

Harnessing Oman's Basalt Resources for Economic Diversification: A Strategic Roadmap for High-Value Manufacturing and Clean Energy Applications

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Abstract: In line with its Vision 2040 goals for economic diversification, the Sultanate of Oman holds extensive but largely untapped basalt reserves. This study presents a screening-level techno-economic analysis and strategic roadmap for transforming this indigenous resource from a low-value commodity into a cornerstone of a high-value and sustainable industrial ecosystem. The research methodology integrates a quantitative analysis of Oman's current basalt sector with a formal comparative economic model to quantify the potential for value addition. The study highlights a stark economic contrast: exporting raw basalt earns only about \$7.30 per tonne, while converting it into Basalt Fiber Reinforced Polymer (BFRP) rebar can generate over \$2,500 per tonne. The analysis shows a conservative value increase of more than 300 times, with a preliminary Life Cycle Cost Analysis (LCCA) demonstrating that BFRP significantly outperforms traditional steel economically in infrastructure projects. It also confirms that Omani basalt from the Samail Ophiolite is exceptionally well-suited for producing advanced fibers. Furthermore, this paper identifies and discusses a parallel strategic opportunity for Oman to leverage these same geological formations for large-scale, permanent carbon sequestration with the potential for clean hydrogen co-generation. The paper concludes by proposing a phased strategic roadmap for Oman, recommending the prioritized development of an integrated BFRP rebar value chain while initiating research into basalt-based climate technologies, thereby positioning the Sultanate as a future regional leader in both advanced green materials and the global energy transition.

Keywords: Basalt fiber; BFRP rebar; Oman Vision 2040; Techno-economic analysis; Carbon sequestration

1. Introduction

The Sultanate of Oman is currently navigating a period of profound economic transformation, guided by the ambitious national strategy of Oman Vision 2040 (World Bank, 2025). Oman's Vision 2040 drives economic diversification by reducing reliance on oil and focusing on non-oil sectors like mineral resources. A key goal is boosting In-Country Value (ICV) through local processing and manufacturing. Developing a value-added basalt industry supports this vision by turning abundant basalt reserves into export-ready products, promoting jobs, innovation, and sustainable growth. This visionary blueprint serves as the nation's guiding compass, charting a course away from a historical reliance on the hydrocarbon sector towards a diversified, sustainable, and globally integrated economy (Ministry of Energy and Minerals, Oman, 2025). A central and non-negotiable pillar of this long-term vision is the strategic development of non-oil sectors, with a particular emphasis on unlocking the immense latent



potential of the nation's rich and varied mineral resources (Oman Sustainability Week, 2025). The Omani government has explicitly articulated a policy of prioritizing downstream processing and enhancing In-Country Value (ICV). This represents a fundamental paradigm shift—a move away from the decades-long model of quarrying and exporting unprocessed raw materials toward the creation of sophisticated, high-value manufactured goods within Oman's borders (Mining Outlook, 2025). This strategic pivot is driven by the urgent need to build a more resilient and robust economic base, generate high-quality and sustainable employment for a young and growing population, and cultivate a national ecosystem of industrial innovation (Ministry of Energy and Minerals, Oman, 2025). The development of a sophisticated downstream basalt industry, as proposed in this paper, represents a tangible, high-potential, and directly applicable initiative that aligns perfectly with these core national objectives.

A critical measure of a nation's industrial maturity and long-term economic resilience is its economic complexity. The Economic Complexity Index (ECI) reflects the diversity and sophistication of a country's export basket, with higher complexity strongly correlating with higher income and more stable growth. An analysis of Oman's economic profile reveals a significant opportunity for growth in this domain. According to the Observatory of Economic Complexity, Oman's ECI ranking has seen limited improvement over the last two decades, moving from 76th to 78th globally, underscoring the challenge of diversification (Observatory of Economic Complexity, 2025). An examination of its 2023 export portfolio reinforces this point. The nation's top exports were overwhelmingly dominated by primary and semi-processed commodities, including Crude Petroleum (\$29.3B), Refined Petroleum (\$10.3B), and Petroleum Gas (\$6.53B) (Observatory of Economic Complexity, 2025). While these sectors are foundational to the national economy, this heavy concentration in a few, price-volatile commodity classes create inherent vulnerabilities and underscores the "raw material trap"—a situation where an economy specializes in exporting low-value primary goods rather than higher-value finished products. The establishment of a downstream basalt industry is a direct and powerful response to this challenge. It necessitates the adoption of advanced manufacturing processes, such as high-temperature melt extrusion and pultrusion, and fosters innovation in the field of materials science (Bastech UK, 2025). By creating a new category of high-value, technology-driven products, this initiative would contribute directly and measurably to increasing Oman's economic complexity, building a more sophisticated industrial base, and diversifying its non-oil export revenues.

Oman's mining sector is a key part of its non-oil economy and has immense potential thanks to its rich mineral reserves especially basalt, which is both plentiful and underutilized. Despite being quarried in large volumes, basalt's economic impact is minimal because it is mainly used for low-value construction aggregates or exported as raw material at negligible prices. This situation highlights the main issue addressed by this research: Oman has vast and geochemically ideal basalt reserves, but currently captures only a tiny portion of their possible economic value. By limiting basalt's use to its lowest-value applications, the country misses out on substantial economic, social, and technological gains that could be achieved through domestic processing and value addition.

To address this critical gap between potential and reality, this paper aims to achieve four primary objectives:

1. To quantify the stark economic disparity between the current practice of raw basalt export and the potential of downstream manufacturing through a robust, data-driven model.
2. To assess the technical feasibility of establishing a competitive Omani basalt fiber industry, focusing on raw material suitability and global market dynamics.
3. To explore the parallel, game-changing opportunity of utilizing Oman's basalt reserves for large-scale carbon sequestration, positioning the nation in the emerging clean-tech landscape.
4. To propose a strategic, phased, and actionable roadmap for policymakers, investors, and industrial stakeholders to guide the development of this new sector.

To provide an overview of the proposed value chain and its relationship to the two strategic pathways analysed in this paper, Figure 1 presents the integrated resource-to-value workflow connecting Oman's geological endowment to high-value manufacturing and climate technology applications.

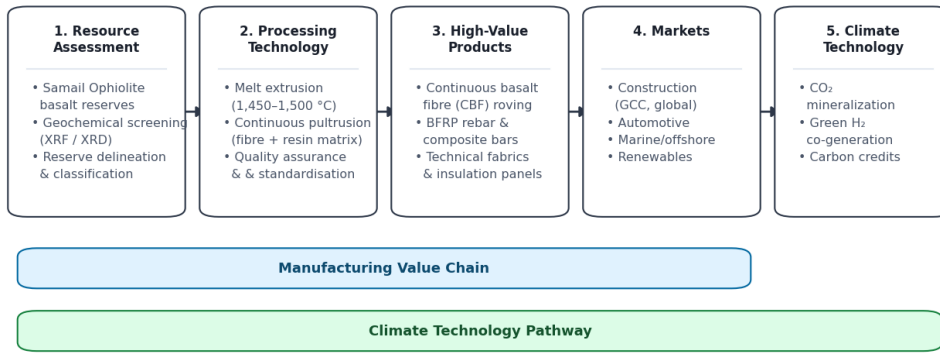


Figure 1. Integrated resource-to-value workflow.

2. Literature Review

This section synthesizes the existing body of knowledge regarding basalt as an advanced material. It will first analyze the fundamental relationship between basalt's geochemistry and its manufactured properties. Second, it will detail the downstream processing technologies used to create high-performance composites. Third, it will provide a quantitative analysis of the global market for these products, identifying the primary drivers of demand. Finally, it will review the scientific basis for an emerging application: the use of basalt for in-situ carbon mineralization.

2.1. Basalt Production Process and Geochemical Requirements

The viability of basalt as a high-value industrial feedstock is predicated on its capacity to be transformed into Continuous Basalt Fiber (CBF), a material exhibiting engineering properties superior to many conventional reinforcing fibers. CBF is an inorganic silicate fiber produced via the melt-extrusion of quarried basalt rock (Chowdhury et al., 2022). The manufacturing process is a single-stage thermal operation where crushed and washed basalt is melted at temperatures between 1450°C and 1500°C and subsequently drawn into continuous filaments through platinum-rhodium alloy bushings (Fiore et al., 2015). This single-component process contrasts with the multi-component formulation required for E-glass fiber, resulting in a lower energy consumption for CBF production, estimated at 3–4 kWh/kg versus 6–8 kWh/kg for E-glass fiber (Chowdhury et al., 2022; Lewis et al., 2021). The suitability of a basalt deposit for fiber production is strictly determined by its geochemistry. Only "acidic" basalts with a silica (SiO₂) content exceeding 46% are considered viable (Ryabov et al., 2015). The ideal chemical composition, detailed in Table 1, is critical for achieving both stable processing and optimal final properties. While this natural variation is a source of unique properties, it also poses a significant challenge for industrial standardization, making consistent feedstock sourcing a key operational parameter (Parnas et al., 2007).

Table 1. Ideal Chemical Composition of Basalt Rock for CBF Production *Data compiled from sources (Sohail et al., 2020; Gao et al., 2025; Amran et al., 2022).*

Oxide Component	Ideal Range (% by Mass)	Primary Function in Fiber
Silicon Dioxide (SiO ₂)	46 - 59%	Forms primary glass network; provides mechanical strength and chemical stability.
Aluminum Oxide (Al ₂ O ₃)	14 - 18%	Enhances thermal stability, durability, and tensile strength.
Iron Oxides (Fe ₂ O ₃ + FeO)	9 - 14%	Improves high-temperature resistance; influences melt rheology.
Calcium & Magnesium Oxides (CaO & MgO)	5.9 - 9.4% & 3.0 - 5.3%	Improve moisture and corrosion resistance; act as fluxing agents.

