From Source to Success: Inside Rolls Royce's Titanium Inbound Process

Group 7

Ahsan, Eeshah (20550587)

Chen, Ying-Yin(20535637)

Maqbool, Shahmeer (20540187)

Namole, Roshni Yunus (20542740)

Sabir, Fatima (20597221)

Zaheer, Wania (20518122)

Supply Chain Planning and Management - (BUSI4496 UNUK)

AUT 1, 23 - 24

7th December, 2023

Table of Contents

1 Abstract 5

2 Introduction 5

3 Sourcing for Titanium 6

3.1 Industry Overview 7

3.1.1 Product Characteristics 7

3.1.2 Market Dynamics 7

3.1.3 Business Characteristics 8

3.1.4 Technological and Operational Constraints: 8

3.2 Demand Characteristics 8

3.2.1 Nature of Demand 8

3.2.2 Customer Types 8

3.2.3 Variety and Customization 8

3.3 Supply Chain Factors and Configuration 9

3.3.1 Raw Material Availability 9

3.3.2 Supplier Relationships 9

3.3.3 Production and Technology Issues 10

3.3.4 Upstream-Downstream Balance 10

3.4 Impact on Supply Chain Characteristics 10

3.4.1 Flexibility and Responsiveness 10

3.4.2 Inventory Management 10

3.4.3 Lead Time Management 10

3.5 Risk Management 11

3.6 Supplier Selection and Evaluation 12

3.6.1 Criteria for Supplier Selection 12
3.6.2 Supplier Evaluation Process 12
3.7 Transportation Challenges 12
4 Process, Technologies and Challenges 13
4.1 Production process 14
4.2 Supply chain characteristics 15
4.2.1 MTO (Make-to-Order) or ETO(Engineer-to-Order): 15
4.2.2 CODP (Customer order decoupling point): 15
5 Sustainability and Environmental Concerns 15
5.1 Reduce, Reuse, Recycle 15
5.2 Decarbonization Strategy of Rolls-Royce 17
6 Outbound 17
6.1 Rolls-Royce's Role in Boeing's Fleet 17
6.2 Airbus and the Trent Engine Series 17
6.3 Engine Preferences of Airlines 18
7 Future 18
7.1 Future Innovation 18
7.2 Current Titanium Supply Chain Challenges 19
7.3 Shifts in the Titanium Supply Chain 19
7.4 European Challenges 20
7.5 Mitigating Long-term Risks 20
8 Traceability in Rolls Royce’s Supply Chain 21
8.1 GS3001: Guiding Traceability Standards 21
8.1.1 Material Traceability 21

8.1.2 Human Resource Traceability 22
8.1.3 Equipment Traceability 22
8.2 Supply Chain Disruptions – Traceability Non-Negotiable 23
8.3 Digital Improvements for Enhanced Traceability 23
9 Digitalization of the supply chain 23
10 Conclusion 24
11 References 25
12 Appendix 30
Table of Figures 30
Chat GPT Prompts 30

1 Abstract

This report will provide an analysis of the inbound titanium supply chain for Rolls-Royce. It will shed light on the manufacturing process, operations, bottlenecks and future forecasts of the company in context to the challenges in its intricate titanium supply chain as part of the inbound process of the supply chain.

The report delves into Rolls-Royce's supply chain technology, including ERP, SRM, inventory management, and digitization. It then explores the unique aspects of the Rolls-Royce titanium supply chain, focusing on supplier selection and evaluation processes. The report examines manufacturing processes, traceability, and highlights disruptions in the global titanium supply chain, particularly due to COVID-19 and the Russia-Ukraine conflict.

Lastly, our research will rely primarily on secondary data that has been rigorously acquired using a qualitative research approach. We attempt to integrate the report's authority and academic rigor with insightful insights drawn from a wide range of academia and third-party sources.

2 Introduction

With an illustrious history spanning over a century, Rolls-Royce Holdings plc is a trailblazer in aerospace and defense, now embarking on a transformative journey. Established in 1904, the British multinational has evolved into a powerhouse, specializing in cutting-edge power systems crucial for global industries.

Rolls-Royce has many products for business aviation, government defense and power systems, but we will only focus on the crucial material of civil aerospace, titanium, in this report because it plays a key role in Rolls-Royce’s business. Considering the rising traveling demand after COVID-19, and the sales of civil aerospace take approximately half of their revenue as below chart, ensuring the stable supply of titanium will be an important issue (Refer to Figure 1)

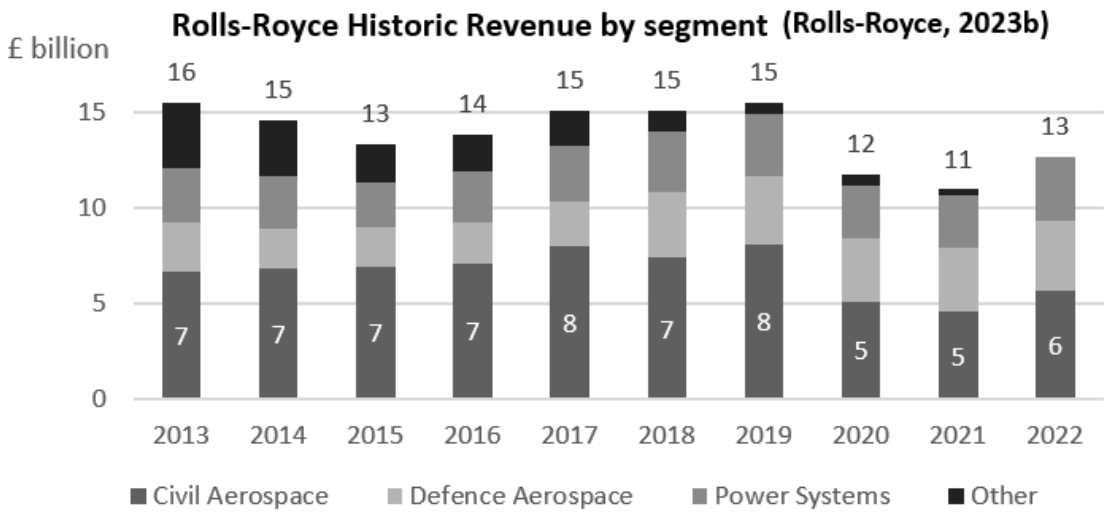

Figure 1Rolls Royce Plc Annual Statement 2023

Rolls-Royce's strategic framework for growth and resilience aligns seamlessly with our project objectives. By delving into their core operating businesses in Civil Aerospace, Defence, and Power Systems, we aim to dissect the nuances of their supply chain, leveraging tailored products and technologies for diverse markets.

In the realm of supply chain innovation, our exploration of Rolls-Royce's journey encompasses a commitment to governance, leadership, and risk management—essential components ensuring value creation for stakeholders. As we navigate through this project, our goal is to uncover insights that contribute not only to Rolls-Royce's ongoing success but also to the broader discourse on optimizing supply chain dynamics in the aerospace and defense industry.

