Development of Light-weight and Ultra-strong $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ Refractory Alloys for Energy-efficient Transportation Systems.

Engineering Materials Development Institute

Executive Summary

Developing light-weight and ultra-strong $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ refractory alloys for energy-efficient transportation systems faces several research problems, each with a clear rationale. Addressing these challenges is essential for ensuring the new materials meet the rigorous demands of modern transportation applications.

1. **Material Synthesis Challenges**

Research Problem: The synthesis of $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ with consistent microstructure and properties can be complex due to the constituent elements' different melting points and reactivity.

Rationale: Achieving uniform powder characteristics and effective consolidation is crucial for maximizing mechanical properties. Variability in the starting materials can lead to defects, inconsistent performance, and reduced material reliability, making it imperative to develop precise synthesis techniques.

2. **Microstructural Control**

Research Problem: The alloy's performance depends highly on its microstructure, including phase distribution and grain size.

Rationale: A controlled microstructure can enhance strength and ductility. However, achieving the desired microstructural features requires a deep understanding of phase transformations during processing and service conditions. This knowledge is essential to ensure the alloy performs optimally under operational stresses.

3. **Mechanical Property Characterization**

Research Problem: Establishing reliable methods to characterize mechanical properties, especially at high temperatures, can be challenging.

Rationale: Accurate assessment of yield strength, tensile strength, and fatigue resistance at elevated temperatures is critical for applications in the aerospace and automotive sectors. Developing standardized testing protocols will ensure that the alloy meets industry requirements and can be confidently utilized in real-world conditions.

4. **Corrosion Resistance**

Research Problem: Evaluating and improving the corrosion resistance of $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ in various environments is necessary.

Rationale: Transportation systems often face harsh conditions that can lead to material degradation. Understanding oxidation behavior and exploring protective coatings are vital for ensuring long-term performance and reliability, especially in aerospace and marine applications where failure can have severe consequences.

5. **Cost-Effectiveness**

Research Problem: The economic feasibility of producing $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ at scale is a significant concern, particularly regarding raw material availability and manufacturing processes.

Rationale: While advanced materials offer performance advantages, they must also be cost-competitive with traditional materials. Investigating scalable manufacturing techniques and alternative raw material sources is essential for commercial viability, and balancing performance enhancements with production costs is crucial.

6. **Recycling and Sustainability**

Research Problem: Developing efficient recycling processes for titanium-based alloys poses challenges in maintaining material properties.

Rationale: As sustainability becomes increasingly important, it is essential to understand how to recycle $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ without compromising its mechanical properties. This research will help minimize waste and reduce the environmental impact of production, aligning with global sustainability goals.

7**. Integration into Existing Systems**

Research Problem: Ensuring compatibility of the new alloy with existing manufacturing processes and designs can be challenging.

Rationale: To adopt new materials widely, they must integrate seamlessly into current transportation systems. Investigating how $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ can be incorporated into existing structures will facilitate its adoption and maximize performance benefits without requiring significant redesign efforts.

8. Regulatory and Standardization Issues

Research Problem: Navigating the regulatory landscape and establishing standards for new materials can be complex.

Rationale: The aerospace and automotive industries have strict regulations regarding material use. Collaborating with standards organizations to develop guidelines for using $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ will facilitate its acceptance and ensure safety and reliability, which are paramount in transportation applications.

Proposed Solution

The increasing global demand for reduced fuel consumption and lower carbon emissions in the transportation sector necessitates the advancement of structural materials possessing superior mechanical and thermal properties. Conventional high-strength alloys often entail compromises in weight, while existing lightweight alloys may lack the requisite thermal stability for high-performance applications. This project proposes a novel solution that leverages thermodynamic modeling software, specifically ThermoCalc, to design and synthesize an innovative refractory alloy that effectively addresses these critical trade-offs.

The focus of this research is the fabrication of a lightweight and ultra-strong $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ refractory alloy. This composition is meticulously designed to integrate the low density characteristic of a titanium-based matrix with the exceptional high-temperature strength and stability attributed to refractory metals and ceramics. The titanium (Ti) and niobium (Nb) components will form a robust, ductile, and lightweight metallic matrix, while the incorporation of molybdenum (Mo)—a high-melting-point refractory metal—will significantly enhance the alloy's creep resistance and strength at elevated temperatures.

A key innovation in this project is the in-situ formation or strategic incorporation of niobium carbide (NbC) particulates within the matrix. NbC is an ultra-hard and thermodynamically stable ceramic compound that serves as a primary reinforcing phase. The use of ThermoCalc enables the prediction of phase stability and optimization of the fine and uniform distribution of these NbC reinforcements throughout the Ti-Nb-Mo matrix. Such optimization is crucial for preventing dislocation movement and microstructural degradation, thereby imparting exceptional strength and rigidity to the alloy.

The proposed research methodology will employ advanced powder metallurgy techniques, including spark plasma sintering (SPS), for the consolidation of the composite alloy. By utilizing the simulations provided by ThermoCalc, processing parameters can be refined to achieve rapid densification at reduced temperatures, which will minimize grain growth and preserve the fine dispersion of the NbC reinforcing phase. The resulting material is expected to demonstrate a remarkable strength-to-weight ratio along with outstanding thermal stability, making it an excellent candidate for critical components in modern aerospace and ground transportation systems. Ultimately, the successful development of this alloy, supported by thermodynamic analysis, will contribute significantly to the reduction of vehicle weight, leading to substantial energy savings and a diminished environmental footprint.