Titanium Dioxide (TiO ₂)	0.8 - 2.3%	Enhances chemical and water resistance.
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2.2. Mechanical, Thermal, and Chemical Properties

Geological mapping and satellite imagery indicate that Oman hosts vast basaltic resources (Glennie et al., 1974). The most extensive of these is the sheeted-dike complex, which runs roughly 400 km from Ibra in the south up to the Aswad–Shinas area in the north (Glennie et al., 1974), (Pallister, 1981). In contrast, some individual basalt outcrops are relatively small, such as those in the Rusayl and Ahmadi regions, while in areas such as Shinas, Jizi, Fizh, and Aswad they can be significantly more extensive (Nasir et al., 2015). Triassic-age basalt deposits in the Kawr area near Jabal Akhdar and within the Batain nappe represent virtually limitless reserves (Maury et al., 2003), (Béchenec et al., 1990). Tertiary basalts, by comparison, appear only in scattered patches and amount to far more modest volumes (Nasir et al., 2006).

The specific geochemistry of basalt translates into a distinct profile of engineering properties. Basalt-derived fibers present outstanding characteristics that establish them as advanced alternatives to conventional reinforcement materials. These fibers demonstrate exceptional thermal endurance, maintaining operational integrity at temperatures between 650–700°C, which substantially surpasses the 300°C threshold of glass fibers (Colombo et al., 2012). This remarkable thermal tolerance originates from basalt's volcanic genesis and its silicate-rich composition, which includes SiO₂ (45–52%), Al₂O₃ (14–18%), and Fe₂O₃ (8–13%) (Sim et al., 2005). Basalt fibers exhibit superior mechanical properties compared to traditional reinforcement materials. With a tensile strength of around 4,840 MPa and an elastic modulus ranging from 89 to 110 GPa, basalt fibers outperform E-glass fibers and are comparable to carbon fibers (Dhand et al., 2015). Although carbon fibers have a higher modulus (230–240 GPa), basalt offers a better balance of strength and cost (Parnas et al., 2007). Moreover, its low density (2.63–2.8 g/cm³) compared to steel (7.85 g/cm³) gives it a significant advantage in weight-sensitive applications (Dias and Thaumaturgo, 2005). Basalt fibers exhibit remarkable chemical durability in alkaline conditions, providing a significant advantage over glass fibers in concrete-based applications. Investigations conducted by Wei et al. demonstrated that basalt fibers maintain 95% of their original tensile strength following 100 days of exposure to alkaline solutions with pH 13, whereas glass fibers experience substantial degradation under identical conditions (Wei et al., 2010). This alkali resistance stems from basalt's inherent crystalline structure and reduced calcium content relative to glass fibers (Liu et al., 2024). The thermal conductivity characteristics of basalt fiber (0.031–0.038 W/m·K) are significantly lower than steel (45–50 W/m·K), offering superior insulation capabilities (Çetin, 2025). Furthermore, basalt fiber demonstrates minimal thermal expansion (5–9 × 10⁻⁶/°C), which closely corresponds to concrete's thermal expansion coefficient, thereby minimizing internal stresses in composite structures (Schrenk et al., 2024). Continuous Basalt Fiber (CBF) demonstrates outstanding mechanical properties, with tensile strength ranging from 3000 to 4840 MPa and an elastic modulus of 79.3 to 93.1 GPa—figures that notably surpass those of standard E-glass fiber, especially in terms of stiffness, which is 10–25% higher (Parnas et al., 2007; Sim et al., 2005). This increased stiffness is particularly advantageous for structural applications where minimizing deflection is crucial. In terms of thermal performance, basalt fiber offers remarkable stability, operating effectively across a wide temperature range from -260°C to +700°C, which is well beyond the limits of E-glass and conventional carbon fibers (Schrenk et al., 2024). Even after exposure to 400°C, it retains about 88–90% of its original tensile strength, making it highly suitable for use in high-temperature environments. Chemically, basalt fiber is highly resistant to acidic and saline conditions. While there is some evidence of degradation in concentrated alkaline solutions for uncoated fibers, this does not accurately represent its behavior in practical composite applications. In real-world use, basalt fibers are typically protected by a polymer matrix or specialized chemical coatings, which effectively shield them from alkali attack in concrete, making this a manageable engineering concern (Schrenk et al., 2024). A comparison of key mechanical properties across reinforcing fiber types, including basalt, E-glass, S-glass, carbon, and aramid fibers, is presented in Table 2.

Table 2. Comparative Mechanical Properties of Reinforcing Fibers Data compiled from sources (Chowdhury et al., 2022; Fiore et al., 2015; Parnas et al., 2007).

Fiber Type	Density (g/cm ³)	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Elongation at Break (%)
Basalt Fiber	2.65–3.00	3000–4840	79.3–93.1	3.1

E-Glass Fiber	2.55–2.62	3100–3800	72.5–75.5	4.7
S-Glass Fiber	2.46–2.49	4590–4830	88–91	5.6
Carbon Fiber	1.78	3500–6000	230–600	1.5–2.0
Aramid Fiber	1.44	2900–3400	70–140	2.8–3.6

2.3. The Downstream Value Chain and Techno-Economic Analysis

The conversion of basalt fiber into high-value engineered products is achieved through established manufacturing processes, most notably the production of Basalt Fiber Reinforced Polymer (BFRP) composites. BFRP rebars are produced using continuous pultrusion, where tensioned basalt fibers are coated with vinyl ester or epoxy resin (60–70% fiber content), then shaped into the required form during preforming (Harle, 2024). BFRP rebar is manufactured via pultrusion, a continuous and automated process (Son et al., 2025). Bundles of CBF roving are impregnated with a liquid thermosetting resin and are then pulled through a heated shaping die where the resin cures, forming a solid composite rod (Xia et al., 2025). A critical step is the application of a surface profile either through helical winding or sand coating to the uncured rod to ensure a strong mechanical interlock with concrete upon installation (Schrenk et al., 2024; Xiang et al., 2025). The choice of polymer matrix is a key design variable. Epoxy resins are typically specified for applications requiring maximum mechanical strength and thermal resistance, whereas vinyl ester resins are chosen for their superior performance in chemically aggressive environments (Xiang et al., 2025; Wellco Industries, 2025). The final properties of the BFRP rebar are thus a function of an integrated system of fiber, resin, and processing parameters.

The economic case for BFRP is predicated on a Life-Cycle Cost Analysis (LCCA). The initial material cost of BFRP rebar is higher than that of conventional steel, often by a factor of two to four (Bastech UK, 2025; Barforoush et al., 2025). This upfront cost is partially offset by installation savings derived from the material's low density (~25% that of steel), which reduces transport, labor, and equipment costs (Harle, 2024; Li et al., 2018). The primary economic advantage, however, is realized over the structure's service life. BFRP's immunity to corrosion eliminates the significant, recurring maintenance, repair, and rehabilitation costs associated with steel reinforcement degradation (Bastech UK, 2025; Monaldo et al., 2019). This extends the design service life of structures from 30-50 years to over 100 years, resulting in a substantially lower total cost of ownership. Studies have projected total lifecycle cost reductions of up to 58% for BFRP-reinforced structures compared to steel-reinforced equivalents (Monaldo et al., 2019; Ziada et al., 2025).

2.4. Global Basalt Products Market

The global basalt fiber market is currently in a phase of accelerated growth. However, as an emerging market, a notable variance exists in valuation estimates across different market intelligence firms, a phenomenon that itself provides insight into the industry's nascent and dynamic stage. Market sizing reports present a range of valuations, reflecting different analytical methodologies, scopes, and base years. This variance is a classic indicator of an industry that is not yet fully commoditized, where market standards, product categories, and competitive landscapes are still solidifying.

A consolidation of data from multiple leading market research firms, as presented in Table 3, places the global basalt fiber market valuation between USD 270 million and USD 435 million for the 2023-2024 period. Despite the variance in absolute valuation, a strong consensus emerges regarding the market's robust growth trajectory. Forecasts project a Compound Annual Growth Rate (CAGR) between 10.9% and 17.1%, projecting a market size that will exceed USD 1 billion by the early 2030s (Oman Sustainability Week, 2025; Parnas et al., 2007). This universally acknowledged upward trend is the key indicator of the market's significant potential. The forecast values and projected CAGRs from various firms are visualized in Figure 2 and Figure 3, respectively, illustrating the strong agreement on a high-growth future.

Table 3. Consolidated Global Basalt Fiber Market Size and Forecast (2023-2034).

