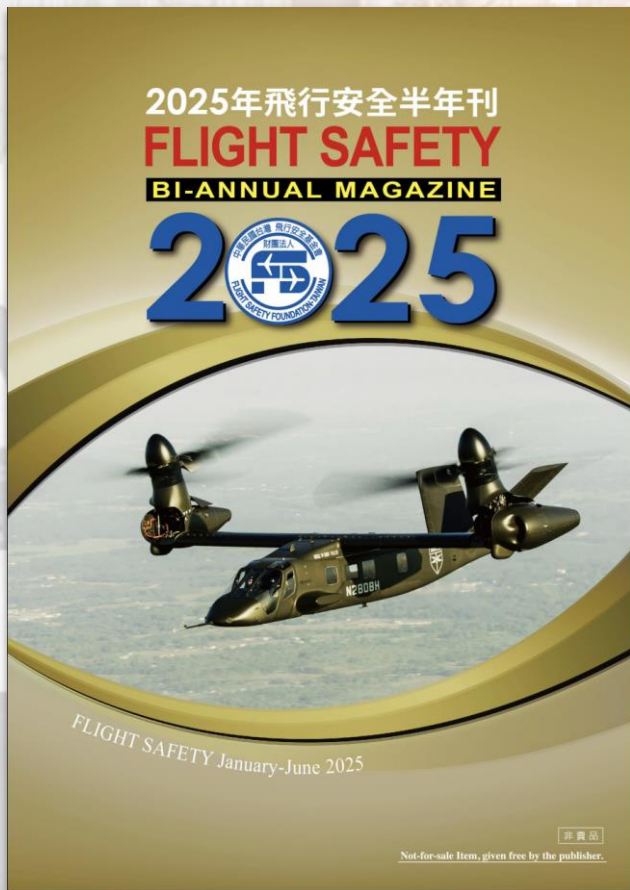
# 航空器循環經濟學

## Aircraft Eco-Economy Industry:

退役航空器處置策略

Aircraft Disposal and Recycle (D&R) strategy

ALPA Taiwan  
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航空器循環經濟學：永續發展及成長

## 航空器循環經濟學： 永續發展及成長

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### 摘要

隨著全球航空業的快速發展以及環保意識的提升，退役航空器的回收與處置已成為永續航空產業的關鍵議題。本研究以航空器循環經濟學（Aircraft Eco-Economy Industry）為核心，提出「退役航空器處置策略」（Aircraft Disposal and Recycle, D&R），並分析國際成功案例如空中巴士 PAMELA 計畫及航空器機隊回收協會（AFRA）的實踐經驗。透過拆解、材料回收及再利用等方法，不僅可最大化退役航空器的剩餘價值，亦能有效降低對環境的負面影響。本文特別聚焦於台灣的產業優勢，探討其在全球航空器回收市場的潛力與發展策略，旨在為航空業的永續發展提供建設性建議。

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# Outline



Background

Core Concept

Operation Strategy

Assessment

Success Stories

Potential

Conclusion



# Background

- Pandemic
- Order disruption
- Rise of ESG

## Global Air Traffic and Operating Profit Trends

(2004-2023, with a forecast for 2024)



Source: Business Travel News; Statista

More charts: [genuineimpact.substack.com](https://genuineimpact.substack.com)