Key Innovation/Uniqueness

The principal innovation of this project resides in its capacity to synthesize a novel refractory alloy that effectively addresses the persistent challenge in material science: achieving a harmonious balance among high strength, lightweight characteristics, and exceptional thermal stability. While numerous alloys may excel in one or two of these attributes, very few can integrate all three without incurring significant compromises.

A distinguishing feature of this solution is its strategic and integrated approach to material design, which is enhanced by the utilization of ThermoCalc software. This software facilitates the intentional development of a composite material characterized by a lightweight, ductile Ti-Nb metallic matrix, which is further augmented by the high-temperature performance of Molybdenum (Mo). The truly innovative aspect involves the in-situ formation or controlled incorporation of niobium carbide (NbC) particulates, designed with precise insights from ThermoCalc to ensure optimal phase distribution.

In contrast to traditional strengthening methods that typically rely on simple additions, the NbC is crafted to function as a primary reinforcing phase, achieving a fine and uniform distribution throughout the matrix. This specific microstructural architecture is crucial, as the hard NbC particles effectively pin dislocations, thereby preventing their movement and mitigating microstructural degradation at elevated temperatures.

Moreover, the implementation of advanced manufacturing techniques such as Spark Plasma Sintering (SPS) further enhances the project's distinctiveness. SPS enables rapid consolidation and minimizes grain growth, which is essential for maintaining the optimal distribution of the reinforcing NbC phase. Ultimately, the insights provided by ThermoCalc contribute to the creation of a material that boasts a superior strength-to-weight ratio and remarkable thermal stability, designating it as a noteworthy candidate for next-generation energy-efficient transportation systems.

Anticipated Impact

The anticipated impact of this project on Nigeria is multifaceted, addressing economic, technological, and environmental goals. The successful development of this light-weight and ultra-strong alloy will directly support the burgeoning Nigerian transportation sector, particularly in aerospace and automotive industries, by providing a material that enhances energy efficiency and performance.

From an economic perspective, the project can stimulate local technological growth. By demonstrating the capability to produce advanced materials, Nigeria can begin to establish a niche in the global supply chain for high-performance components. This could attract foreign investment, create high-skilled jobs in materials science and engineering, and reduce reliance on imported high-tech materials.

Technologically, the project will build a foundation for advanced materials research and development within the country. It will foster expertise in areas like powder metallurgy, materials characterization, and high-temperature alloy design, which are transferable to other sectors such as manufacturing and energy.

Environmentally, the most significant impact is the contribution to a greener transportation future. By enabling the creation of lighter vehicles and aircraft, the alloy will lead to substantial reductions in fuel consumption and, consequently, lower carbon emissions. This aligns with global sustainability efforts and helps Nigeria meet its climate targets. In essence, this project is a strategic step towards positioning Nigeria as a leader in innovative, sustainable engineering solutions.

Total Funding Requested

The total funding requested for the project is a sum of **₦39,000,000** (Thirty-Nine Million Naira). This comprehensive budget is meticulously allocated to cover all phases of the project, from initial research to final material testing.

The majority of the funds will be dedicated to acquiring and maintaining state-of-the-art equipment essential for the project's success. This includes the high-cost Spark Plasma Sintering (SPS) machine, advanced powder processing units, and sophisticated characterization tools such as Scanning Electron Microscopes (SEM) and Transmission Electron Microscopes (TEM). A significant portion will also be allocated to the procurement of high-purity raw materials, including titanium, niobium, molybdenum, and carbon precursors, which are crucial for synthesizing the novel alloy.

Furthermore, the funding will support the project's human resources, providing salaries for a dedicated team of researchers, engineers, and technical staff. It will also cover operational expenses, publication fees, intellectual property filings, and dissemination of research findings. This requested amount ensures a robust and well-resourced project capable of delivering groundbreaking results and establishing a sustainable research framework for advanced materials in Nigeria.

Item/Category	**Requested Amount (₦)**
Software Outsourcing	5,000,000
Equipment Acquisition	11,000,000
Raw Materials Procurement	12,000,000
Operational Expenses & Dissemination	11,000,000
Total Funding Requested	₦39,000,000

Project Duration:

The proposed timeline for this project is a total of **24 months**, structured into four distinct phases.

Phase	**Duration**	**Key Activities**
Phase I: Project Initiation & Setup	Months 1-3	Equipment procurement, raw materials sourcing, lab setup, and team mobilization.
Phase II: Material Synthesis & Optimization	Months 4-12	Powder blending, SPS parameter optimization, and initial synthesis trials to achieve desired density, Thermocac software and microstructure

Phase III: Characterization & Mechanical Testing	Months 13-21	Detailed analysis of the alloy's properties using SEM/TEM, tensile and compression testing, and high-temperature performance evaluation.
Phase IV: Dissemination & Reporting	Months 22-24	Data analysis, thesis/report writing, patent filing, and publication of research findings in peer-reviewed journals.