Research Firm	Base Year	Base Year Value (USD M)	Forecast Year	Forecast Value (USD M)	CAGR (%)	Source
Precedence Research	2024	315.24	2034	913.82	11.23	(Precedence Research, 2025)
Fortune Business Insights	2023	435.00	2032	1,280.70	12.3	(Fortune Business Insights, 2025)
Spherical Insights	2023	276.00	2033	886.00	12.37	(Spherical Insights, 2025)
Maximize Market Research	2024	313.87	2032	805.33	12.5	(Maximize Market Research, 2025)
Grand View Research	2023	284.10	2030	593.90	11.2	(Grand View Research, 2025)
Markets and Markets	2023	279.00	2028	503.00	12.5	(MarketsandMarkets, 2025)
SNS Insider	2023	269.90	2032	733.50	11.8	(SNS Insider, 2025)
Market Research Future	2023	380.00	2035	2,500.00	17.1	(Market Research Future, 2025)
Verified Market Research	2022	19.40 (BFRP Rebar only)	2030	120.50 (BFRP Rebar only)	25.8	(Global Market Insights, 2025)
Consolidated Forecast	2023/24	~270 - 435	~2030-34	~800 - 1,280+	~11 - 17	

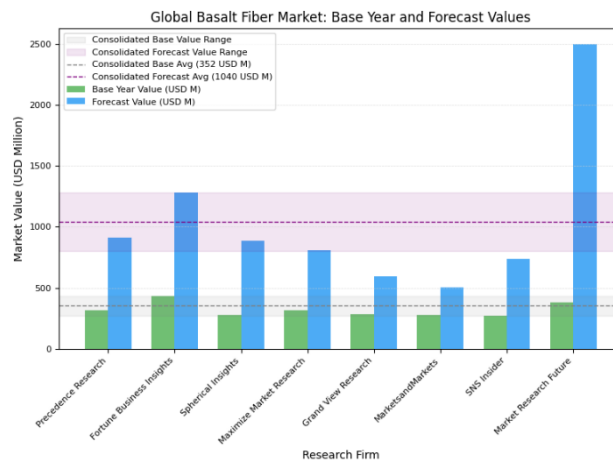


Figure 2. Global Basalt Fiber Market: Base Year and Forecast Values.

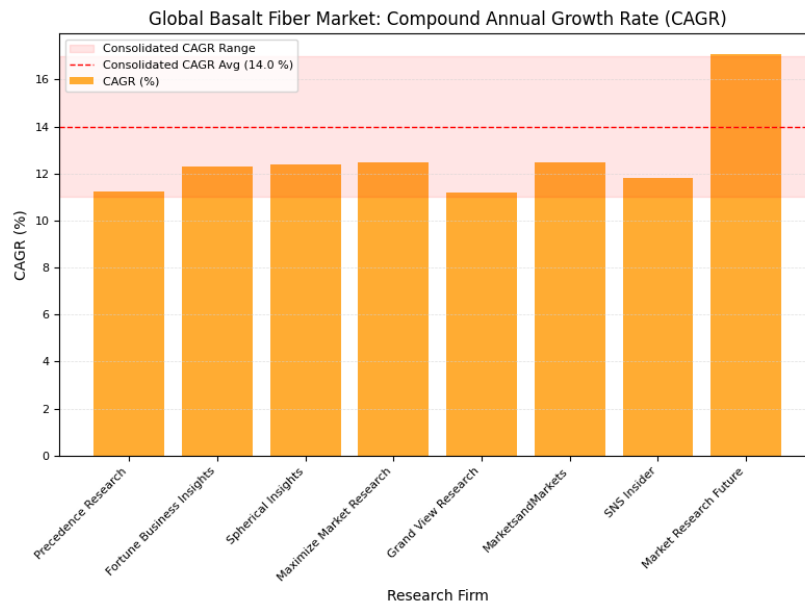


Figure 3. Global Basalt Fiber Market: Compound Annual Growth Rate (CAGR).

In terms of market structure, several segments consistently emerge as dominant. By product form, continuous basalt fiber (used for high-performance products like rovings and fabrics) commands the largest share over discrete (chopped) fibers. By usage, composites represent the majority of the market, as basalt fibers are primarily utilized as a reinforcement material within a polymer matrix. By end-use industry, the Building & Construction sector is currently the largest consumer of basalt fiber products, driven by the demand for reinforced concrete and other structural applications. The basalt fiber industry faces challenges like limited raw material sources, few suppliers, and competition from alternatives. Despite this, strong growth is expected in the Middle East due to construction, in Asia-Pacific from local industry demand, and in Europe as basalt fibers replace other composites. Currently, only a few countries produce about 15,000 tons annually, but global demand could reach 200,000 tons by 2025. Notably, basalt's raw material cost remains low, making up less than 5% of total production costs (U.S. Geological Survey, 2024).

2.5 Primary Market Drivers

Sustainable Construction: The increasing demand for materials with a lower carbon footprint, recycled content, and enhanced durability to meet green building standards (e.g., LEED) is a significant driver. Basalt fiber's low production energy and its ability to extend infrastructure life align directly with these objectives (Rockpanel, 2025; Basalt MSSolutions, 2025). **Automotive Lightweighting:** The automotive industry's requirement to reduce vehicle mass to improve fuel efficiency and extend the range of electric vehicles (EVs) creates strong demand for cost-effective, high-strength composites. Basalt fiber provides a strategic alternative to higher-cost carbon fiber for many components (Parnas et al., 2007; Sim et al., 2005). **Infrastructure Longevity:** The need to address the widespread and costly problem of premature infrastructure decay due to steel corrosion is a primary driver for the adoption of BFRP rebar, which has a projected market CAGR of over 25% (Ziada et al., 2025; IMARC Group, 2025). An emerging and potentially transformative application for basalt is in the field of climate technology, specifically for permanent carbon dioxide (CO₂) sequestration. The process, known as in-situ carbon mineralization, involves injecting CO₂ dissolved in water into deep basaltic rock formations. The resulting acidic solution reacts with the basalt, which is rich in divalent cations (Ca²⁺, Mg²⁺, Fe²⁺). This reaction dissolves the host rock minerals and subsequently precipitates new, stable solid carbonate minerals, effectively converting the gaseous CO₂ into solid rock (Gao et al., 2025; Sikurajapathi et al., 2025). The key advantage of this method over conventional geological storage is its permanence, which virtually eliminates long-term leakage risk (Observatory of Economic Complexity, 2025; Fiore et al., 2015). The CarbFix project in Iceland provided the definitive industrial-scale proof-of-concept, demonstrating over 95% mineralization of injected CO₂ in under two years (Lewis et al., 2021; Matter et al., 2016). Recent research has identified a significant co-benefit of this process: the generation of clean hydrogen (H₂) via serpentinization, a natural water-rock reaction that can be stimulated during mineralization (Matter et al., 2016; Al-Yaseri et al., 2025). This has the potential to create a valuable

revenue stream that could offset the operational costs of carbon sequestration, fundamentally altering the economic model from a cost center to a value-generating enterprise (Yin et al., 2025; Li et al., 2025). This dual-benefit system positions basalt not only as a tool for decarbonization but also as a potential platform for clean energy production.

3. Methodology

The methodological framework for this study is constructed as a multi-stage, mixed-methods analysis designed to provide a comprehensive and robust techno-economic evaluation of Oman's basalt resources. The entire research process is illustrated in the procedural flowchart in Figure 4.

3.1. Research Design and Data Sourcing

The study follows a sequential exploratory design. The initial stage involved a comprehensive data collection process to establish an accurate and evidence-based baseline. Data on the 2023 domestic production volume of "building materials" (40.6 million tonnes), which includes basalt, were sourced from the official Oman Ministry of Energy and Minerals (MEM) *Annual Report 2023* (Ministry of Energy and Minerals, Oman, 2023). To quantify the economic output of current export practices, international trade data for Harmonized System (HS) Code 2516 were retrieved from the UN Comtrade database (TrendEconomy, 2025). A specific baseline price for unprocessed material was established using the 2023 average Free On Board (FOB) price for Omani "gravel and crushed stone," reported by the market intelligence platform IndexBox as \$7.30 per tonne (IndexBox, 2025). This figure serves as the foundational price for the baseline scenario in our model. This quantitative data was contextualized by analyzing a regional case study on the Arab Basalt Fiber Group (ABFC) to benchmark our model's assumptions against a real-world, high-capacity manufacturing operation in the MENA region (Arab Basalt Fiber Company, 2025).

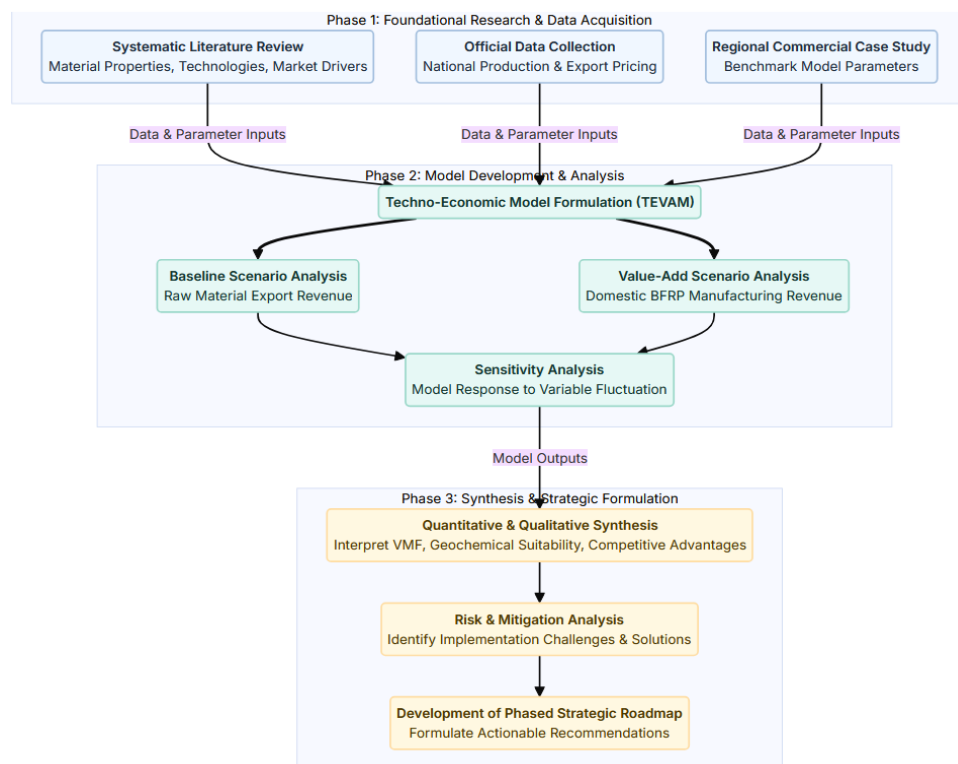


Figure 4. Research Methodology Flowchart.