3 Sourcing for Titanium

Rolls Royce, led by ex-CEO Warren East, previously acquired 20% of its titanium from Russia's VSMPO-Avisma (Patel & Ryan, 2022). Post the Russia-Ukraine war, the company diversified its titanium sources, engaging with US-based ATI Metals and Japanese firm Toho Titanium (Commodity Evolution, 2023).

3.1 Industry Overview

The global titanium market reached $28.59 billion in 2022, with projections to hit $31 billion by June 2023 and an anticipated surge to $52 billion by 2030, driven by aerospace and defense demands (Statista, 2023).

3.1.1 Product Characteristics

Rolls Royce leverages titanium's attributes—lightweight, high strength, and resistance—in aerospace applications. Innovations like CFRP, seen in the UltraFan aero engine, underscore Rolls Royce's commitment to technological advancement (KAWAKAMI & FUJII, 2014; Rolls-Royce, 2023).

3.1.2 Market Dynamics

The aerospace titanium market is projected to grow at a CAGR of 4.89%, reaching $5.08 billion by 2030. Increased demand for aircraft deliveries and lightweight materials contributes to this growth, with Rolls Royce being a key player alongside MTU Aero Engines and GE Aviation (Refer to Figure 2)

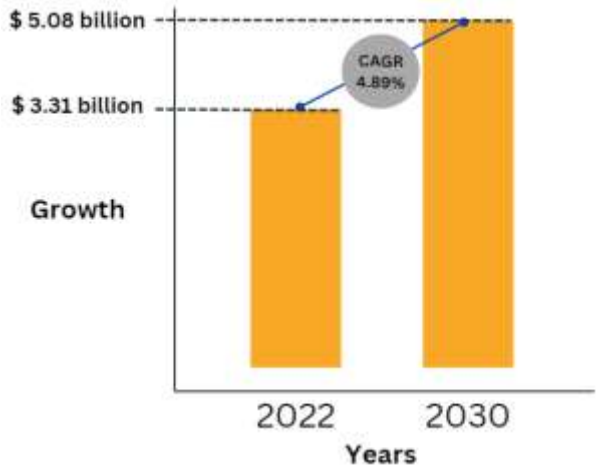

Figure 2 Verified Market Research, 2023

3.1.3 Business Characteristics

Rolls Royce operates in aerospace and defence, utilizing titanium across various applications. Specializing in engine design, development, and services, the company demonstrates market diversity and resilience to economic fluctuations (Expert Research Updates, 2023).

3.1.4 Technological and Operational Constraints:

Rolls Royce encountered challenges in 2019 with the Trent 1000 engine, addressing cooling hole issues. Subsequent difficulties arose due to wartime sanctions, inflation, and Covid-19, resulting in a £111 million loss in 2022, impacting the supply chain with delays and increased production costs (Jolly, 2022; Bloomberg, 2023).

3.2 Demand Characteristics

3.2.1 Nature of Demand

Rolls Royce experienced increased product demand pre-Covid-19, projecting a recovery post-2022 and a full rebound by 2024. Inelastic demand for defence and commercial aircraft and engines contributed to successful recovery by 2022 (Patterson, 2022).

3.2.2 Customer Types

Serving diverse clientele from power systems, aerospace, and military sectors, Rolls Royce extends its services globally to military, marine industries, businesses, maintenance, repair, and overhaul companies, and government and space agencies (Rolls Royce Holdings plc, 2023).

3.2.3 Variety and Customization

Rolls Royce, powering over 12,000 engines globally, caters to 35+ commercial aircraft types, providing flexible aftercare services like TotalCare® Life, TotalCare® Term, and SelectCare™ (Rolls Royce, 2023).

3.3 Supply Chain Factors and Configuration

3.3.1 Raw Material Availability

The diagram illustrates titanium's raw material availability and the supply configuration for Rolls Royce, showcasing the transition from VSMPO-Avisma to diversified sources (Refer to Figure 3)

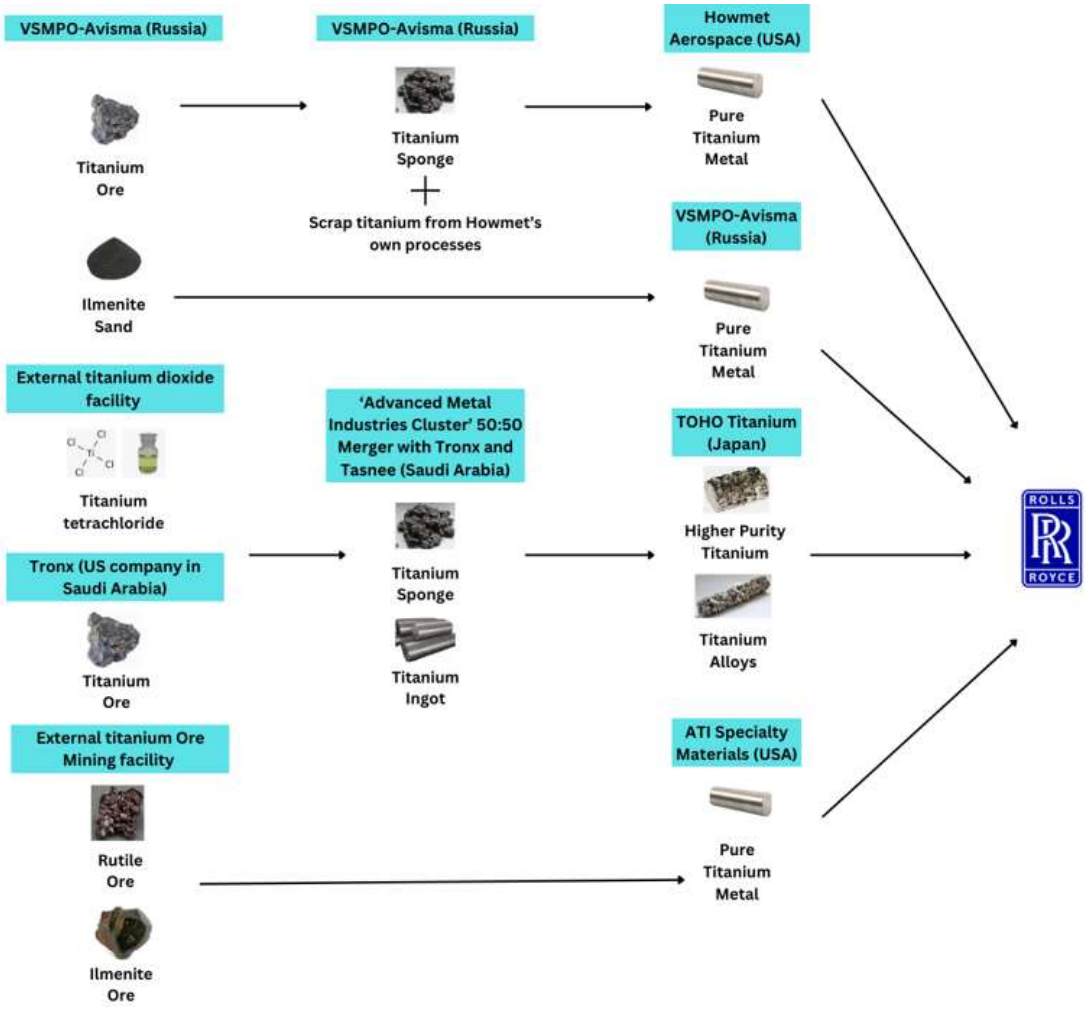

Figure 3 Resource World, 2023; Toho Titanium, 2022; Argus Media, 2019; Monroe, NC, n.d