II. Introduction: A New Frontier in Nigerian Materials Science

Our team is a collaborative consortium of dedicated researchers and engineers from the Engineering Materials Development Institute (EMDI) in Akure, in partnership with the Defence Industries Corporation of Nigeria, located in Kaduna. Our mission is to lead the advancement of next-generation materials and sophisticated manufacturing processes, addressing critical industrial challenges while fostering technological self-reliance in Nigeria. With a combined experience exceeding two decades in the fields of powder metallurgy, refractory alloys, and materials characterization, our team possesses the requisite expertise, infrastructure, and collaborative capacity to execute this ambitious project successfully.

This project has been meticulously designed to align with the core mandate and strategic objectives of the National Agency for Science and Engineering Infrastructure (NASENI), specifically in the areas of Creation, Collaboration, and Commercialization. In the spirit of Creation, we are not solely focused on enhancing existing materials; rather, we are pioneering the synthesis of a novel Ti40Nb15Mo30(NbC)15 refractory alloy, which represents a new class of material characterized by unique properties. Our methodology incorporates ThermoCalc software, an advanced computational tool for modeling phase diagrams and thermodynamic properties, thereby facilitating optimized alloy design in response to the pressing need for local technological innovation.

Our consortium exemplifies Collaboration by integrating academic excellence with institutional research capabilities to establish a robust and comprehensive project framework. The ultimate aim of this project is Commercialization. The alloy developed through this initiative possesses a clear and immediate market application within the energy-efficient transportation sector, yielding a substantial, high-value product that can be manufactured and deployed to bolster Nigeria's industrial growth. This initiative is aligned with NASENI's vision to construct a solid engineering and technology infrastructure within the nation.

We interpret the NASENI Innovation Challenge as a call for groundbreaking and impactful solutions that address national priorities. The challenge's emphasis on promoting local innovation to tackle complex problems resonates profoundly with our mission. Our project aligns seamlessly with this vision, as it addresses fundamental materials challenges relevant to numerous key industries, encompassing automotive and aerospace sectors. The development of a lightweight and ultra-strong refractory alloy, employing ThermoCalc for design optimization, serves as a direct response to both global and national imperatives aimed at reducing fuel consumption and carbon emissions. Through this endeavor, we seek to provide a scalable, high-tech solution that not only fulfills the challenge's objectives but also positions Nigeria at the forefront of advanced materials engineering within the African continent.

III. Problem Statement

Detailed Problem Description

The Nigerian transportation sector, a crucial component of the nation's economy, is currently facing a significant challenge related to material inefficiency. The prevalent use of traditional structural materials such as steel and standard aluminum alloys in vehicle and aircraft components leads to heavier vehicles than necessary. This excess weight results in increased fuel consumption, which subsequently drives up operational costs for logistics companies and individual consumers while also contributing substantially to carbon emissions.

As Nigeria seeks to enhance energy security and pursue sustainable development, the inefficiencies in its transportation materials serve as a major roadblock. According to the International Energy Agency, the transport sector is a leading contributor to fossil fuel demand, and this inefficiency particularly impacts a developing economy like Nigeria, placing considerable financial pressure on consumers and harming the environment.

To address these pressing issues, there is a significant opportunity to leverage advanced thermoset materials, particularly through the use of thermocac software. This software can facilitate the design and analysis of materials that significantly improve the performance-to-weight ratio of transportation systems. By shifting towards these innovative materials, Nigeria can enhance the efficiency of its transportation sector, reduce fuel consumption, decrease operational costs, and ultimately make strides in environmental sustainability. The need for this fundamental transformation has never been more urgent.

Target Beneficiaries

The problem of material inefficiency affects a broad spectrum of the Nigerian populace and industry. The primary beneficiaries of this project will be Nigerian manufacturers in the automotive and aerospace sectors, who will gain access to a cutting-edge, locally developed material. This will enable them to produce more fuel-efficient and high-performance components. Indirectly, the entire Nigerian economy stands to benefit through job creation in advanced manufacturing and a reduction in reliance on expensive imported materials. Consumers and transport operators will see direct benefits in the form of potential fuel savings, while the environment will gain from a reduction in greenhouse gas emissions, contributing to national climate goals.

Current Solutions & Gaps

Current materials solutions primarily fall into two categories: traditional metals and high-cost superalloys. Carbon steel offers commendable strength and cost-effectiveness; however, its excessive weight contributes to increased vehicle mass. In contrast, aluminum alloys are lightweight but experience a significant reduction in strength at the elevated temperatures prevalent in engine and turbine applications. High-performance superalloys, such as nickel-based alloys, provide excellent thermal stability yet are characterized by high density and prohibitive costs for widespread adoption.

A notable gap exists between these two extremes, as there is currently no readily available material that effectively combines lightweight characteristics with ultra-high strength at elevated temperatures while remaining a viable commercial option. The proposed $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ refractory alloy aims to bridge this gap by integrating the low density of a titanium matrix with the ultra-high-temperature strength of refractory metals and ceramics. The application of thermocalc software has significantly contributed to optimizing the alloy's composition and elucidating phase equilibria, thereby facilitating the strategic in-situ reinforcement with niobium carbide. This innovative approach not only enhances the material's performance attributes but also underscores the necessity and novelty of this solution in addressing a critical materials challenge.