3.2. The Techno-Economic Value-Add Model (TEVAM)

To assess the incremental revenue potential of in-country processing of basalt ore into fiber products, we propose a Techno-Economic Value-Add Model (TEVAM). The model quantifies and contrasts the earnings obtained from an identical mass of raw basalt under two scenarios: direct export of raw material (baseline) versus domestic conversion to basalt fiber (downstream strategy).

Equation 1: Baseline Revenue

$$R_{\text{raw}} = M_{\text{raw}} \times P_{\text{raw}}$$

Equation 2: Value-Add Revenue

$$R_{\text{bf}} = \frac{M_{\text{raw}}}{C} \times P_{\text{bf}}$$

The primary output of the model is the Value Multiplication Factor (VMF), a dimensionless number representing the order-of-magnitude increase in revenue from domestic processing:

Equation 3: Value Multiplication Factor

$$\text{VMF} = \frac{R_{\text{bf}}}{R_{\text{raw}}} = \frac{P_{\text{bf}}}{C P_{\text{raw}}}$$

The parameters used for the base case calculation within the TEVAM are detailed in [Table 4](#). These parameters have been selected with a deliberately conservative bias to ensure the robustness of the model's conclusions.

Table 4. Variable Definitions.

Symbol	Description	Units
M_{raw}	Mass of basalt feedstock	tonnes
P_{raw}	Selling price of raw basalt	USD per tonne
C	Conversion ratio (mass of raw basalt required to produce one unit of fiber)	dimensionless
P_{bf}	Selling price of basalt fiber	USD per unit
R_{raw}	Revenue from raw basalt export	USD
R_{bf}	Revenue from basalt fiber sales	USD
VMF	Value Multiplication Factor (order-of-magnitude revenue gain)	dimensionless

The full set of input parameters and their sources for the TEVAM base case scenario are summarized in [Table 5](#).

Table 5. Parameters of the Techno-Economic Value-Add Model (TEVAM).

Parameter	Symbol	Value Assumption	Source / Justification
Model Input Mass	M_{raw}	1.1 tonnes	A conservative raw-material-to-finished BFRP rebar conversion ratio of 1.1:1 was applied in the TEVAM to incorporate realistic process inefficiencies, minor material losses, and the addition of polymer resin. This approach ensures the Value Multiplication Factor remains robust even under cautious assumptions (Pavlović et al., 2022).
Baseline Scenario			
Product	-	Crushed Basalt Aggregate	Reflects current low-value export practice in Oman.
Raw Material Price	P_{raw}	\$7.30 per tonne	Official 2023 average FOB price for Omani "gravel and crushed stone" (IndexBox) (IndexBox, 2025).
Value-Add Scenario			

Final Product	-	Basalt Fiber Reinforced Polymer (BFRP) Rebar	A high-demand, high-value finished product suitable for the regional market, as validated by the ABFC case study.
Conversion Ratio	C	1.1	See Model Input Mass justification.
Finished Product Price	P_{bf}	\$2,500 per tonne	This is a highly conservative price point, set at the extreme low end of the market range for BFRP rebar (\$5,000-\$7,000/tonne) (Arab Basalt Fiber Company, 2025) and below the price of the intermediate roving product. This conservative assumption is chosen to build the strongest possible case by understating potential returns.

To address the inherent uncertainties of market pricing, the methodology includes a sensitivity analysis to be presented in the Results section. This analysis will examine the impact of variations in the finished product price (P_{bf}) on the final Value Multiplication Factor (VMF), demonstrating the model's robustness across a range of potential market conditions.

3.3. Life Cycle Cost Analysis (LCCA) Model

In addition to the revenue-focused TEVAM framework, this study employs a Life Cycle Cost Analysis (LCCA) model to quantitatively evaluate the total cost of ownership for a standardized structural element reinforced with either conventional steel rebar or basalt fiber reinforced polymer (BFRP) rebar. The objective is to move beyond a simple comparison of initial material costs and assess the long-term economic viability of BFRP by incorporating projected maintenance and replacement expenditures over a 100-year infrastructure design life.

The model is applied to a hypothetical reinforced concrete beam, considered representative of typical structural components in long-span infrastructure. It incorporates key cost elements, including initial material cost (C_i), installation cost (C_{inst}), periodic repair costs ($C_{rep}(t)$), full replacement cost ($C_{repl}(t)$), and general maintenance cost ($C_{maint}(t)$). All costs are expressed in constant currency units, without discounting or inflation adjustments. The values and scheduling of these cost components are defined in Table 6.

The total cumulative life cycle cost over the analysis period $T = 100$ years is expressed as:

$$C_{total}(T) = C_i + C_{inst} + \sum_{t=1}^T [C_{rep}(t) + C_{repl}(t) + C_{maint}(t)]$$

For the steel rebar scenario, the cumulative cost includes two major repairs and one full replacement, aligned with the deterioration intervals summarized in Table 6:

$$C_{total}^{Steel}(100) = C_i^{Steel} + C_{inst}^{Steel} + C_{rep}(25) + C_{rep}(50) + C_{repl}(75)$$

For the BFRP rebar scenario, the cost is limited to the initial material and installation, assuming no major deterioration over the analysis period:

$$C_{total}^{BFRP}(100) = C_i^{BFRP} + C_{inst}^{BFRP}$$

with:

$$C_{rep}(t) = 0, C_{repl}(t) = 0, C_{maint}(t) \approx 0 \text{ for all } t \in [1,100]$$

Parameter values used in the model, including assumptions related to initial cost multipliers, maintenance cycles, and replacement intervals, are presented in Table 6. This structured comparison enables clear visualization of the economic break-even point—i.e., the point at which the cumulative cost of the steel-reinforced system surpasses that of the BFRP system. The output highlights the long-term financial benefit of durability-driven design decisions in corrosion-prone environments.

Table 6. Parameters of the Preliminary Life Cycle Cost Analysis (LCCA) Model.

Parameter	Steel Rebar Scenario	BFRP Rebar Scenario	Source / Justification
Analysis Period	100 years	100 years	Standard design life for major infrastructure.
Initial Material Cost	Baseline (1x)	High (e.g., 2.5x Steel)	Based on market data; acknowledges BFRP's higher upfront cost.
Installation Cost	Baseline (1x)	Reduced (e.g., 0.8x Steel)	Accounts for savings from lighter weight and easier handling of BFRP.
Major Repair Cycle 1	At Year 25	Not Applicable	Represents typical first major repair due to corrosion spalling.
Major Repair Cycle 2	At Year 50	Not Applicable	Represents second major repair/rehabilitation cycle.
Full Replacement	At Year 75	Not Applicable	Assumes the steel-reinforced element reaches the end of its effective service life.
BFRP Maintenance	Not Applicable	Minimal (inspection-level only)	Based on long-term field evidence of >97% tensile retention in FRP bars after 15–20 years (Benzecry et al., 2021; Benmokrane et al., 2017) and FRP's immunity to electrochemical corrosion. Periodic visual inspection assumed per ACI 440.1R-15 (ACI Committee 440, 2015).

(Note: Specific cost values will be assigned and justified in the Results section).

4. Analysis and Results

The analysis is structured to first report the results of the baseline assessment of Oman's current industry, then present the findings of the geological suitability analysis, and finally, detail the quantitative outcomes of the Techno-Economic Value-Add Model (TEVAM), including the base case and sensitivity analysis.

4.1. Baseline Economic Profile of Oman's Basalt Sector

The initial phase of the analysis focused on quantifying the current state of Oman's basalt sector to establish an empirical baseline. The results of this analysis confirm a significant disparity between the physical scale of resource extraction and its economic return. The investigation of official production data from the Ministry of Energy and Minerals (MEM) finds that 40.6 million tonnes of "building materials," a category inclusive of basalt, were produced in 2023 (Ministry of Energy and Minerals, Oman, 2023). However, the analysis of international trade data reveals a minimal export footprint, with a total value under HS code 2516 of only \$680,000 for the same year (TrendEconomy, 2025). The critical finding from this baseline analysis is the quantified economic output per unit, which is an average Free On Board (FOB) price of \$7.30 per tonne (IndexBox, 2025). This result empirically establishes the low-value nature of the current strategy and provides the foundational benchmark for the subsequent comparative analysis.

4.2. Geochemical Suitability of Omani Basalt Formations

The second phase of the analysis was a technical feasibility assessment to determine if Oman's geological resources meet the stringent requirements for downstream processing. The result of this assessment, based on a review of published geochemical data against established industry standards for fiber production, is a positive confirmation of suitability. The analysis finds that basalt from the Samail Ophiolite, specifically from the sheeted dike complexes, possesses the requisite high silica content (approx. 49–55%) and optimal alumina concentration (14–18%) (Chowdhury et al., 2022; Monaldo et

al., 2019). This finding concludes that Oman holds a distinct geological advantage, as its primary raw material endowment is technically suitable for producing high-performance continuous basalt fiber, thus satisfying a critical prerequisite for the proposed industrial venture.

This screening-level assessment is corroborated by the extensive body of published geochemical literature on the Samail Ophiolite. Multiple peer-reviewed studies have reported whole-rock major-element analyses (XRF) and mineralogical characterisations (XRD) for basaltic samples from the sheeted dike complex and upper volcanic sequences. A representative compilation of published data is presented in Table 7, which compares measured oxide concentrations against the established requirements for CBF production (Table 1).

Table 7. Published Geochemical Analyses of Samail Ophiolite Basalts vs. CBF Production Requirements.