3.3.2 Supplier Relationships

Rolls Royce maintains robust supplier relationships through a global code of conduct, Process Standardization app, and the Digital Supply Chain app, ensuring collaboration and ISO 14001 compliance (Global Supplier Portal, 2023).

3.3.3 Production and Technology Issues

Geopolitical, technological, and operational factors disrupted Rolls Royce's titanium supply chain. Trent 1000 engine issues in 2019 and subsequent challenges due to sanctions, inflation, and Covid-19 resulted in significant losses in 2022 (Bailey, 2021; Jolly, 2022)

3.3.4 Upstream-Downstream Balance

Rolls Royce strives to maintain a balanced supply chain through apps like the process standardization app and Digital Supply Chain app, ensuring effective communication during stable periods. However, geopolitical and economic challenges necessitated seeking new titanium suppliers in the US and Japan for stability.

3.4 Impact on Supply Chain Characteristics

3.4.1 Flexibility and Responsiveness

Rolls-Royce enhances sourcing flexibility by fostering strong supplier relationships, streamlining processes, eliminating redundancies, preferring multiple suppliers per product, and utilizing real-time data for proactive issue resolution.

3.4.2 Inventory Management

Rolls-Royce utilizes a comprehensive inventory strategy, including demand forecasting, optimized levels, strategic procurement, control systems, warehouse management, excess inventory control, supplier collaboration, and continuous improvement, ensuring timely material availability.

3.4.3 Lead Time Management

Rolls-Royce employs a comprehensive lead time strategy, including analysis, strategic sourcing, communication, visibility, logistics optimization, and continuous improvement. This ensures timely procurement and delivery, minimizing costs and disruptions.

3.5 Risk Management

Rolls-Royce has procedures to manage and oversee the Risk Management System (RMS) (Rolls Royce, 2019). These procedures help determine the nature and extent of principal and emerging risks and are overseen by the Audit Committee and the Board.

Principal Risks

- **Deep Dive Analysis:** Principal risks, owned by the Executive Team, undergo deep dives at least annually.
- **Review by the Board:** The Board reviews principal risks and assesses any changes in nature annually.

Emerging Risks:

- **Identification Activities:** Additional activities, including workshops and digital tools, are introduced to identify emerging risks.
- **Integration into RMS:** Emerging risks are recorded in the RMS and monitored alongside existing risks.

The following steps are undertaken for risk management:

- **Identification and Assessment:** Risks are identified across the organization. Risk owners assess risks, considering current mitigating activities and risk appetite.
- **Discussion in Management Forums:** Results are brought to management forums, including monthly Executive Team and regular Board meetings.
- **Continuous Improvement**
    - **Refinement of Risk Metrics:** Rolls-Royce refines risk appetite metrics and uses them systematically in assessing mitigating activities.
    - **Strengthening Controls:** Continuous efforts to strengthen controls in place, particularly at remote sites.

3.6 Supplier Selection and Evaluation

3.6.1 Criteria for Supplier Selection

Rolls-Royce's supplier selection criteria includes (Rolls Royce, 2023):

- **Quality & Reliability:** Assessment of the supplier's management abilities, financial stability, quality management and ability to timely deliver at the right price.
- **Reputation:** Use of Dow Jones Risk & Compliance Platform to screen assessments on watch lists, sanctions and negative media reports.
- **Sustainability:** Ability to adhere to Rolls-Royce Global Supplier Code of Conduct and uphold ethical and lawful labour and sourcing practices.
- **Technical Expertise & Strategic Alignment:** Demonstrating alignment with Rolls-Royce's long-term goals, business objectives, and commitment to innovation, sustainability, and operational excellence.

3.6.2 Supplier Evaluation Process

Rolls-Royce ensures high supplier standards through a rigorous evaluation process (Rolls Royce, 2023):

- **Site Audits:** Rolls-Royce conducts on-site inspections to assess technical expertise and quality management.
- **Performance Audits:** Gives ratings to suppliers based on delivered quality, supplier complexity, customer complaints, delivery adherence, average length of arrears, etc.
- **Reputation Audits:** Regular screening of watch lists, negative media reports and sanctions through Dow Jones Risk & Compliance Platform.

3.7 Transportation Challenges

Transporting titanium, a lightweight yet robust metal poses challenges due to its susceptibility to corrosion and fire. Safety precautions are vital during transportation. While air shipment ensures swift delivery, it comes at a high cost. Effectively addressing transportation

challenges is paramount for Rolls Royce, given the extensive distances involved in sourcing supplies. (Refer to Figure 4)

Figure 4 Supply Chain Configuration Map

Rolls-Royce addresses these challenges through strategic measures. Utilizing multiple transportation modes (air, sea, land) minimizes disruptions. Investments in logistics technology, like RFID tags and route optimization, enhance tracking and management. These steps secure a dependable titanium supply for Rolls-Royce's manufacturing needs.

4 Process, Technologies and Challenges

Rolls-Royce, a global leader in the aerospace and defence industry, strategically manages its complex and diverse supply chain to ensure a stable supply of high-quality titanium for manufacturing critical aerospace components. With 950 purchasing employees globally and 18,000 active suppliers, Rolls-Royce operates in a complex international environment across Europe, Asia, and North America. (Refer to Figure 5)