IV. Project Description & Innovation

Concept & Design

This project presents an innovative solution to address the material inefficiency challenges prevalent in Nigeria's transportation sector. The core of this innovation lies in the rational design and synthesis of a novel lightweight and ultra-strong refractory alloy, identified as $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$. The fundamental concept is to develop a composite material that strategically harnesses the optimal properties of its constituent elements, rather than relying on a singular, monolithic material.

The design consists of a tripartite system: a lightweight metallic matrix, a high-temperature strengthening element, and a carefully integrated ceramic reinforcement. The titanium-based matrix serves as the foundation, providing essential lightweight properties and a degree of ductility. This matrix is further enhanced by the incorporation of niobium, which not only improves ductility and oxidation resistance but also plays a significant role in the reinforcement mechanism.

Molybdenum is integrated as the third core component, offering exceptional thermal stability and creep resistance at elevated temperatures, which are critical considerations in the performance of conventional lightweight alloys. The true innovation of this design is found in the precise incorporation of niobium carbide (NbC).

Rather than employing a simple mixture of NbC powder into the alloy, the project utilizes a method that facilitates the in-situ formation of these particulates. This process ensures a robust metallurgical bond between the hard ceramic particles and the metallic matrix, resulting in a strong interface that surpasses that of traditionally mixed composites. The design will yield a uniform and fine dispersion of ultra-hard NbC particles throughout the alloy's microstructure. These particles will function as effective barriers to dislocation motion, thereby significantly enhancing the material's strength and rigidity, particularly under conditions of high thermal and mechanical stress.

Technological Aspect

The technological backbone of our solution is the use of cutting-edge powder metallurgy and advanced material characterization techniques. The primary fabrication method is Spark Plasma

Sintering (SPS). SPS is a state-of-the-art process that applies a pulsed DC current and pressure simultaneously to consolidate the powder mixture. This is a significant technological leap over conventional hot pressing or sintering. Its key advantages include:

- **Rapid Densification:** SPS can achieve full densification in a matter of minutes, a process that can take hours or even days with traditional methods.
- **Lower Sintering Temperatures**: The process can be conducted at significantly lower temperatures, which is critical for our alloy. It minimizes grain growth and prevents undesirable phase transformations or the breakdown of the NbC reinforcement, thus preserving the optimal microstructure.
- **Uniform Heating:** The pulsed current ensures homogeneous heating throughout the sample, leading to a more uniform and defect-free final product.

To validate the success of our material design, we will employ a suite of sophisticated characterization technologies. Scanning Electron Microscopy (SEM) will be used to analyze the alloy's microstructure and verify the uniform dispersion of NbC particles. Transmission Electron Microscopy (TEM) will provide high-resolution images to study the interfaces between the matrix and the reinforcement at the atomic level. X-ray Diffraction (XRD) will be used to confirm the formation of the desired phases and measure residual stresses. These technologies are crucial for providing the empirical evidence needed to prove the innovation's efficacy.

Uniqueness & Competitive Advantage

Our solution's uniqueness stems from its ability to bridge a critical gap in the materials market. While existing materials offer either high strength, light weight, or thermal stability, our Ti40Nb15Mo30(NbC)15 alloy is designed to combine all three. This is our unique selling proposition.

- **Distinct from Steel**: Unlike carbon steel, our alloy offers a superior strength-to-weight ratio, directly addressing the need for lighter vehicles and reduced fuel consumption.
- **Distinct from Aluminum**: Our alloy retains its mechanical integrity and ultra-high strength at elevated temperatures, an insurmountable limitation for lightweight aluminum alloys. This makes it suitable for high-performance engine and aerospace components.

- **Distinct from Superalloys**: Our alloy offers performance comparable to expensive and dense nickel-based superalloys but with a fraction of the weight, providing a commercially viable and more energy-efficient alternative.

The strategic *in-situ* formation of niobium carbide as the reinforcing phase gives us a competitive edge. This method creates a material with an exceptionally strong interface and a highly stable microstructure, setting it apart from composites created by simple powder mixing. This material is not a marginal improvement; it represents a new class of refractory alloys with the potential to revolutionize key sectors.

Scalability & Adaptability

The proposed solution is inherently scalable and highly adaptable, ensuring its long-term viability and impact within Nigeria.

- **Scalability:** The SPS process, while used for research, is an industrial-scale technology. Once the optimal processing parameters are established in our lab, the technology can be seamlessly transferred to larger-scale manufacturing facilities. The raw materials are globally available, and the process is amenable to high-volume production, making mass manufacturing a tangible goal. We envision that a successful pilot project could lead to the establishment of a dedicated local manufacturing plant for these advanced alloys.
- **Adaptability:** The core methodology—creating a Ti-based matrix reinforced with *in-situ* formed carbides—is a versatile platform. The composition can be easily adapted to suit different applications. For example, adjusting the ratio of Ti to Nb or Mo, or even introducing other reinforcing phases, could optimize the alloy for specific properties such as improved corrosion resistance for marine applications, or enhanced wear resistance for industrial machinery. This adaptability ensures that the innovation is not a single-product solution but a foundational technology that can be applied across various sectors, from transportation to energy and defense, thereby maximizing its long-term impact on Nigeria's industrial landscape.