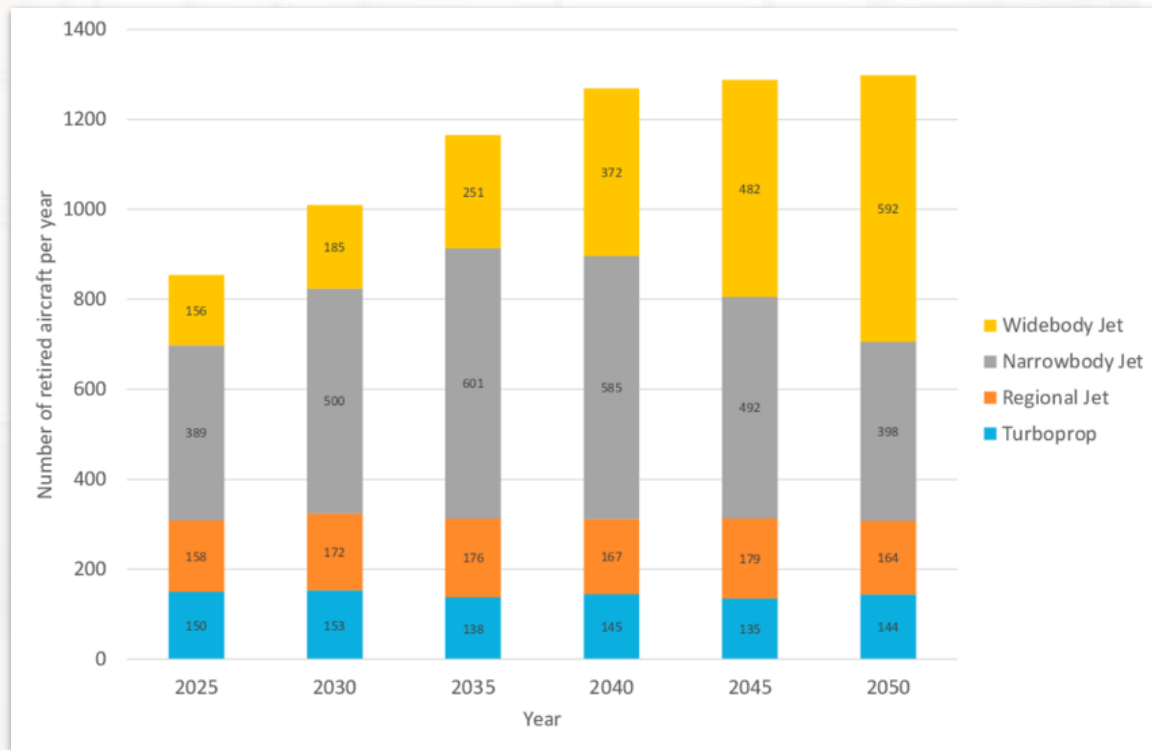
# Background

- Pandemic
- Order disruption
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- Pandemic
- Order disruption
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# Core Concept

- Eco-economy:  
max benefits with  
min impacts
- Disposal ( 處置 )  
disassemble
- Recycle ( 回收 )  
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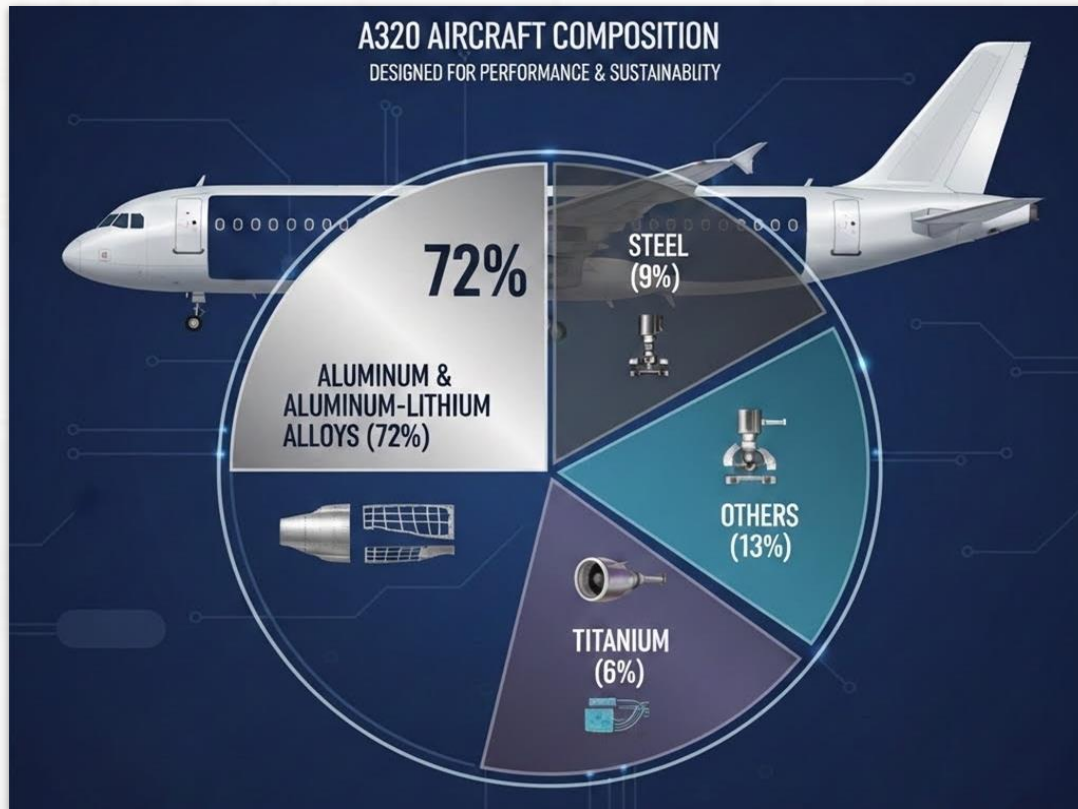
# Core Concept