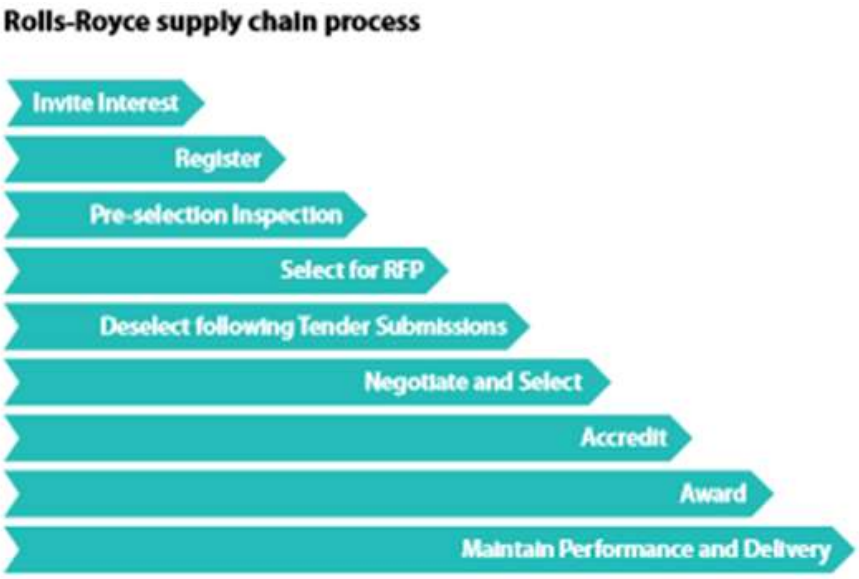

Figure 5 Supply Chain Process

4.1 Production process

Rolls-Royce strategically sources titanium with rigorous quality control, utilizing precision machining and advanced technologies. Integrated supply chain management enhances visibility and collaboration with suppliers..

ERP System: An effective inventory management tool (SAP R3)

For Enterprise Resource Planning (ERP), Rolls-Royce has adopted SAP R3, a cloud-based solution. This move aligns with industry trends, emphasizing standardization for consistency across business units. The ERP system aims to improve profitability, maximize ROI, and minimize the total cost of the supply value chain, crucial in an industry requiring precision and efficiency (*ERP Implementation At Rolls-Royce*, 2023).

SRM system and supply chain traceability (Digitization)

Rolls-Royce's embrace of digital transformation includes Supplier Relationship Management (SRM) systems and supply chain traceability. SRM systems facilitate transparent and collaborative relationships with titanium suppliers, while digital traceability technologies ensure the origin and quality of the material. Blockchain and advanced tracking systems create a

digital thread that follows the titanium supply chain, aligning with the industry's trend towards digitization.

4.2 Supply chain characteristics

Rolls-Royce's titanium supply chain emphasizes global sourcing, quality, and stability through long-term contracts. Strategic relationships and risk mitigation address challenges, while collaboration ensures innovation and compliance. The company prioritizes visibility, sustainability, and continuous improvement.

4.2.1 MTO (Make-to-Order) or ETO(Engineer-to-Order):

Rolls-Royce employs a hybrid strategy in aerospace manufacturing, blending Make-to-Order (MTO) for standard parts and Engineer-to-Order (ETO) for specialized components. Technological integration ensures precision, and supply chain agility is crucial for efficient production coordination.

4.2.2 CODP (Customer order decoupling point):

Rolls-Royce's CODP denotes the shift from standardized to customer-specific titanium customization. Pre-CODP uses a Make-to-Order strategy for standardized parts, transitioning post-CODP to precision engineering. Advanced tech and supplier collaboration ensure flexibility, responsiveness, and aviation standards adherence.

5 Sustainability and Environmental Concerns

5.1 Reduce, Reuse, Recycle

Unfortunately, titanium wastes are inevitable in the manufacturing process, so how to reduce and deal with these scraps is important. In the casting and machining period (Refer to Figure 6) it usually generates titanium alloy scrap due to many restrictions, such as keeping specific characteristics of titanium (Titanium Exposed, n.d.).

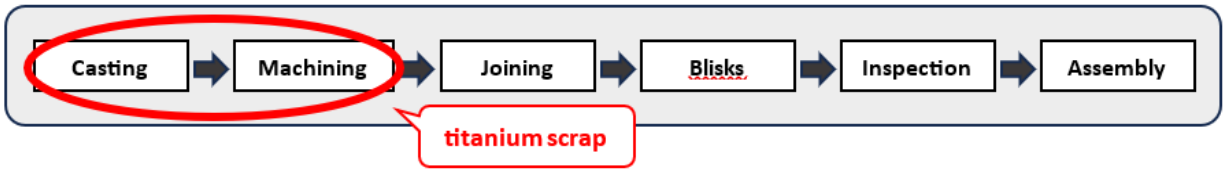

Figure 6 Manufacturing Process of Engine, Rolls Royce Plc, 2015

Although the melting of titanium scrap would need more extra processing, the economic value of titanium scrap makes it viable (Titanium Exposed, n.d.). Therefore, Rolls-Royce introduced a programme called "Revert", a closed-loop system for the disposal, recycling and re-use of this waste. (Refer to Figure 7)

Unlike the way that just ended up in a landfill in the past, Rolls-Royce chooses to hand the titanium scrap to a supplier that melts the waste and re-supply to Rolls-Royce. This system leads to the reduction of a considerable amount of ore usage and CCH emissions and makes more effective use of the raw materials which also saves the cost. (Bagshaw, 2005)

Rolls Royce Plc (2018) said that it has reused over 20,000 tonnes of high-value metal alloys, 300,000-megawatt hours, and 80,000 tonnes of carbon dioxide each year through "Revert".

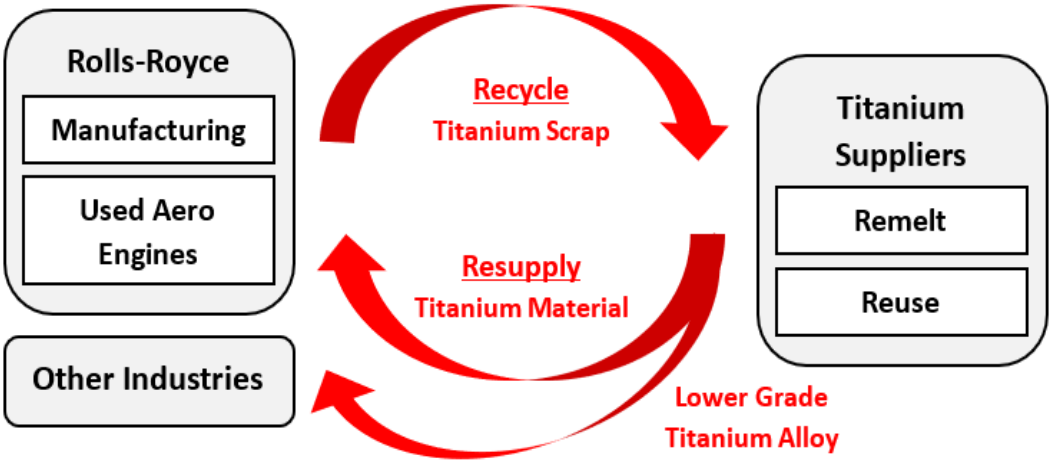

Figure 7 Rolls Royce Titanium Recycle Process, Rolls-Royce, 2021

5.2 Decarbonization Strategy of Rolls-Royce

Apart from the action for the raw materials, Rolls-Royce also sets a target, Net-Zero by 2050. They try to achieve this goal by updating the equipment in operations and factories, improving the design of aircraft engines and working with suppliers and customers (Rolls Royce, 2023c).