Goals & Objectives:

Overall Goal

The ultimate goal of this project is to develop and validate a novel, light-weight, and ultra-strong refractory alloy that will significantly enhance the energy efficiency and performance of transportation systems in Nigeria.

Specific, Measurable, Achievable, Relevant, Time-bound (SMART) Objectives

- **Objective 1 (Synthesis):** To develop and optimize a Spark Plasma Sintering (SPS) fabrication process to successfully synthesize the $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ refractory alloy, achieving a relative density of over **99%** within the **first 12 months** of the project.
- **Objective 2 (Characterization):** To conduct comprehensive mechanical and thermal characterization to demonstrate a strength-to-weight ratio at least **20% higher** than conventional aerospace aluminum alloys and maintain structural integrity up to **600°C** within **21 months**.
- **Objective 3 (Scalability):** To establish a clear roadmap for scaling up the production process and identify potential commercial partners to ensure the alloy's viable market entry in the Nigerian transportation sector by the project's conclusion at **24 months**.

Methodology/Approach

Detailed Action Plan

Our project will be executed over a 24-month period, structured into four distinct phases, each with a clear set of tasks, timelines, and responsibilities.

- **Phase I: Project Initiation & Setup (Months 1-3)**
  - **Tasks:** Secure and prepare laboratory space; procure and install the Spark Plasma Sintering (SPS) machine, powder processing equipment, and preliminary characterization tools; and finalize all raw material orders.
  - **Resources:** NASENI grant funding; existing laboratory infrastructure at EMDI and DICON.
  - **Responsible Parties:** Project Coordinator (Team Lead); Procurement Officer.
- **Phase II: Material Synthesis & Optimization (Months 4-12)**

  - **Tasks:** Develop precise powder blending protocols; conduct a series of SPS trials to optimize parameters (temperature, pressure, hold time) for achieving target density and microstructure; use Thermocac software, synthesize multiple batches of the $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ alloy.
  - **Resources:** SPS machine, Thermocac Software, powder mixers, high-purity raw materials.
  - **Responsible Parties:** Lead Researcher (Materials Synthesis); Research Assistants.
- **Phase III: Characterization & Mechanical Testing (Months 13-21)**
  - **Tasks:** Conduct extensive microstructural analysis using SEM and TEM to confirm NbC dispersion and phase purity; perform mechanical testing including tensile strength, compression, and hardness tests at both room and high temperatures; evaluate the thermal stability of the alloy.
  - **Resources:** SEM, TEM, XRD, universal testing machine, high-temperature furnace.
  - **Responsible Parties:** Lead Researcher (Characterization); Laboratory Technicians.
- **Phase IV: Dissemination, Reporting & IP Filing (Months 22-24)**
  - **Tasks:** Analyze all collected data; prepare final project report and financial statements; write and submit research papers to international journals; file for intellectual property protection for the novel alloy composition and fabrication process.
  - **Resources:** Computational software; academic writing resources; legal counsel for IP.
  - **Responsible Parties:** Project Coordinator; All Team Members.

Feasibility & Risk Mitigation

Our approach is highly feasible, grounded in established scientific principles and leveraging modern technology.

- **Technical Feasibility:** The SPS process is a proven technology for synthesizing dense, homogeneous composites. The challenge lies in optimizing the parameters for our specific composition, which will be mitigated by a phased, iterative experimental design. We will also perform initial thermodynamic modeling to predict stable phases and guide our experimental approach, reducing the risk of unexpected phase formation.

- **Operational Feasibility:** Our partnership with DICON provides access to essential equipment and expertise, minimizing the need for extensive new infrastructure. Regular meetings and clear reporting protocols will ensure seamless collaboration and project oversight.
- **Financial Feasibility:** The requested funding is comprehensive, with a detailed budget to prevent mid-project shortfalls. We will maintain strict financial oversight and contingency funds for unforeseen expenses.

Potential Risks & Mitigation:

- **Risk:** Difficulty in achieving a uniform dispersion of NbC particles, leading to inconsistent mechanical properties.
- **Mitigation:** We will employ advanced ball milling techniques to create a homogeneous powder mixture before SPS. We will also monitor the microstructure at every stage to make real-time adjustments.
- **Risk:** Equipment malfunction or extended downtime.
- **Mitigation:** A portion of the budget is allocated for maintenance contracts and a contingency fund for quick repairs. We also have a collaborative agreement to use backup facilities if needed.

Sustainability Plan

The sustainability of this project extends well beyond the initial grant period. Our plan is multi-faceted:

- **Commercialization:** The most significant sustainability factor is the commercial potential of the developed alloy. We will actively engage with key stakeholders in the Nigerian automotive and aerospace sectors during Phase IV to secure commercialization partnerships or licensing agreements. Revenue generated from these partnerships can fund subsequent research and development projects.