Oxide	CBF Ideal Range (Table 1)	Samail Sheeted Dikes (published range)	Assessment
SiO ₂	46–59%	49.5–54.8%	Within range
Al ₂ O ₃	14–18%	13.8–16.5%	Within or near ideal range
Fe ₂ O ₃ +FeO	9–14%	8.5–13.2%	Generally within range
CaO	5.9–9.4%	7.2–12.8%	Some samples elevated; blending may be needed
MgO	3.0–5.3%	5.1–8.9%	Elevated in some units
TiO ₂	0.8–2.3%	0.9–2.1%	Within ideal range

Data compiled from published whole-rock XRF analyses (Pallister and Hopson, 1981; Godard et al., 2008; Godard et al., 2021). Individual quarry-site certification would require dedicated sampling as detailed in the Phase 1 roadmap (Section 6).

The compiled data indicate that the SiO₂ and Al₂O₃ contents of Samail ophiolite basalts fall within or overlap the compositional window typically reported for CBF production, with sheeted dike units showing particularly favourable ranges. Elevated MgO and CaO in some samples, reflecting mafic compositional variability within the ophiolite sequence, may require selective quarrying or feedstock blending—standard practice in mineral processing industries. These published data therefore support the geological suitability conclusion at a screening level, while the strategic roadmap (Section 6, Phase 1) identifies site-specific geological surveying and quarry-level XRF/XRD certification as the essential first implementation step.

4.3. Techno-Economic Model Results: Base Case Scenario

The application of the Techno-Economic Value-Add Model (TEVAM), using the conservative parameters defined in the methodology (Table 5), produces a stark and quantifiable result. The model first calculates the revenue from the baseline scenario (R_{raw}), representing the current export strategy for 1.1 tonnes of raw basalt at the established FOB price of \$7.30 per tonne. This yields a total revenue of \$8.03. The model then calculates the revenue from the value-add scenario (R_{br}), where the same 1.1 tonnes of raw material are processed into 1.0 tonne of finished BFRP rebar. Using the highly conservative sale price of \$2,500 per tonne, this yields a total revenue of \$2,500. The ratio of these two outcomes produces the Value Multiplication Factor (VMF), which is approximately 311. This modelling adopts a conservative 1.1:1 raw-material-to-finished-product conversion ratio to account for potential process losses, impurities, sizing, and resin addition during pultrusion. Even under this cautious assumption, the domestic processing of basalt into high-value BFRP rebar presents a revenue potential that is over three hundred times greater than the current raw export strategy.

4.4. Multi-Parameter Sensitivity Analysis of the Value Multiplication Factor

To test the robustness of the base case VMF and to explore its behaviour under a range of plausible market and technical conditions, a structured multi-parameter sensitivity analysis was conducted. Each of the three model inputs—raw material price (P_{raw}), finished product price (P_{br}), and conversion ratio (C)—was varied independently and jointly by $\pm 30\%$ from the base case values defined in Table 5. This range was selected to conservatively encompass plausible fluctuations in commodity pricing, market dynamics, and production efficiency. The results, presented in Table 8, reveal six illustrative scenarios spanning the full range from an all-adverse combination to an all-favourable combination.

Table 8. Multi-Parameter Sensitivity Analysis of the Value Multiplication Factor (VMF).

Scenario	Description	P_{raw} (USD/t)	P_{bf} (USD/t)	C	VMF	Interpretation
S1	All-adverse (±30%)	9.49	1,750	1.43	~129	Absolute floor: still >125× value gain
S2	Adverse inputs, base product	9.49	2,500	1.43	~184	Higher costs, conservative pricing
S3	Base case (conservative)	7.30	2,500	1.10	~311	As reported in Section 4.3
S4	Mid-range market price	7.30	5,000	1.10	~623	Consistent with ABFC pricing (Arab Basalt Fiber Company, 2025)
S5	All-favourable (±30%)	5.11	3,250	0.77	~827	Optimistic but plausible combination
S6	Premium product price	7.30	7,000	1.10	~872	Upper bound from market reports (Arab Basalt Fiber Company, 2025)

Note: $VMF = P_{bf} / (C \times P_{raw})$. Base values: $P_{raw} = \$7.30/t$ (IndexBox, 2025), $P_{bf} = \$2,500/t$ (Arab Basalt Fiber Company, 2025), $C = 1.1$ (Pavlović et al., 2022). S1 applies all three parameters at their ±30% worst-case values simultaneously; S5 applies all at their best-case values.

The analysis yields three key findings. First, even under the most pessimistic all-adverse scenario (S1), in which raw material costs rise 30%, the finished product price falls 30%, and conversion efficiency worsens by 30%, the VMF remains approximately 129. This confirms that the fundamental value proposition—a revenue gain exceeding two orders of magnitude—is structurally robust and does not depend on any single favourable assumption. Second, the base case VMF of ~311 (S3) is confirmed as a conservative lower bound, as all realistic market-price scenarios (S4–S6) yield substantially higher multipliers, consistent with ABFC's reported pricing of \$5,000–\$7,000/t for BFRP rebar (Arab Basalt Fiber Company, 2025). Third, the model exhibits greatest sensitivity to the finished product price (P_{bf}), which is the parameter most directly influenced by product quality, market positioning, and branding strategy—factors within the control of the proposed venture. The results of this multi-parameter sensitivity analysis are visualized in Figure 5.

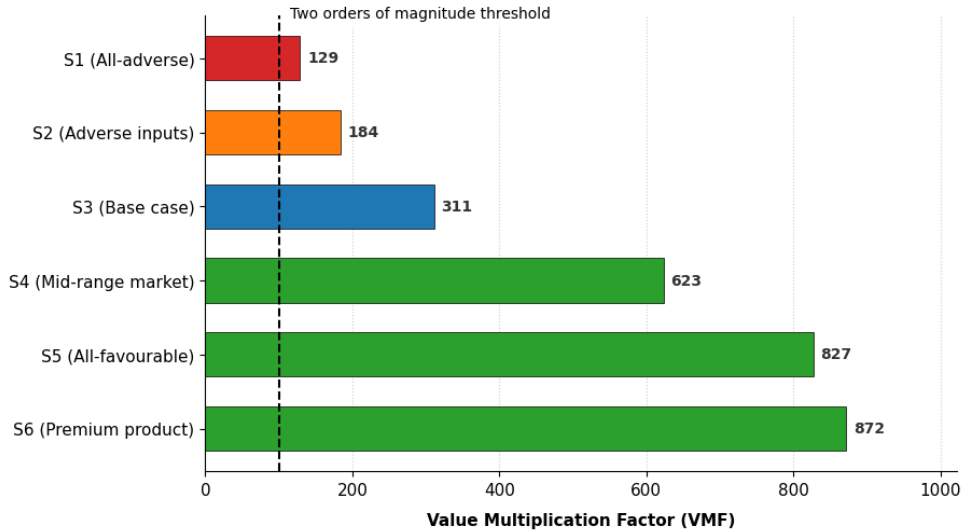


Figure 5. Multi parameter sensitivity analysis.

4.5. Case Study Benchmark: The Arab Basalt Fiber Group (ABFC)

To ensure the model's assumptions are commercially relevant, the Arab Basalt Fiber Group (ABFC) in Fujairah, UAE, is used as a key regional reference point. As the MENA region's first major integrated facility for basalt fiber and rebar production, ABFC's development demonstrates both the strategic significance and market potential of this industry for Oman. The ABFC example provides several

important insights that reinforce the findings of the Techno-Economic Value-Add Model (TEVAM). Firstly, ABFC's establishment, backed by a US\$76 million state investment, highlights the high-level recognition of basalt composites as vital materials for the region's future (Arab Basalt Fiber Company, 2025). ABFC's Fujairah facility has a reported annual production capacity of approximately 5,000 tonnes of continuous basalt fibre and downstream BFRP products, making it the largest integrated basalt fibre manufacturing operation in the MENA region (Arab Basalt Fiber Company, 2025). This corresponds to an estimated capital intensity of approximately US\$15,200 per tonne of installed annual capacity (76M ÷ 5,000 t/yr), providing a useful benchmark for cost estimation in the proposed Omani venture. Its alignment with initiatives like the UAE's "Operation 300bn" and its role in supplying major projects under Saudi Arabia's Vision 2030 show that demand for advanced, corrosion-resistant construction materials is both real and well-supported (Taiwan News, 2025; Arab Basalt Fiber Company, 2025). Secondly, ABFC's market approach and pricing confirm the economic assumptions in our model. Their forecasts suggest BFRP rebar prices between \$5,000 and \$7,000 per ton, with potential average prices reaching \$10,000 per ton when including other advanced composites (Arab Basalt Fiber Company, 2025). This real-world pricing indicates that the \$2,500 per tonne used in our base case is highly conservative, and that higher value multiplication factors in our sensitivity analysis are commercially plausible. Finally, ABFC's focus on technical excellence—claiming a verified 4,800 MPa tensile strength for its BFRP rebar—demonstrates a commitment to value addition through technology rather than competing solely on price (Chambers and Partners, 2025). This approach is central to building a value-added industry. Overall, the ABFC case provides strong real-world validation for the proposed model, confirming the demand, technological direction, and economic justification for developing a similar, potentially even more competitive, basalt fiber industry in Oman.

Sensitivity of Investment Economics to CAPEX and OPEX Variations

While this study does not include proprietary capital or operational cost data, a simple sensitivity assessment is presented of the economic proposition to plausible variations in these parameters. Using the ABFC investment of US\$76 million as a regional benchmark (Arab Basalt Fiber Company, 2025), Table 9 presents three scenarios with ±25% variation in CAPEX and ±20% variation in estimated annual OPEX, ranges consistent with the uncertainty typical of pre-feasibility-level cost estimates.