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# Core Concept

- 92% Recycle Rate
- 99% Engine Recycle



# Operation Strategy



# Assessment

- Cost

$$C_{D\&R} = \sum_k C_{D\&R,k} = C_{D\&R,storing} + C_{D\&R,disassembly\&dismantling} + C_{D\&R,component\_management} \\ + C_{D\&R,material\_management} + C_{D\&R,reuse} + C_{D\&R,alternative\_reuse} + C_{D\&R,energy\_recovery} + C_{D\&R,land\_filling} \\ + C_{D\&R,recycling\_lq} + C_{D\&R,recycling\_hq} + C_{D\&R,resale}$$

$$C_{D\&R,k} = \sum_j C_{D\&R,k,j} = C_{D\&R,k,labour} + C_{D\&R,k,material} + C_{D\&R,k,energy} + C_{D\&R,k,facility} \\ + C_{D\&R,k,tooling\&equipment} + C_{D\&R,k,miscellaneous}$$

- Value

$$V_{residual} = P_{AC}(1+I)^{FY-FY_0} - C_{depreciation} = \frac{P_{AC}}{n_{depreciation}} \left( (1+I)^{FY-FY_0} n_{depreciation} - (1+I)^{n_{depreciation}} (FY - FY_0) \right)$$

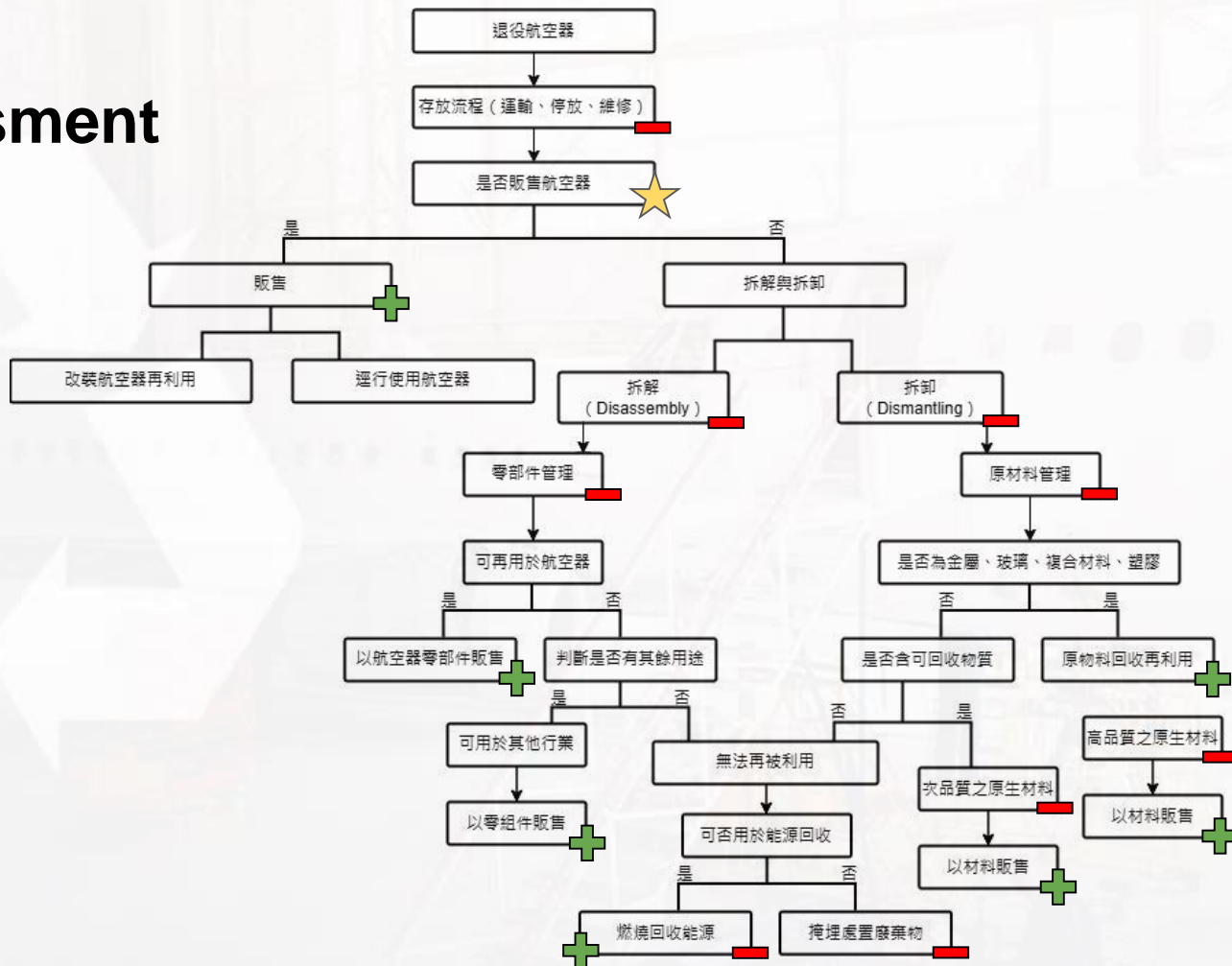
$$PV = \frac{FV}{(1+r)^n}$$

$$V_{residual} = \frac{V_{salvage}}{(1+r_{D\&R})^{n_{D\&R}}}$$

$$V_{salvage} = V_{residual}(1+r_{D\&R})^{n_{D\&R}}$$

$$V_{salvage} = V_{component\_reuse} + V_{component\_alter\_reuse} + V_{energy\_rcv} + V_{material\_hq} + V_{material\_lq} + V_{resale}$$

# Assessment



# Assessment

- Index

$$I_{D\&R} = \frac{V_{salvage} - V_{residual}}{C_{D\&R}}$$

+ - ★  
—  
—

- Other assessment models

1. 經濟效率比率 ( Cost per Ton Recycled )
  - Scheelhaase et al. (2022)
2. 淨現值與ROI分析 ( NPV/ROI for Component Reuse )
  - Dyberg (2023) Jet Engine Recycle Model
3. 價值捕獲模型 ( USM Sales Net Value )
  - KPMG Circularity in Flight (2024)