Rolls-Royce keeps increasing R&D spending on sustainable technology, and make all the engines fully compatible with SAF (Sustainable Aviation Fuel) which is a non-fossil-based source by 2023 (Rolls Royce, 2023a). Recently, they have worked with UK universities and their customers to make the flights further SAF use. On 28 November 2023, the world’s first net zero flight took off from London to New York. It sets a new milestone in the sustainability of aerospace and also proves the capability of SAF as a safe drop-in replacement for fossil-derived jet fuel (Virgin Atlantic, 2023).

6 Outbound

The aerospace industry, driven by major players like Boeing and Airbus, is intricately connected to engine manufacturers such as Rolls-Royce, a global leader powering over 35 types of commercial aircraft with 13,000 engines worldwide (Rolls Royce First Network, n.d.).

6.1 Rolls-Royce's Role in Boeing's Fleet

Boeing collaborates with Rolls-Royce to propel key aircraft, including the Boeing 787 Dreamliner. The Dreamliner offers a choice between engines, with the Rolls-Royce Trent 1000 standing out for its efficiency, playing a crucial role in the Dreamliner's success (Rolls Royce, n.d.).

6.2 Airbus and the Trent Engine Series

Rolls-Royce's influence extends to Airbus, with the Trent engine series featuring prominently in Airbus aircraft. The A330, A340, A350, A380, Boeing 777, and 787 Dreamliner all incorporate variations of the Trent engine, showcasing its versatility (Refer to Figure 8).

Figure 8 Airbus A350 Materials Flow

6.3 Engine Preferences of Airlines

The Trent engines, used by global airlines like British Airways and Virgin Atlantic, provide operational efficiency and sustainability. British Airways, a major Boeing and Airbus operator, depends on Rolls-Royce engines, while Virgin Atlantic chooses the Trent series for their long-haul flights, emphasizing performance and environmental responsibility.

7 Future

7.1 Future Innovation

Rolls-Royce's commitment to aerospace innovation focuses on the UltraFan. With scalability and sustainability features, the UltraFan's variable pitch fan system promises a minimum 25% improvement in fuel burn (Rolls Royce, n.d.). Targeting a 15:1 bypass ratio and 70:1 overall pressure ratio, the UltraFan aims to redefine air travel (Refer to Figure 9) (ADVANCE, 2018).

Figure 9 Rolls Royce Ultra Fan, Rolls Royce Plc 2023

7.2 Current Titanium Supply Chain Challenges

Despite its aerospace prominence, Rolls-Royce faces challenges in its titanium supply chain due to the Russia-Ukraine conflict. The reliance on Russian titanium, facilitated through VSMPO-AVISMA, prompts concerns about stability. The conflict disrupts the supply chain, leading Rolls-Royce to reevaluate dependencies and seek alternative titanium sources to mitigate geopolitical risks (Refer to Figure 10) (Catala, n.d.).

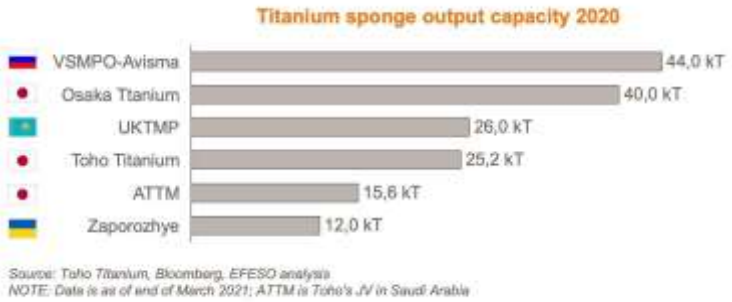

Figure 10 EFESO Management Consultants, 2022

7.3 Shifts in the Titanium Supply Chain

Anticipating a medium-term shift, the aerospace industry eyes the U.S. and Japan as potential alternatives in the titanium supply chain. Companies like Osaka Titanium and Allegheny Technologies Incorporated, with strong positions in primary and secondary fabrication, emerge as key players (Refer to Figure 11, Figure 12) (Catala, n.d.).

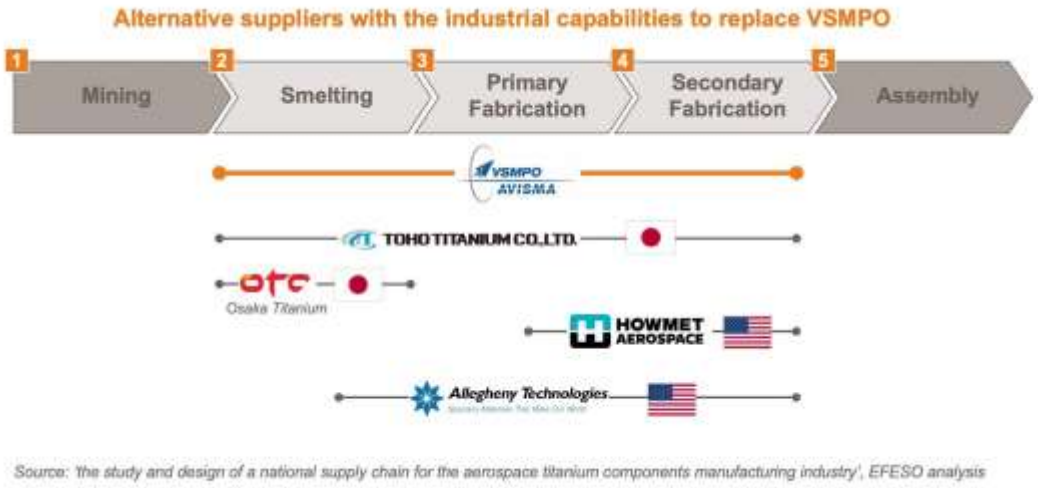

Figure 11 Alternative Suppliers with the Industrial Capabilities to replace VSMPO

Figure 12 Stock Price Evolution for Toho Titanium, Osaka Titanium and Allegheny Technologies

7.4 European Challenges

Europe faces hurdles in capturing the titanium value chain movement, impacting the efficiency of major aerospace companies like Airbus and Safran (AEROSPACE & DEFENSE, n.d., #). Developing capabilities in Europe becomes crucial for the long-term strategic interests of aerospace, healthcare, and power industries.

7.5 Mitigating Long-term Risks

The Russia-Ukraine conflict urges Rolls-Royce and the aerospace industry to reassess and diversify titanium supply chains. Beyond immediate challenges of disruptions and potential

shortages, strategic investments in securing alternative sources and enhancing regional capabilities become paramount for long-term resilience and sustainability in the titanium supply chain.

8 Traceability in Rolls Royce’s Supply Chain

Air travel stands out as one of the safest modes of transportation, but the gravity of potential mishaps necessitates an unwavering commitment to traceability in Rolls Royce's aircraft engine components.