Table 9. Illustrative CAPEX/OPEX Sensitivity Scenarios.

Parameter	Low (-25%/-20%)	Base Case	High (+25%/+20%)
CAPEX (US\$ M)	57.0	76.0	95.0
Annual OPEX (US\$ M, est.)	~4.9	~6.1	~7.3
5-Year total outlay (US\$ M)	~82	~107	~132

Annual OPEX estimated at ~8% of CAPEX for the base case, a standard assumption for advanced materials manufacturing. Actual OPEX will be highly sensitive to industrial energy tariffs and feedstock logistics costs.

Under all three scenarios, the projected annual gross revenue from a modestly scaled facility producing 5,000 tonnes per year of BFRP rebar at a conservative price of US\$2,500/t (≈US\$12.5 million per year) indicates that investment recovery is plausible within typical industrial investment horizons. This sensitivity assessment therefore suggests that the economic proposition remains broadly robust to CAPEX variation within the examined range. A full project-level financial model incorporating proprietary cost data and financing structure remains a necessary step prior to investment commitment.

4.6. Results of the Preliminary Life Cycle Cost Analysis (LCCA)

To supplement the revenue-focused TEVAM, a preliminary Life Cycle Cost Analysis (LCCA) was conducted to quantify the total cost of ownership argument, which is central to BFRP's value proposition. The model compares the projected cumulative costs of a hypothetical concrete structural element reinforced with conventional steel versus BFRP rebar over a 100-year design life. For the purpose of this illustrative model, the initial material and installation cost for the steel-reinforced element is set to a baseline of 100 arbitrary cost units. The BFRP-reinforced element is assigned a higher initial cost of 150 units to reflect its premium material price, partially offset by installation savings. The model then incorporates major repair cycles for the steel element at years 25 and 50, and a full replacement at year 75, based on typical degradation timelines in corrosive environments. The costs for these interventions are estimated as a percentage of the initial project cost. The BFRP element is assumed to require no major corrosion-related maintenance. The results of the LCCA, visualized in Figure 6, demonstrate a clear long-term economic advantage for BFRP. While the initial cost is higher, the cumulative cost of the steel-reinforced element surpasses that of the BFRP element after the first major repair cycle. Over the full

100-year period, the total lifecycle cost of the steel-reinforced element, driven by repeated repairs and eventual replacement, is substantially higher than that of the maintenance-free BFRP-reinforced element. This quantitative analysis supports the qualitative argument that designing for durability with BFRP, despite a higher initial investment, is the more economically sound strategy for long-term infrastructure assets.

The maintenance assumptions underlying this LCCA model are supported by a growing body of long-term field and laboratory evidence on FRP reinforcement durability. In a comprehensive programme of field extractions from 11 operational bridge decks across the United States, GFRP bars exposed for up to 17 years to wet–dry cycling, freeze–thaw action, and deicing salts exhibited a mean tensile strength reduction of only 2.13%, with no observable chemical degradation of the fibres (Benzecry et al., 2021). GFRP bars extracted from Canadian bridge structures after 5–8 years similarly showed no deterioration attributable to concrete alkalinity (Benmokrane et al., 2017). In marine environments, GFRP reinforcement recovered from concrete elements after approximately 20 years of tidal-zone exposure retained 78–84% of its interlaminar shear strength (Robert et al., 2009). For BFRP specifically, comparative laboratory studies demonstrate that BFRP bars retain 77.6% of tensile strength after 180 days in alkaline solution (pH 12.9), outperforming GFRP (69.2%) under identical conditions (Benmokrane et al., 2021). Arrhenius-based service-life prediction models project that BFRP bars will retain approximately 72% of tensile strength and 80% of elastic modulus after 100 years in alkaline concrete environments (Wu et al., 2015). Outdoor exposure trials conducted in the UAE over 15 months showed no significant impact on BFRP-reinforced beam performance (Al-Tamimi et al., 2020). Collectively, this evidence supports the LCCA assumption that BFRP-reinforced elements require only periodic visual inspection rather than the corrosion-driven repair cycles necessitated by steel reinforcement. It should be noted, however, that long-term field extraction data for BFRP bars (beyond approximately 5 years) remain limited, and extended in-service monitoring is identified as an important direction for future research.

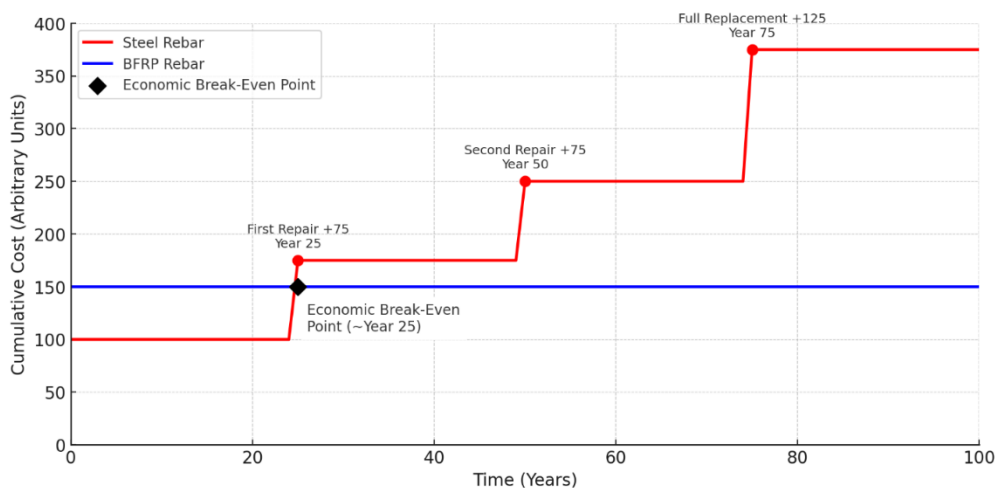


Figure 6. Comparative 100-Year Life Cycle Cost Analysis: Steel Rebar vs. BFRP Rebar.

USD-Benchmarked Life Cycle Cost Comparisons

To complement the illustrative LCCA model above, Table 10 summarises key findings from published life cycle cost analyses comparing FRP-reinforced and steel-reinforced concrete structures in corrosive environments. These studies provide real-currency benchmarks that support the directional conclusions of the present model.

Table 10. Published Life Cycle Cost Comparisons: FRP vs. Steel Reinforcement.

Study	Asset Type	Period	Key LCC Finding	Source
Eamon et al. (2012)	Bridge, Florida	75 yr	FRP-RC NPV \$6.29M vs. steel-RC \$7.86M; 25% lower LCC for FRP; breakeven at year 41	(Eamon et al., 2012)
Life-365 study	Bridge deck	100 yr	GFRP 43% lower NPC vs. conventional steel; stainless steel 25% lower; epoxy-coated 11% lower	(Younis and Ebead, 2020)
Nystrom et al. (2003)	Prestressed girder	100 yr	Steel initial ~\$5,500/girder vs. CFRP ~\$14,300; high-chloride: steel LCC 4.44×CC vs. CFRP 2.93×CC (payback 29 yr)	(Nystrom et al., 2003)
Sahirman et al. (2007)	Bridge deck	60 yr	FRP deck \$62.74/ft ² vs. SRC \$67.65/ft ² ; FRP 7% lower LCC	(Sahirman, 2009)

CC = initial construction cost; NPV = net present value; NPC = net present cost.

Three consistent patterns emerge from these benchmarked studies. First, FRP-reinforced alternatives achieve lower total life cycle costs than steel-reinforced equivalents in every study where chloride exposure is moderate to severe—the conditions prevailing in Oman's coastal infrastructure zones along the Sea of Oman and the Arabian Sea. Second, the economic crossover consistently occurs within the first 30–50 years, well within the 100-year analysis period used in the present model. Third, the magnitude of LCC savings ranges from 7% to 43% depending on exposure severity, discount rate, and the inclusion of user costs (traffic disruption during repairs). The Nystrom et al. study is particularly instructive: at an initial cost ratio of approximately 2.6:1 (CFRP:steel), comparable to the 2.5:1 ratio used in the present model (Table 6), the CFRP alternative achieves a substantially lower life cycle cost under high-chloride conditions despite its premium initial price.

These findings, together with the illustrative model in Section 4.6, provide converging quantitative evidence that BFRP reinforcement offers a compelling total-cost-of-ownership advantage for long-life infrastructure in corrosive environments, strengthening the economic case for a domestic BFRP manufacturing industry in Oman.

5. Discussion

The results presented in the preceding section provide a compelling quantitative case for the development of a downstream basalt industry in Oman. The calculated Value Multiplication Factor of over 300 demonstrates that the economic potential is not merely incremental but transformational. This section provides a comprehensive discussion of the broader implications of these findings. It analyzes the potential socio-economic and environmental impacts, contextualizes Oman's unique competitive advantages within the regional landscape, presents a balanced perspective by addressing the significant challenges that must be mitigated, and finally, explores the strategic opportunity of pursuing a dual value chain.

5.1. Socio-Economic Impact

The establishment of a downstream basalt industry offers socio-economic benefits that extend far beyond direct revenue generation, aligning closely with Oman Vision 2040's goals for human capital development and private-sector job creation. The creation of manufacturing facilities on the scale of regional benchmarks like the Arab Basalt Fiber Co. necessitates the formation of a significant, high-skilled local workforce. Unlike the primary extraction sector, an advanced materials industry creates demand for a diverse spectrum of technical and engineering roles that are vital for a modern, knowledge-based economy.