評估方法	核心特點	公式/邏輯	應用案例	優點	缺點
<p>本文循環經濟效益評估</p>	<p>比較總產出價值與殘值和成本，判斷D&amp;R經濟可行性，涵蓋10步驟成本（勞動、材料等）。</p>	<p>總產出價值 - 殘值 &gt; 總處置成本；考慮通膨、折舊、未來值轉現值。</p>	<p>通用於航空公司決策，如評估A320回收收益（92%機體、99%引擎）。</p>	<p>全面涵蓋D&amp;R全流程，適用於多機型，財務導向明確。</p>	<p>計算複雜，需詳細成本數據，未強調環境效益量化。</p>
<p>Scheelhaase et al. (2022) 經濟效率比率</p>	<p>以每噸回收成本衡量效率，強調環境效益（回收噸數）。</p>	<p>成本 / 回收噸數（如1,666 USD/噸寬體機）。</p>	<p>歐洲窄體機回收，成本138,000 USD，回收60%重量，獲AFRA採用。</p>	<p>簡單直觀，環境效益突出，適合大規模回收比較。</p>	<p>忽略高價值零件（如引擎）的獨立收益，市場需求考量不足。</p>
<p>Dyberg (2023) 淨現值/ROI分析</p>	<p>聚焦高價值零件（引擎），計算NPV與ROI，考慮修復機率與非航空市場。</p>	<p>淨效益 = 回收價值 - 拆解成本；NPV &gt; 0則可行。</p>	<p>CFM56-5C引擎，回收價值250萬USD，成本130萬USD，斯堪地那維亞應用。</p>	<p>專注引擎等高價值部件，考慮市場靈活性，ROI明確。</p>	<p>範圍較窄（零件為主），對結構材料回收分析不足。</p>
<p>KPMG (2024) 價值捕獲模型</p>	<p>計算二手材料（USM）銷售淨價值，結合ESG（減碳）與供應鏈預測。</p>	<p>淨價值 = USM產出 - (殘值 + 成本)，需正值。</p>	<p>PAMELA計畫，A300回收85%，收益50萬歐元，減碳50,000噸。</p>	<p>整合ESG與市場預測，適用租賃公司，回收率高。</p>	<p>公式不夠明確，需外部工具（如AR/VR）支持預測。</p>

## Success Stories - PAMELA Project (2005)

- Initiated by Airbus
- Recycle Rate 85%
- Less than 5% buried
- 200~300k euros metal
- 500k euros parts
- Decarbon 50k+ tons
- Modelizing
- Digital management