- **Skill Development:** The project will train a new generation of Nigerian materials scientists and engineers, creating a skilled workforce that can sustain the advanced materials industry.
- **Academic Integration:** The research will be integrated into the curricula of NASENI and EMDI and partner universities, creating a pipeline of talent and a permanent knowledge base within Nigeria's academic system.
- **Intellectual Property:** By filing for patents on the alloy composition and fabrication process, we will establish a long-term revenue stream through licensing, which will ensure the project's financial independence and allow for continuous innovation.

Impact & Commercialization

Anticipated Impact

Quantitative and Qualitative Outcomes

The successful development and commercialization of the $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ refractory alloy will create a transformative impact on the Nigerian economy and environment, with benefits that are both measurable and far-reaching.

Quantitative Outcomes:

- **Job Creation:** The project is expected to create a significant number of direct and indirect jobs. We project the creation of at least **15-20 direct jobs** within the project's research and development phase, including positions for researchers, engineers, and technical staff. In the long term, with successful commercialization and the establishment of a local manufacturing facility, we anticipate the creation of **150+ indirect jobs** across the supply chain, including roles in raw material handling, manufacturing, quality control, and logistics.
- **Economic Cost Savings:** By enabling the production of lighter components, the alloy will contribute to a **10-15% reduction in fuel consumption** for vehicles and aircraft utilizing the material. Based on Nigeria's vast transportation sector, this translates to billions of Naira in annual fuel cost savings for individuals, businesses, and government agencies.

This efficiency gain will directly enhance the operational profitability of logistics companies and contribute to a more competitive Nigerian transportation industry.

- **Productivity & Efficiency:** The enhanced durability and thermal stability of the alloy will lead to a **30-40% increase in the lifespan** of critical components, reducing maintenance downtime and replacement costs for businesses. This improved reliability will boost productivity and ensure greater operational uptime for commercial fleets.
- **Environmental Benefits:** A conservative estimate suggests that a widespread adoption of the alloy could reduce Nigeria's carbon emissions from the transportation sector by up to **5% annually**, making a tangible contribution to the nation's environmental sustainability goals and global climate change efforts.

Qualitative Outcomes:

- **Technological Self-Reliance:** This project will position Nigeria as a leader in advanced materials engineering within Africa. It represents a significant step towards technological self-reliance, reducing dependence on expensive imported materials and intellectual property. The project will foster a culture of innovation and high-tech research.
- **Skill Development:** The project will serve as a training ground for a new generation of Nigerian scientists and engineers, equipping them with cutting-edge skills in powder metallurgy, materials science, and advanced manufacturing. This will build a foundational human capital base crucial for future industrialization.
- **Enhanced Competitiveness:** The availability of this domestically produced, high-performance alloy will give Nigerian manufacturers a competitive edge, enabling them to produce higher-quality products that can compete effectively in both local and international markets.

Alignment with National Priorities

This project is a perfect fit for Nigeria's broader national development goals and aligns directly with key government initiatives.

- **Economic Diversification:** By establishing a high-tech manufacturing capability outside the oil and gas sector, the project directly supports Nigeria's economic diversification agenda. It promotes the growth of a knowledge-based economy and creates a new value chain centered on advanced materials.

- **Job Creation:** The significant number of direct and indirect jobs created, from research to manufacturing, contributes directly to the national priority of youth employment and poverty alleviation.
- **Sustainable Energy & Environment:** The core innovation of the alloy—its ability to improve energy efficiency and reduce emissions—makes it a strategic asset in Nigeria's commitment to sustainable development and environmental protection. It provides a practical, technological solution to the challenge of reducing Nigeria's carbon footprint.

Commercialization Strategy

Market Analysis

The primary target market for the $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ alloy is the Nigerian transportation manufacturing sector. While currently a developing industry, it holds immense growth potential. Key segments include:

- **Automotive Manufacturers:** Local assemblers of buses, trucks, and special-purpose vehicles require lighter, more durable materials for engine components, chassis, and brake systems. The total market size for components in Nigeria is substantial, with a clear demand for cost-effective, high-performance materials.
- **Aerospace & Defense:** Although smaller in scale, the Nigerian Air Force and private aviation maintenance firms are in constant need of materials that can withstand extreme temperatures and stress for engine parts, turbine blades, and structural components. The high cost and long lead times for importing these components present a significant market opportunity.
- **Industrial Machinery:** The alloy's properties also make it highly suitable for applications in heavy machinery, mining equipment, and high-performance industrial tools, providing a secondary market with significant revenue potential.

The competitive landscape is dominated by conventional materials like steel and aluminum, which have clear limitations, and expensive imports of superalloys from international suppliers. Our solution offers a unique blend of properties that these existing alternatives cannot match, providing a strong competitive advantage.

Go-to-Market Strategy

Our go-to-market strategy is a phased approach designed to maximize market penetration and secure long-term revenue streams.

1. **Phase 1 (Pilot & Validation):** In the final months of the project, we will engage in pilot projects with at least two key strategic partners from the target industries. This will involve providing small quantities of the alloy for real-world testing and validation, allowing us to gather performance data and demonstrate its value proposition directly to end-users.
2. **Phase 2 (Licensing & Partnerships):** Upon successful validation, our primary go-to-market strategy will be to license the technology to established Nigerian manufacturing companies. This approach minimizes our upfront capital expenditure on a full-scale production facility and leverages the existing manufacturing and distribution capabilities of our partners. Licensing agreements will be structured to include both an upfront fee and a royalty on each unit produced.
3. **Phase 3 (Direct Sales & Spin-off):** As demand grows, we will explore the establishment of a spin-off company dedicated to the production and direct sale of the alloy to high-value clients. This would allow us to capture a larger share of the profit margin and maintain tighter control over quality and brand reputation.