Rolls Royce's approach to traceability incorporates geopolitical dynamics, characteristics of the industry, and processes of private governance. Contrary to the conventional notion that countries with more industry players exert greater influence, Rolls Royce strategically leverages its exclusivity and geographical connections, emphasizing traceability over geographical dominance to enhance the integrity of its supply chain (Scholneich, Saulich and Muller, 2023).

8.1 GS3001: Guiding Traceability Standards

To enforce stringent traceability standards, Rolls Royce has implemented GS3001, a comprehensive set of guidelines for suppliers. This document serves not only to communicate the company's quality standards but also as a mandate for ensuring traceability of raw materials at various stages within the supply chain (Rolls Royce Plc, n.d.).

8.1.1 Material Traceability

Rolls Royce classifies titanium as a Class A material, subjecting it to meticulous traceability checks. From cast numbers to suppliers in the UK, USA, or Western Europe, the company ensures transparency throughout the procurement process. Titanium suppliers are obligated to adhere to ISO 9001 and ISO 17025 compliant management systems, with traceability extending to the United Kingdom Accreditation Service (UKAS). Moreover, the robust traceability checks extend beyond tier 1 suppliers, encompassing material distributors (tier 2 suppliers). Traceability therefore becomes crucial for Rolls Royce to keep a track of suppliers in both tiers. (Refer to Figure 13)

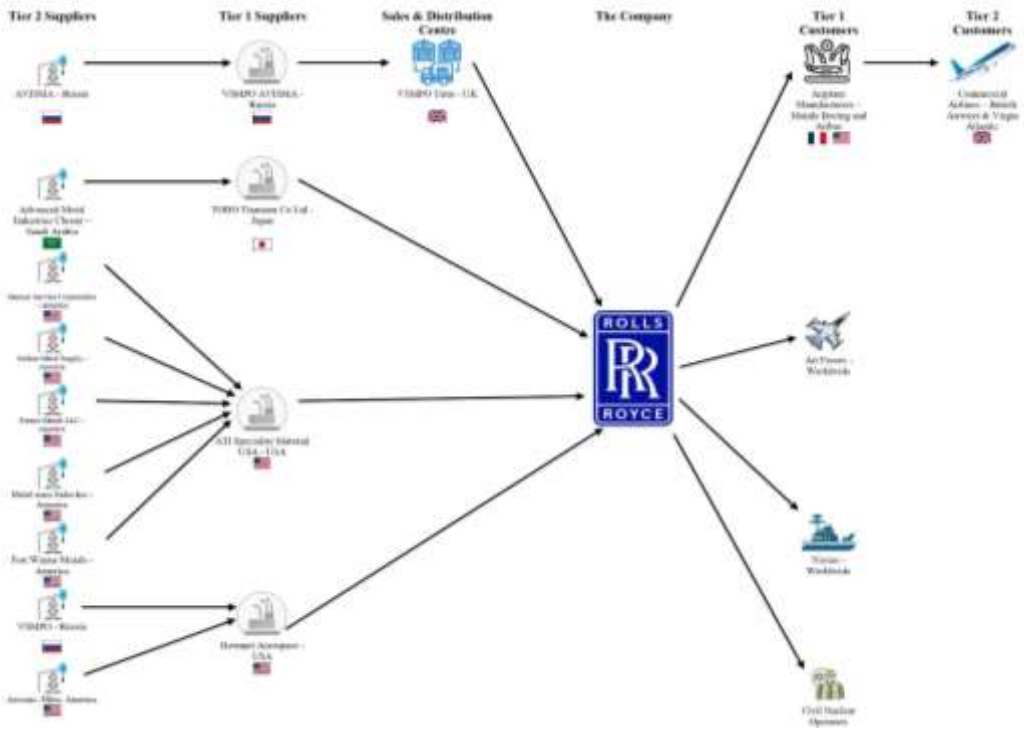

Figure 13 Rolls Royce Supply Chain Tiers

8.1.2 Human Resource Traceability

Traceability extends to human resources involved in critical tasks. Suppliers are obligated to maintain a "Method of Manufacture" (MoM) as outlined in GS3001, creating traceable references for operators, inspectors, and individuals authorizing special process procedures. (Rolls Royce, 2017). Even in the case of a special process procedure, clause 5.6 of GS3001 states that a traceable reference about the person authorised to approve documented procedures must be created (Rolls Royce Plc, n.d.).

8.1.3 Equipment Traceability

Rolls Royce extends traceability beyond materials and human resources to the equipment used for product verification. Compliance with national or international measurement standards (GS3001, Clause 5.1) is ensured, with a parallel emphasis on the permanent maintenance of calibration records for comprehensive traceability (Rolls Royce Plc, n.d.).

8.2 Supply Chain Disruptions – Traceability Non-Negotiable

Recent global disruptions, such as the COVID-19 pandemic and the conflict in Ukraine, underscore the critical importance of traceability. Rolls Royce, heavily reliant on airborne engine hours for revenue, faced significant challenges due to disrupted supply chains. Geopolitical considerations prompted the company to seek alternative titanium sources, distancing itself from Russian suppliers. The effectiveness of Rolls Royce's traceability strategy allowed it to swiftly adapt, securing new suppliers and resuming operations in 2022 (Jolly, 2022).

8.3 Digital Improvements for Enhanced Traceability

In response to evolving challenges, Rolls Royce explores digital solutions to further enhance traceability.

- **Blockchain Integration:** The company contemplates the incorporation of all tier suppliers into a private blockchain, ensuring foolproof monitoring and end-to-end traceability. While the mining industry has been an early adopter of blockchain, challenges may arise if smaller suppliers face difficulties integrating such technologies (Calvao and Archer, 2021)
- **Tagging Initiatives:** Leveraging the scale of titanium suppliers, Rolls Royce adopts tagging initiatives like mineralogical fingerprinting. This involves creating unique markers for each titanium batch, facilitating streamlined tracking and movement monitoring.

Rolls Royce's unwavering commitment to traceability across materials, human resources, and equipment is not merely a matter of compliance; it stands as a strategic imperative for ensuring aviation safety and operational resilience in the face of global disruptions (Scholneich, Saulich and Muller, 2023).

9 Digitalization of the supply chain

The following Digital technologies are currently in use by Rolls Royce (Rolls Royce Plc, 2018)

- **AI and Predictive Analytics** Predictive analytics powered by AI improve demand forecasting, facilitating better planning and lowering the possibility of shortages. Inventory levels get tracked by IOT devices and smart sensors, providing precise supply chain control and real-time insight.

- **Emerging Technologies (AR, Drones, 3D Printing):** Improve maintenance and training through augmented reality, enhance inventory management with drones and robotics, and introduce 3D printing for flexible and efficient manufacturing, collectively fortifying the resilience and efficiency of the supply chain.