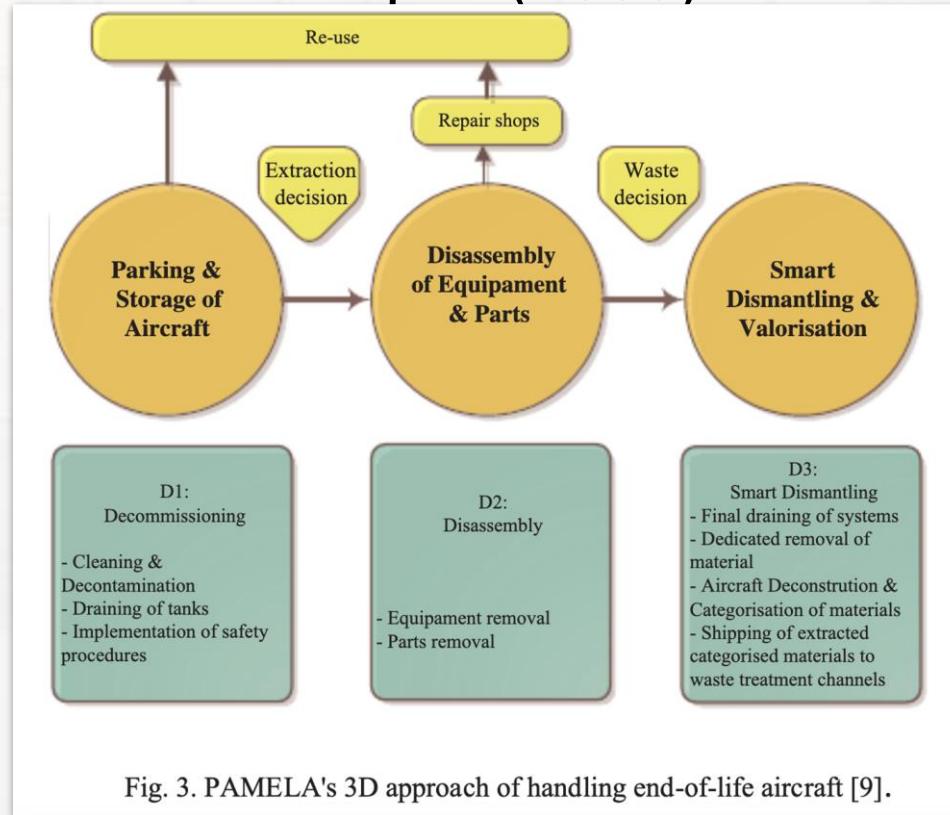


Fig. 3. PAMELA's 3D approach of handling end-of-life aircraft [9].

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The aircraft end-of-life process presents both risks & opportunities



Handling of Hazardous substances and fluids



Special treatment of some components



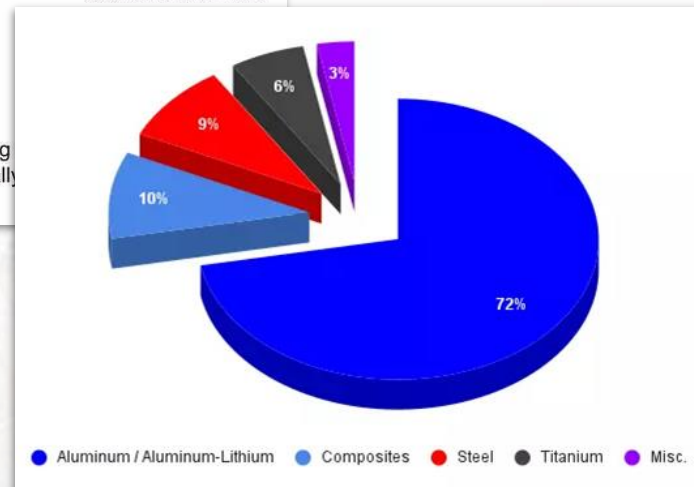
Contamination of soils and water from abandoned aircraft



High recyclability rates with no specific precaution



Re-use and recycling parts is economically interesting



## Success Stories - AFRA (2006)

- Initiated by Boeing
- Non-profit org.
- Recycle Rate 90%
- BMP standard



## Aircraft Fleet Recycling Association Best Management Practices

Jason Dickstein  
General Counsel

## Success Stories - AFRA (2006)

- BMP Accreditation
- Environment
- Parts management
- Material management

### **Best Management Practice for Management of Used Aircraft Parts and Assemblies and for Recycling of Aircraft Materials**

*Published by the*  
**Aircraft Fleet Recycling Association**

Version 3.3

(Approved by the AFRA Board on July 11, 2013. Revised 1 July 2017)

**Revision History**

**AFRA Best Management Practice (BMP) Guide**

## Success Stories - Aviation Circularity Consortium (2024)

- Originated from Singapore Airshow
- Main Founder Airbus, Satair, Tarmac Aerosave, University of Strathclyde
- Highlights:
  - Material Certification
  - Digital tracking
  - Standardization
  - Decarbonization