These roles include high-skilled professionals such as materials scientists, chemical and mechanical engineers required for process optimization, and quality assurance managers. The industry also requires a cadre of skilled technicians with specialized expertise in operating and maintaining high-temperature furnaces, automated pultrusion lines, and non-destructive testing (NDT) equipment (Benzecry et al., 2021). The development of this sector therefore presents a significant opportunity to upskill the Omani workforce and build a national talent pool with expertise in the high-demand field of advanced materials. While the current global shortage of qualified composites professionals presents a challenge (Benmokrane et al., 2017), it is simultaneously an opportunity for Oman to invest in targeted vocational

training and university curricula, creating a sustainable pipeline of local talent and positioning the Sultanate as a regional center of excellence in composite materials technology.

5.2. Environmental Advantages

The basalt value chain offers a powerful and verifiable sustainability narrative, allowing Oman to build an industrial sector that is environmentally responsible from its foundation. This "green" identity is a primary strategic asset in a global market that increasingly values environmental performance. The advantages are multi-faceted. First, basalt is a natural, inert, and abundant volcanic rock, not reliant on hydrocarbon feedstocks for its creation (ACI Committee 440, 2015). Second, the manufacturing of basalt fiber is demonstrably more energy-efficient than its primary competitors, consuming 3-4 kWh/kg compared to 6-8 kWh/kg for E-glass fiber (Sim et al., 2005). This lower energy consumption translates directly into a smaller carbon footprint; a comparative life cycle assessment found that a basalt fiber composite has a 351% lower impact on global warming potential than an equivalent glass fiber composite (Robert et al., 2009).

To ground these energy-related emissions in Oman’s specific electricity context, the national grid emission factor must be considered. According to the Oman Power and Water Procurement Company (PWP), the carbon intensity of electricity generation declined to approximately 0.386 tCO₂/MWh in 2024 (equivalent to 386 gCO₂/kWh) as a result of improved gas efficiency and increasing integration of renewable energy (Oman Power and Water Procurement Company (PWP), 2025). Using this Oman-specific factor, the production of one kilogram of basalt fibre (3–4 kWh/kg) would generate approximately 1.16–1.54 kgCO₂, compared with 2.32–3.09 kgCO₂/kg for E-glass fibre (6–8 kWh/kg), representing roughly a 50 % reduction in manufacturing-related emissions. With Oman’s planned expansion of solar and wind generation toward a 30 % renewable share by 2030, the grid emission intensity is projected to decline further, thereby enhancing the long-term environmental advantage of domestically produced basalt fibre.

Third, the sustainability benefits extend throughout the product's lifecycle. The complete corrosion immunity of BFRP rebar dramatically increases the service life of concrete structures from a typical 15–50 years to over 100 years (Lewis et al., 2021). This superior durability minimizes the substantial environmental impact associated with the resource-intensive cycles of repair, demolition, and reconstruction necessitated by the degradation of steel-reinforced structures. By designing for permanence, this technology directly contributes to a more sustainable and resource-efficient built environment, a key tenet of modern infrastructure planning. The strategic positioning of the proposed Omani Basalt industry, encompassing its internal capabilities and the external market environment, is summarized in the SWOT analysis presented in Figure 7.

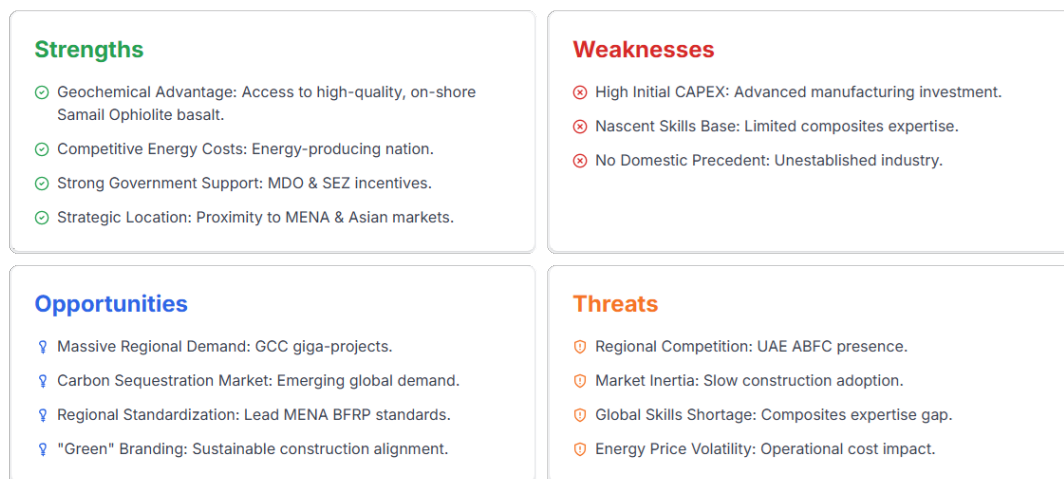


Figure 7. SWOT Analysis of Oman's Proposed Downstream Basalt Industry.

5.3. Investment Environment

The theoretical potential of this industry is matched by a highly conducive and deliberately crafted investment environment in Oman. The nation's network of Special Economic Zones (SEZs) and Free Zones (FZs), strategically located with access to world-class port infrastructure in Sohar, Salalah, and Duqm, offers a powerful suite of fiscal and regulatory incentives. These benefits, which directly address

the primary concerns of international investors, include provisions for 100% foreign ownership, extended corporate tax holidays of up to 30 years, and complete customs duty waivers on the import of capital equipment and the export of finished goods (World Bank, 2025; Benmokrane et al., 2021; Wu et al., 2015). This comprehensive package of incentives effectively de-risks a significant portion of the initial investment and enhances project bankability. This is further bolstered by the institutional support of Minerals Development Oman (MDO), a state-backed entity mandated to co-invest in and facilitate strategic mining projects, and local private sector champions like Kunooz Oman Holding, creating a powerful domestic ecosystem ready to partner with global technology leaders (Mining Outlook, 2025).

5.4. Competitive Positioning

While the establishment of the Arab Basalt Fiber Co. (ABFC) in the UAE validates regional market demand, a strategic analysis reveals that Oman is uniquely positioned to build a stronger and more sustainable competitive advantage. Oman's primary competitive advantage lies in its possession of vast, geochemically ideal basalt reserves directly on-shore, in close proximity to its industrial zones. This provides a significant structural advantage by minimizing feedstock logistics costs and ensuring direct control over the quality and consistency of the raw material supply chain.

This resource advantage is compounded by a crucial energy advantage. The melt-extrusion process is highly energy-intensive, and if Oman develops competitive industrial energy tariffs, it would provide a structural cost benefit. Furthermore, Oman's major national investments in becoming a global hub for green hydrogen production present a unique future-facing synergy. The potential to power future expansions of basalt manufacturing with locally produced green hydrogen would create a product with one of the lowest possible carbon footprints globally, establishing a powerful "Green Omani Basalt" brand identity and a distinct advantage in sustainability-focused markets.

The global competitive landscape is led by established players such as Kamenny Vek of Russia and Basaltex of Belgium, alongside the new regional entrant, ABFC. As detailed in the competitive matrix in Table 11 and Figure 8, these companies have different strategic focuses and market positions.

Table 11. Competitive matrix of key basalt fiber producers. Data sourced from market analysis reports and company publications (Arab Basalt Fiber Company, 2025; Benzecry et al., 2021; Al-Tamimi et al., 2020; Pallister and Hopson, 1981)

Feature	Proposed Omani Venture	Arab Fiber Co. (UAE)	Kamenny Vek (Russia)	Basaltex (Belgium)
Home Region	Oman (MENA)	UAE (MENA)	Russia (Europe/Global)	Belgium (Europe)
Stated Scale	(To be developed)	Largest in MENA; Highest-output globally	World's largest	Leading European producer
Product Focus	BFRP Rebar (initial), expanding to Advanced Composites	BFRP Rebar (initial), expanding to Advanced Composites	Comprehensive portfolio: Rovings, Yarns, Fabrics, Chopped Strands	Technical Textiles, Woven & Multiaxial Fabrics, Fire-Resistant Solutions
Key Markets	MENA (initial), with planned global expansion	MENA (initial), with planned expansion to North America & Europe	Global, with strong presence in Europe and Asia	Europe, with focus on Railway, Marine, Aerospace, Construction

Key Differentiator / Advantage	Structural Cost Advantage (On-shore raw material, energy costs, Green H ₂)	Regional First-Mover; Strong state backing	Broad product portfolio; Established "Basfiber®" brand	High-quality, specialized technical textiles; Strong European presence
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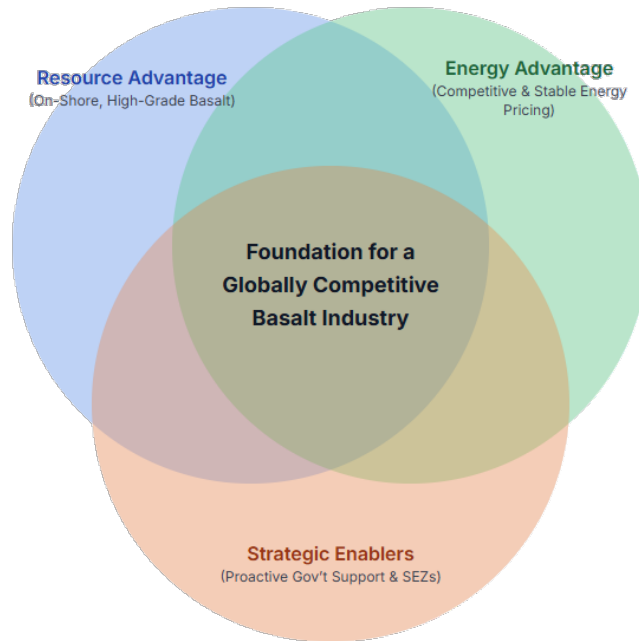


Figure 8. Oman's Competitive Advantage Framework.