Additional technologies which can be used in the supply chain can include

- **Blockchain for Traceability:** Blockchain's decentralized nature ensures precise tracking of titanium components, enhancing transparency and authenticity verification in the aerospace supply chain. Its unique features, like immutability, bolster reliability, addressing concerns related to material genuineness and origin.
- **Quantum Computing:** Adopting this cutting-edge technology might potentially provide Rolls-Royce access to sophisticated computational power for more complex risk management and supply chain optimization.

10 Conclusion

Rolls-Royce's titanium supply chain resilience was evident in response to challenges from the Russia-Ukraine conflict and the global impact of COVID-19. Diversification of titanium sources, strategic technology adoption, and flexible procurement processes showcased the company's adaptability. The commitment to sustainability through initiatives like the "Revert" program for recycling titanium waste and a robust decarbonization strategy demonstrated Rolls-Royce's environmental responsibility. The report highlighted the critical role of traceability in the supply chain, emphasizing GS3001 guidelines and digital solutions like blockchain integration. Looking forward, the company's focus on innovation, as seen in the UltraFan, positions Rolls-Royce strategically in the evolving aerospace industry. This analysis provides valuable insights into Rolls-Royce's titanium supply chain, emphasizing resilience, sustainability, and innovation in a dynamic industry.

11 References

ADVANCE. (2018, July 16). *Rolls-Royce's Advance3 demonstrator running at full power.* Retrieved December 7, 2023, from ADS Advance: https://www.adsadvance.co.uk/rolls-royce-s-advance3-demonstrator-running-at-full-power.html

AEROSPACE & DEFENSE. (n.d.). AEROSPACE & DEFENSE. *INDUSTRY OUTLOOK*, 5. Retrieved from file:///C:/Users/LLR%20User/Downloads/EFESO%20Aeronautique%20A&D%20%20(1).pdf

Argus Media. (2019, October 8). *Saudi-Japanese venture begins titanium sponge output.* Retrieved December 7, 2023, from Argus Media: https://www.argusmedia.com/en/news/1991192-saudijapanese-venture-begins-titanium-sponge-output

Bagshaw, S. (2005) 'Material benefits', *Supply Management*, 10(23), p. 26.

Bailey, J. (2021, September 22). *How Rolls-Royce Solved Its Trent 1000 Issues.* Retrieved December 7, 2023, from Simple Flying: https://simpleflying.com/rolls-royce-trent-1000-solved/

Bloomberg. (2023, May 12). *Rolls-Royce Says Supply-Chain Disruptions Remain Key Concern.* Retrieved December 7, 2023, from Supply Chain Brain: https://www.supplychainbrain.com/articles/37262-rolls-royce-says-supply-chain-disruptions-remain-key-concern

Calvao and Archer. (2021, June 16). *\/.* Retrieved December 7, 2023, from YouTube: https://www.sciencedirect.com/science/article/pii/S096262982100041X

Catala, L. (n.d.). *The impact of the Russia-Ukraine conflict on the aerospace supply chain: which are the options to replace Russian Titanium?* Retrieved December 7, 2023, from EFESO Management Consultants: https://www.efeso.com/knowledge/insight/the-impact-of-the-russia-ukraine-conflict-on-the-aerospace-supply-chain-which-are-the-options-to-replace-russian-titanium

Commodity Evolution. (2022, April 21). *Titanium: Boeing, Airbus and Rolls-Royce looking for new suppliers.* Retrieved December 7, 2023, from Commodity Evolution:

https://www.commodityevolution.com/2022/04/21/titanium-boeing-airbus-and-rolls-royce-looking-for-new-suppliers/?lang=en

ERP Implementation At Rolls-Royce. (2023, May 3). Retrieved December 7, 2023, from Geektonight: https://www.geektonight.com/erp-implementation-at-rolls-royce/

Expert Research Updates. (2023, October 26). *Aerospace Titanium Market Analysis Research Report [2023-2030] | 107 Pages.* Retrieved December 7, 2023, from LinkedIn: https://www.linkedin.com/pulse/aerospace-titanium-market-analysis-research-report-5kehe/

Global Supplier Portal. (2023). *Rolls Royce.* Retrieved December 7, 2023, from Global Supplier Portal - Guest Desktop: https://suppliers.rolls-royce.com/GSPWeb/appmanager/gsp/guest?_nfpb=true&_pageLabel=article_page&_nfls=false&articleNode=%2FDigital+Supply+Chain+App

Jolly, J. (2022, August 4). *Rolls-Royce blames supply chain woes and Covid hit to aviation for £111m loss.* Retrieved December 7, 2023, from The Guardian: https://www.theguardian.com/business/2022/aug/04/rolls-royce-blames-pandemic-supply-chain-woes-and-hit-to-aviation-for-111m-loss

Jolly, J. (2022, August 4). *Rolls-Royce blames supply chain woes and Covid hit to aviation for £111m loss.* Retrieved December 7, 2023, from The Guardian: https://www.theguardian.com/business/2022/aug/04/rolls-royce-blames-pandemic-supply-chain-woes-and-hit-to-aviation-for-111m-loss

Jolly, J. (2022, August 4). *Rolls-Royce blames supply chain woes and Covid hit to aviation for £111m loss.* Retrieved December 7, 2023, from The Guardian: https://www.theguardian.com/business/2022/aug/04/rolls-royce-blames-pandemic-supply-chain-woes-and-hit-to-aviation-for-111m-loss

KAWAKAMI, A., & FUJII, H. (2014). *Development of Ti-Al-Fe Based Titanium Alloy Super-TIXTM51AF Hot Rolled Strip Products.* Retrieved December 7, 2023, from Nippon Steel: https://www.nipponsteel.com/en/tech/report/nssmc/pdf/106-12.pdf

Monroe. (n.d.). *ATI Specialty Metals | Titanium.* Retrieved December 7, 2023, from Titanium Manufacturers: https://www.titaniummanufacturers.com/ati-specialty-metals/

Patel, T., & Ryan, C. (2022, February 24). *Jet-engine makers look for titanium supplies outside Russia.* Retrieved December 7, 2023, from The Seattle Times: https://www.seattletimes.com/business/jet-engine-makers-look-for-titanium-supplies-outside-russia/

Patterson, T. (2022, July 8). *Rolls-Royce Sees Rising Demand for Large Aircraft.* Retrieved December 7, 2023, from FLYING Magazine: https://www.flyingmag.com/rolls-royce-sees-rising-demand-for-large-aircraft/

Resource World Magazine. (2023). *Global nations are interested in the development of Ukrainian titanium deposits – Resource World Magazine.* Retrieved December 7, 2023, from Resource World Magazine: https://resourceworld.com/global-nations-are-interested-in-the-development-of-ukrainian-titanium-deposits/