## Success Stories - Aviation Circularity Consortium (2024)

- 2050 Industry Roadmap
- Closed-loop recycling



**ACC Launches 2050  
Industry Roadmap**



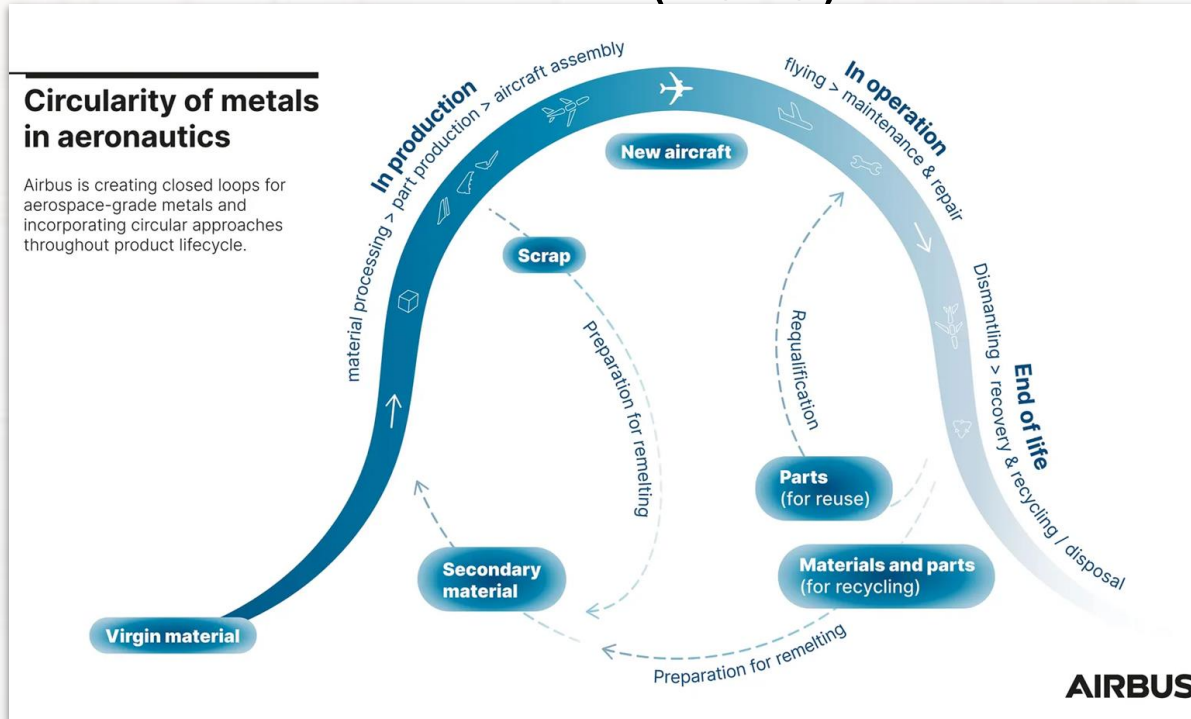
## Success Stories - ALSC (2024)

- Airbus Lifecycle Services Centre
- Chengdu, China
- EASA + CAAC certified
- CFPR recycle
- 90%+ recycle rate



# Success Stories - Airbus & EcoTitanium (2025)

- Closed-loop Recycling
- Jun, 2025
- Retired pylon into Fresh ignot
- Avoid downcycling
- 80% less energy waste



## Success Stories - It goes on and on

- Projects:
  - EcoTitanium
  - CIRPASS
  - Boeing ecoDemonstrator
  - SAP
- Academies:
  - Cranfield
  - MIT
  - DLR



# Potential



## Aircraft Recycling Market

Global Forecast (2025 – 2034)



### MARKET STATISTICS

Market Value (2024)

**\$5.3 BN**

Market Value (2034)

**\$13.2 BN**

CAGR (2025-2034)

**9.7%**



### REGIONAL STATISTICS

North America Market Share (2024)

**53.6%**



### SEGMENT STATISTICS

**Narrow-body segment**

Market Size (2024): **\$3.2 BN**

**Aluminum segment**

CAGR (2025-2034): **>9.5%**



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## Potential - Taiwan

- Mature metallic recycle industry
- Maintenance Capacity
- Governmental policy



## Potential - Taiwan

- Regional Hub for High-Value Material Processing
- Synergy in Closed-Loop Metal & Composite Technologies
- ESG Competitiveness in Local Fleet Decommissioning



## Conclusion

- Analyze Models
- Diverse Business Models
  - PAMELA
  - AFRA
  - ACC
  - ALSC
- Profitable Market
- Potential of Taiwan