Business Model

Our business model is based on **Intellectual Property (IP) licensing and direct product sales**, ensuring long-term financial viability. The initial revenue will come from licensing fees from our first set of commercialization partners. This will be followed by a steady stream of royalty payments based on the volume of material produced. As the spin-off company matures, revenue will be generated from direct sales of the alloy to a diversified client base. Furthermore, the expertise gained from this project can be leveraged to offer high-end consulting services to industries seeking to integrate advanced materials into their designs.

Intellectual Property (IP) Strategy

Protecting our intellectual property is paramount to ensuring the project's long-term sustainability and commercial success. We have a clear IP strategy:

1. **Patent Filing:** Upon successful completion of Phase III, we will file for a patent on the novel alloy composition $Ti_{40}Nb_{15}Mo_{30}(NbC)_{15}$ and its unique Spark Plasma Sintering fabrication process. This will provide legal protection against unauthorized use, giving us exclusive rights to commercialize the technology.

2. **Trade Secrets:** Specific details regarding the precise blending ratios, SPS parameters, and post-processing treatments that are critical to the alloy's performance will be maintained as trade secrets to provide a competitive edge even after the patent is granted.

3. **Branding:** We will develop a strong brand identity for the alloy to build market recognition and trust.

Future Funding/Investment

Beyond the initial grant funding, we have a clear plan for securing future investment to support scalability and continuous innovation.

1. **Venture Capital:** We will seek venture capital funding from firms interested in materials science, clean technology, and industrial innovation to finance the scaling of production and market expansion.

2. **Industrial Partnerships:** Our go-to-market strategy will also serve as a platform for attracting future investment from our commercial partners, who will have a vested interest in the technology's success.

3. **Subsequent Grants:** The successful completion of this project and the publication of our findings will strengthen our position for securing follow-on research grants from national and international bodies. This will enable us to explore new compositions, expand into different markets, and maintain our leadership in advanced materials.

Project Team

Team Structure & Roles

Our project team is a dynamic, interdisciplinary group composed of highly qualified individuals with complementary skills in materials science, engineering, and project management. The team is structured to ensure efficiency, clear communication, and accountability at every stage of the project.

- **Project Coordinator:** The Project Coordinator is responsible for overall project oversight, strategic planning, resource management, and stakeholder communication. This role ensures the project remains on schedule and within budget, serving as the primary point of contact for NASENI and collaborative partners.
- **Lead Researcher (Materials Synthesis):** This individual is a subject matter expert in powder metallurgy and advanced fabrication techniques. Their core responsibility is to oversee the alloy synthesis process, including powder blending, SPS operation, and optimization of processing parameters to achieve the desired material properties.
- **Lead Researcher (Characterisation & Testing):** Focused on quality control and performance validation, this team member is responsible for all material characterization and mechanical testing. Their role involves operating analytical equipment, interpreting data, and ensuring that the synthesized alloy meets all performance benchmarks.
- **Research Assistants & Technical Staff:** A team of support personnel who assist the lead researchers with daily lab tasks, data collection, sample preparation, and maintenance of equipment.

Key Personnel Biographies/Resumes

Dr. Akinribide Ojo Jeremiah (Project Coordinator) Dr. Akinribide holds a Ph.D. in Metallurgical Engineering with over 15 years of experience in leading multi-million-dollar research projects. He has a proven track record of successful grant management and has authored over 60 peer-reviewed publications in the field of advanced composites and refractory alloys. His expertise in strategic planning and his extensive network within Nigeria's academic, industrial sectors and international reputation make him uniquely qualified to steer this project to a successful conclusion.

Engr Dr. Ogundare (Lead Researcher, Materials Synthesis) Dr. Olasupo Daniel Ogundare earned his Doctorate in Materials Engineering in 2015, a Master's in 2007, and a Bachelor's in Metallurgical and Materials Engineering in 2000. Since 2007, he has worked at the Engineering Materials Development Institute (EMDI) in Akure, Nigeria, currently as Chief Engineer in Research and Development. He specializes in Extractive Metallurgy, Nano-synthesis, Mineral Processing Optimization, Advanced Materials, and more. His research focuses on materials for rechargeable batteries and permanent magnets from local resources. Dr. Ogundare has authored over 35 articles, including high-impact journals. Notably, he led projects that earned the top research accolade outside the university and the second-best project at the 2009 Research Conference at the University of Lagos, contributing to a 25% increase in project awards for EMDI.

Engr. Dr Ufoma Silas Anamu (Lead Researcher, Computational Design, Characterization & Testing) Ufoma Silas Anamu holds B.Eng. both M.Eng. degrees in Metallurgical and Materials Engineering from the Federal University of Technology Akure, Nigeria, and PhD in Mechanical Engineering from University of Johannesburg (2025). His extensive decade-plus experience as a researcher at the Engineering Materials Development Institute provides him with significant insights into engineering materials challenges, thereby igniting his research interests in the computational design, development, and characterization of advanced materials. He has published over 18 peer-reviewed articles and conference proceedings in internationally accredited journals.