Rolls-Royce plc (2015) *The jet engine.*, Chichester, West Sussex : Wiley

Rolls-Royce (2017) *Reducing demand.* Retrieved December 02, 2023, from Rolls Royce: https://www.rolls-royce.com/media/our-stories/discover/2017/revert.aspx

Rolls Royce. (2019). *Annual Report | Rolls Royce (2019).* Retrieved December 05, 2023, from Annual Report | Rolls Royce (2019): https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/annual-report/2019/2019-full-annual-report.pdf

Rolls-Royce (2021) *Reduce. Reuse. Recycle.* Retrieved December 02, 2023, from Rolls Royce: https://www.rolls-royce.com/media/our-stories/discover/2021/poweroftrent-reduce-reuse-recycle.aspx

Rolls-Royce (2023a) *Decarbonising complex and critical systems.* Retrieved December 02, 2023, from Rolls Royce: https://www.rolls-royce.com/sustainability/our-approach-to-decarbonisation/decarbonising-complex-critical-systems.aspx

Rolls-Royce (2023b) *Financial Results and Events by Financial Year.* Retrieved December 02, 2023, from Rolls Royce: https://www.rolls-royce.com/investors/results-reports-and-presentations/financial-results.aspx#yr-2023

Rolls-Royce (2023c) *Our approach to decarbonization.* Retrieved December 02, 2023, from Rolls Royce: https://www.rolls-royce.com/sustainability/our-approach-to-decarbonisation.aspx#/decarbonising-complex

Rolls Royce. (2023). *News & Insights.* Retrieved December 7, 2023, from Rolls-Royce: https://www.rolls-royce.com/media/our-stories.aspx

Rolls Royce. (2023). *Supplier Information | Rolls-Royce.* Retrieved December 05, 2023, from Supplier Information: https://www.rolls-royce.com/sustainability/customers-and-suppliers.aspx

Rolls Royce. (2023). *Supplier Total Evaluation Process (STEP).* Retrieved December 05, 2023, from Supplier Total Evaluation Process (STEP): https://suppliers.rolls-royce.com/GSPWeb/ShowProperty?nodePath=/BEA%20Repository/Global%20Supplier%20Portal/Section%20DocLink%20Lists/Supplier%20training/Basic%20training/Column%201/Section%202/Documents/NA%20scorecard%20training//file

Rolls Royce. (2023). *Trent 1000: Boeing 787 Engine.* Retrieved December 7, 2023, from Rolls-Royce: https://www.rolls-royce.com/products-and-services/civil-aerospace/widebody/trent-1000.aspx#section-overview

Rolls Royce. (2023). *UltraFan.* Retrieved December 7, 2023, from Rolls-Royce: https://www.rolls-royce.com/innovation/ultrafan.aspx

Rolls Royce First Network. (n.d.). *Aircraft & Airplane Engines | Rolls-Royce Civil & Defense Aerospace | Aviation.* Retrieved December 7, 2023, from Rolls-Royce FIRST Network Service: https://www.rollsroycefirstnetwork.com/other-rr-engines

Rolls Royce Holdings plc. (2023). *Customers.* Retrieved December 7, 2023, from Rolls-Royce: https://www.rolls-royce.com/country-sites/uk/our-uk-story/customers.aspx

Rolls Royce Plc. (2018, March 6). *Rolls-Royce Holdings plc Annual Report 2017.* Retrieved December 7, 2023, from Rolls-Royce: https://www.rolls-royce.com/~/media/Files/R/Rolls-Royce/documents/annual-report/2017/2017-full-annual-report.pdf

Rolls Royce Plc. (n.d.). *Supplier Quality Management System Requirements.* Retrieved December 7, 2023, from Global Supplier Portal: https://suppliers.rolls-royce.com/GSPWeb/ShowProperty?nodePath=/BEA%20Repository/Global%20Supplier%20Portal/Section%20DocLink%20Lists/RR%20Nuclear%20Suppliers/Main/Column%201/Section%209/Documents/Submarines:%20GS3001%20Issue%2023//file

Rolls Royce. (n.d.). *Power of Trent.* Retrieved from Rolls Royce: https://www.rolls-royce.com/products-and-services/civil-aerospace/widebody/power-of-trent.aspx

Scholneich, Saulich and Muller. (2023, June 16). *\/.* Retrieved December 7, 2023, from YouTube: https://onlinelibrary.wiley.com/doi/full/10.1111/rego.12527

Statista. (2023, October 30). *Titanium: global market value 2030.* Retrieved December 7, 2023, from Statista: https://www.statista.com/statistics/1318587/market-size-of-titanium-worldwide/

Titanium Exposed. (n.d.). *Titanium industries - a single metal, a thousand possibilities.* Retrieved December 7, 2023, from Titanium story, the legend of the metal of the gods: https://www.titaniumexposed.com/titanium-industries.html

Toho Titanium. (2022). Retrieved December 7, 2023, from Titanium Sponge | Toho Titanium Co., Ltd.: https://www.toho-titanium.co.jp/en/products/sponge/

Verified Market Research. (2023). *Aerospace Titanium Market Size, Share, Trends, Opportunities & Forecast.* Retrieved December 7, 2023, from Verified Market Research: https://www.verifiedmarketresearch.com/product/aerospace-titanium-market/

Virgin Atlantic. (2023, November 28). *Virgin Atlantic flies world's first 100% Sustainable Aviation Fuel flight from London Heathrow to New York JFK.* Retrieved December 7, 2023, from Corporate | Virgin Atlantic: https://corporate.virginatlantic.com/gb/en/media/press-releases/worlds-first-sustainable-aviation-fuel-flight.html

12 Appendix

Table of Figures

Figure 1Rolls Royce Plc Annual Statement 2023..... 6

Figure 2 Verified Market Research, 2023..... 7

Figure 3 Resource World, 2023; Toho Titanium, 2022; Argus Media, 2019; Monroe, NC, n.d ... 9

Figure 4 Supply Chain Configuration Map 13

Figure 5 Supply Chain Process 14

Figure 6 Manufacturing Process of Engine, Rolls Royce Plc, 2015..... 16

Figure 7 Rolls Royce Titanium Recycle Process, Rolls Royce Plc 2011 16

Figure 8 Airbus A350 Materials Flow 18

Figure 9 Rolls Royce Ultra Fan, Rolls Royce Plc 2023 19

Figure 10 EFESO Management Consultants, 2022 19

Figure 11 Alternative Suppliers with the Industrial Capabilities to replace VSMPO 20

Figure 12 Stock Price Evolution for Toho Titanium, Osaka Titanium and Allegheny Technologies 20

Figure 13 Rolls Royce Supply Chain Tiers 22

Chat GPT Prompts

We have used the following prompts to optimize our report in terms of the word count.

“Summarize the following text in 100 words”

“Create 5 bullet points from the following text”

“Shorten this paragraph in 3 lines”

“Reduce this text to 500-600 words”