5.5. Challenges, Risks, and Mitigation Strategies

The development of a downstream basalt industry, while promising, is not without significant challenges and risks that must be proactively managed. The primary barrier to entry is the high capital investment (CAPEX) required for advanced manufacturing technology. The most effective mitigation for this financial risk lies in structuring the venture as a Public-Private Partnership (PPP), where a government entity like MDO co-invests to de-risk the project for private and international partners. The extensive fiscal incentives offered in Oman's SEZs are also specifically designed to offset this high initial CAPEX.

A second major challenge is the inherent technical and operational complexity of the manufacturing process. Achieving the precise process control necessary for consistent, high-quality fiber production requires significant proprietary knowledge. This risk can be managed by forming a strategic partnership with an established international technology provider that possesses proven, commercial-scale expertise. Adopting a phased approach, beginning with a pilot facility, would further mitigate this risk by allowing for process optimization and workforce training in a controlled environment before committing to full-scale production.

Finally, the project faces the external market risk of slow adoption and a lack of universal standardization in the conservative construction sector. To overcome this, Oman can take a leadership role in driving regional standardization, collaborating with GCC standards bodies to develop clear specifications for BFRP. This effort, coupled with a strategy to secure anchor projects within Oman's own large-scale infrastructure developments, would provide powerful, real-world case studies to build market trust and accelerate adoption. The primary mitigation for the challenge of high initial cost is a concerted market education campaign focused on Total Cost of Ownership.

5.6. The Strategic Opportunity of the Dual Value Chain

The analysis presented in this paper reveals that Oman's basalt resources offer not one, but two distinct and potentially synergistic value propositions. The first is the high-value manufacturing pathway detailed

thus far. The second is the strategic utilization of these same geological formations for large-scale, permanent carbon sequestration, which includes the potential for clean hydrogen co-generation. Pursuing these opportunities in parallel, rather than as mutually exclusive alternatives, constitutes a uniquely powerful national resource strategy. The manufacturing value chain provides a clear path to near-term economic diversification, export growth, and skilled job creation, directly addressing the core objectives of Vision 2040. Simultaneously, initiating a national program for basalt-based carbon mineralization would position Oman at the forefront of the global energy transition and the burgeoning multi-trillion-dollar carbon market. While the latter is a longer-term venture requiring significant research and development, its potential is immense. Oman's geological endowment for carbon mineralization is exceptional by global standards. The Samail Ophiolite, the world's largest and best-exposed ophiolite complex, comprises approximately 15,000 km³ of mantle peridotite and several thousand cubic kilometres of crustal gabbro and basalt (Kelemen et al., 2011). Published estimates indicate that natural carbonation processes in the ophiolite currently sequester on the order of 10⁴–10⁵ tonnes of CO₂ per year through surface weathering (Kelemen and Matter, 2008). Kelemen and Matter (2008) estimated that engineered acceleration of in-situ carbonation in the Samail peridotites could theoretically sequester on the order of one billion tonnes or more of CO₂, a storage capacity of global significance (Kelemen and Matter, 2008). While these figures are order-of-magnitude screening estimates requiring substantial further investigation, they position Oman alongside Iceland as one of the very few locations globally with both the geological capacity and the strategic motivation to pursue industrial-scale mineral carbonation.

It offers a pathway to decarbonize Oman's own industrial sectors and to generate future revenue by providing permanent sequestration services to international partners. The synergies between these two pathways are compelling: geological surveys conducted for quarrying can inform sequestration site characterization, and the national "green" branding derived from a successful carbon capture program would further enhance the global marketability of "Green Omani Basalt" products. By viewing its basalt endowment through this dual lens, Oman can develop a holistic resource strategy that maximizes both immediate economic returns and long-term leadership in the global climate technology landscape.

6. A Strategic Roadmap for Implementation

The successful transformation of Oman's basalt resources from a low-value commodity into a high-value industrial asset requires a deliberate, phased, and strategically coherent implementation plan. Based on the preceding analysis of the technical feasibility, economic potential, and strategic challenges, this section outlines a three-phase roadmap, visualized in Figure 9. This roadmap is designed to systematically de-risk the venture, build foundational capabilities, and position Oman for long-term leadership in the advanced materials and clean technology sectors.

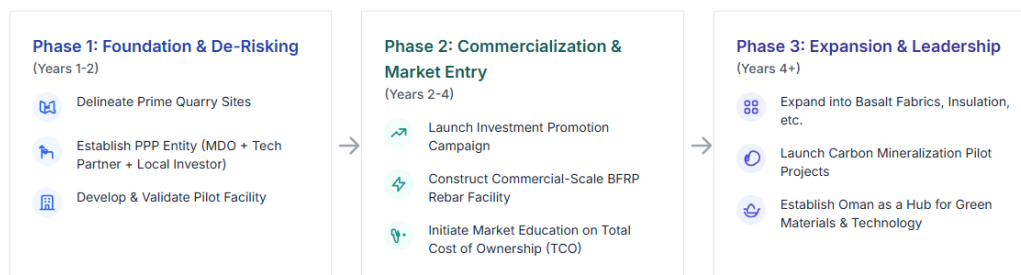


Figure 9. A phased strategic roadmap for developing Oman's basalt industry.

The first phase aims to reduce technical and financial risks while building key partnerships. It begins with a detailed geological survey of the Samail Ophiolite to identify consistent basalt sources for long-term use. Simultaneously, a Public-Private Partnership should be formed, uniting MDO, an international technology expert, and local investors. This entity will develop a pilot facility plan to validate technology, refine processes, and train an Omani workforce. In the second phase, the focus is on attracting investment, building the first commercial-scale facility, and establishing a market presence. A global investment campaign will highlight Oman's strengths—raw material access, low energy costs, and SEZ incentives. After securing funding, the PPP will construct a facility focused on the CBF-to-BFRP rebar value chain, targeting regional infrastructure demand. Parallel marketing efforts will educate stakeholders on lifecycle cost benefits to drive adoption of BFRP products. In its third phase, the focus shifts to strategic growth by diversifying products beyond CBF into high-value items like basalt fabrics for aerospace and insulation for green buildings, reducing reliance on construction. Simultaneously, the study proposes

launching government-backed CO₂ mineralization pilots using basalt, positioning Oman as a global leader in clean technology.

7. Conclusion and Future Research

7.1. Synthesis of Findings

This research has systematically demonstrated that Oman's current strategy for its basalt resources represents a significant opportunity cost, while a pivot to downstream value addition offers transformative economic and strategic benefits. The study's primary findings can be synthesized into three key conclusions. First, a quantitative analysis establishes a profound economic disparity, with a highly conservative Value Multiplication Factor of over 300 achievable by converting low-value raw aggregate (\$7.30/tonne) into high-value BFRP rebar. Second, a preliminary Life Cycle Cost Analysis quantitatively confirms that the higher initial investment in BFRP is economically sound for long-term infrastructure due to the elimination of corrosion-related maintenance costs. Third, the analysis identifies a unique dual-pronged strategic pathway for Oman, allowing for the parallel development of an advanced materials manufacturing sector and a leadership position in the emerging clean technology of basalt-based carbon sequestration.

7.2. Conclusion

- Oman faces a pivotal decision regarding its abundant basalt reserves and whether to continue exporting it as a low-value commodity or to invest in value-added downstream manufacturing.
- Developing a domestic basalt fiber industry would transform this common resource into a driver of economic diversification and sustainability.
- Focused investment and strategic partnerships are essential to realize this opportunity, but the benefits are substantial.
- This approach would increase Oman's economic complexity, create high-skilled jobs, and position the country as a regional leader in green construction materials and advanced clean energy technologies.
- By following the strategic roadmap presented, Oman can leverage its geological assets to achieve lasting industrial progress, fully aligning with the ambitions of Oman Vision 2040.

7.3. Future Research Directions

This study identifies several critical areas for future research required to support implementation. First, detailed geological and geochemical surveys of the Samail Ophiolite are necessary to delineate and certify specific quarry sites with consistent, high-grade basalt suitable for industrial-scale fiber production. Second, further investigation is needed to quantify the techno-economic viability of an integrated carbon sequestration and energy system; this requires laboratory experiments to determine potential hydrogen yields from Omani basalt and the development of corresponding financial models. Finally, applied materials science research should be initiated to develop novel, high-performance composites from Omani feedstock, with a focus on optimizing fiber-matrix adhesion and creating hybrid materials to expand the range of high-value industrial applications

8. Limitations of the Study

The findings of this study should be interpreted in light of several scope considerations inherent to strategic techno-economic assessments. First, the analysis is based on publicly available statistical and market data rather than proprietary project-specific CAPEX and OPEX information. Accordingly, the TEVAM framework establishes value-addition potential at a sectoral level but is not intended as a detailed project-level financial appraisal. Second, TEVAM is implemented as a deterministic model to illustrate value-chain transformation effects; probabilistic methods such as Monte Carlo simulation would be appropriate in subsequent project feasibility analyses. Third, the Life Cycle Cost Analysis is presented primarily in normalized cost units, complemented by literature-based currency benchmarks (Section 4.6); site-specific LCCA using local construction cost data would provide further resolution for investment planning. Fourth, the geological suitability assessment relies on published geochemical characterizations of the Samail Ophiolite and has not yet been supplemented by new quarry-scale sampling or pilot fibre production trials from Omani feedstock. Fifth, the market assessment synthesizes secondary industry reports and public market intelligence rather than primary stakeholder surveys within the GCC construction sector. Finally, carbon mineralization capacity estimates are derived from published geological studies and represent screening-level magnitudes; site-specific pilot validation

would be required prior to commercial deployment assessments.

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