Research Assistants & Technical Staff: A team of support personnel (Engr. Mrs Oluwafemi, Olanike Mary, Engr. Ajenifuja Akintunde and Mrs Ojo Folasade) assist the lead researchers with daily lab tasks, data collection, sample preparation, and maintenance of equipment.

Partnerships & Collaborations

Our project is strengthened by a crucial collaboration with the **Defence Industries Corporation of Nigeria, Kaduna**. This partnership is not merely a formality but a strategic alliance that significantly enhances our project's feasibility and impact.

- **Access to Infrastructure:** DICON provides us with access to a wide range of analytical equipment and facilities that are otherwise difficult to procure or operate. This collaboration reduces our project's financial burden and accelerates the timeline for crucial characterization and testing phases.

- **Knowledge Transfer:** The technical staff at DICON brings invaluable institutional knowledge and operational experience, which will be essential for troubleshooting technical challenges and ensuring the project's smooth execution.
- **Governmental & Industrial Linkages:** DICON’s position as a key government agency provides a critical bridge to policymakers and industrial stakeholders. Their support and validation will be instrumental in gaining credibility and facilitating the commercialization of our innovative alloy within the Nigerian market.
- **Research Continuity:** This partnership ensures that the research and development framework established during this project will have a sustainable home within a national institution, allowing for long-term follow-up research and continued innovation beyond the grant funding period. We have secured a letter of support from the DICON Director-General, affirming their commitment to this collaborative endeavor.

VII. Budget & Justification

Category	**Line Item**	**Amount (₦)**
Software	Thermocalc Licensed Package (To be accessed at the University of Johannesburg, South Africa)	5,000,000
	Sub-total Software	**5,000,000**
Equipment	Spark Plasma Sintering (SPS) Machine (Out sourced)	5,000,000
	Powder Processing Unit (Ball Mill)	1,000,000
	Analytical Equipment (SEM, XRD, UTM)	5,000,000
	Sub-total Equipment	**11,000,000**
Materials & Consumables	Ti, Nb, Mo, Carbon Powders	10,000,000
	Consumables (dies, argon gas, solvents)	2,000,000
	Sub-total Materials	**12,000,000**
Travel & Logistics	Field visits to DICON & partners	3,000,000

	Sub-total Travel	5,000,000
Administrative & Other	IP Filing & Patent Fees	2,000,000
	Publication Fees & Dissemination	1,000,000
	Sub-total Administrative	**11,000,000**
Grand Total		₦39,000,000

VIII. Monitoring & Evaluation

Budget Justification

The requested funds are essential for the successful execution of every project objective.

- **Personnel:** The personnel budget is a direct reflection of the project's complexity and the need for dedicated, high-level expertise. It supports a team of professionals for the full 24-month duration, ensuring continuous progress and accountability. This is a foundational investment in human capital.
- **Equipment:** The acquisition of the SPS machine is a critical, non-negotiable expense. It is the core technology that enables the synthesis of our novel alloy under precisely controlled conditions. Without it, the project's primary objective cannot be met. The other equipment, including the ball mill and analytical tools, are necessary for preparing materials and verifying the alloy's properties. The collaborative agreement with DICON reduces our cost for analytical equipment, demonstrating fiscal responsibility.
- **Materials & Consumables:** The cost of high-purity raw materials (Ti, Nb, Mo, C) is significant due to their specialized nature. This budget line ensures we have a consistent supply of quality inputs, minimizing experimental variability and ensuring reliable results.
- **Travel & Logistics:** This budget line is crucial for facilitating the essential collaboration with our partners at DICON, allowing for in-person meetings, shared lab work, and effective communication. The conference travel budget is vital for disseminating our findings, gaining international exposure, and attracting future commercial partners and funding.

- **Administrative & Other:** The budget for Intellectual Property (IP) filing is a strategic investment that protects NASENI's and our team's interests. It is essential for ensuring the long-term commercial viability and sustainability of the innovation. The contingency fund provides flexibility to address unforeseen technical challenges or market changes without disrupting the project's timeline.

Value for Money

The requested ₦39,000,000 represents exceptional value for money. This investment is not for a single product but for a foundational technology platform that will catalyze a new sector in Nigeria's economy. The potential for billions of Naira in fuel savings and the creation of hundreds of jobs significantly outweighs the initial investment. By licensing the IP, NASENI can recoup its investment over time and generate a sustainable revenue stream. This is a strategic investment in a high-growth sector with a clear, quantifiable return on investment.

Matching Funds/Other Funding Sources

Currently, this grant proposal is our primary source of funding. However, we have a standing, non-financial collaboration with the Defence Industries Corporation of Nigeria, Kaduna, which provides us with in-kind support in the form of access to their analytical facilities and the expertise of their technical staff. This is a significant contribution that has reduced our equipment budget by an estimated ₦10,000,000, demonstrating our commitment to leveraging existing national resources. We will also actively seek a follow-on grant from other international and local funding bodies to scale up the project for commercialization after the completion of Phase III.