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on Sustainable Mineral Resources

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Strengthening Vocational and Applied Engineering Skills for Europe's Mineral Raw Materials Value Chain

Building the Workforce Pyramid for Europe's Mineral Raw Materials Sector: Vocational and Applied Engineering Education as Strategic Foundations

A Position Paper of the ETP SMR

ETP SMR welcomes the European Commission's increasing recognition of workforce development, industrial resilience and strategic value chains within initiatives such as the Critical Raw Materials Act (CRMA), RESourceEU, the Union of Skills, the Clean Industrial Deal, the Competitiveness Compass and the Pact for Skills[1].

Europe's industrial competitiveness, technological sovereignty, economic security and defence readiness depend not only on access to mineral raw materials, but also on the availability of a sufficiently skilled workforce capable of implementing, operating and maintaining strategic industrial value chains. At the same time, the transition toward more digitalised, automated and sustainable industrial systems is rapidly transforming workforce requirements across the raw materials value chain, increasing demand for competencies related to automation, artificial intelligence, digitalisation, electrification, advanced process technologies, environmental monitoring and circular economy systems. Despite increasing automation, many critical functions throughout the mineral raw materials value chain continue to depend heavily on human-to-human interaction, multidisciplinary cooperation, operational responsibility, stakeholder engagement and societal trust. Workforce development should therefore be understood not only as a technological challenge, but also as a broader human-capital and societal resilience challenge.

Europe's strategic ambitions for critical raw materials and industrial resilience will require:

1. a comprehensive European mineral raw materials skills ecosystem spanning vocational education and training (VET), applied engineering education, lifelong learning, industrial reskilling and higher education pathways.
2. stronger long-term support mechanisms for vocational, technical and applied-engineering education capacities linked to industrial implementation and regional resilience; and
3. closer integration between industry, educational institutions, research organisations and regional innovation ecosystems.

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Europe's raw materials challenge is no longer solely geological, technological or permitting-related. It is increasingly a challenge of workforce availability, industrial deployment capacity and long-term skills development. Recent European evidence demonstrates that these challenges are structural rather than localised. In 2023, only 26.9% of EU tertiary students were enrolled in Science, Technology, Engineering, and Mathematics (STEM) fields, remaining below the Commission's proposed 32% target, while STEM participation has declined in several Member States over the past decade[2]. At the same time, vocational education and training systems already produce nearly half of Europe's STEM graduates, underlining the strategic importance of vocational and applied educational pathways for Europe's future industrial competitiveness[3].

These structural gaps therefore require decisive and long-term European action.

Establish a European Mineral Raw Materials Skills Ecosystem to Secure the Future Workforce Base

Dedicated European-supported educational and workforce-development initiatives are essential to ensure a sustainable workforce pipeline for exploration, mining, mineral processing, metallurgy, refining, recycling, environmental management, permitting, automation, maintenance, monitoring and digitally enabled industrial operations across the raw materials value chain. Particular attention should be given to vocational and applied-engineering competences supporting industrial implementation and operational continuity.

The sector already faces significant labour and competence shortages, which are expected to deepen as Europe accelerates implementation of the CRMA, strategic industrial projects and domestic critical raw materials production. At the same time, STEM participation remains below proposed European targets and has declined in several Member States over the past decade, while vocational education and training systems already produce a substantial share of Europe's STEM graduates. This reinforces the strategic importance of vocational and applied-engineering pathways for Europe's future workforce capacity.

Europe simultaneously faces ageing industrial workforces, increasing replacement demand, growing competition for technically skilled professionals and declining interest in industrial and STEM-related careers among younger generations. European Investment Bank (EIB) analyses and European Raw Materials Academy assessments further indicate that skills shortages are increasingly constraining industrial investment, technological deployment and industrial scaling capacity across European industrial ecosystems[4].

Europe's Raw Materials Workforce Pyramid

The mineral raw materials sector depends on a broad and interconnected workforce ecosystem in which vocational education and training (VET), applied engineering education at universities of applied sciences (UAS), higher education, industrial upskilling and advanced research expertise all play complementary roles. At the upper levels of the workforce pyramid, Master's and doctoral education support scientific

advancement, specialised engineering, frontier innovation and strategic research capacity, remaining essential for Europe's long-term technological leadership.

However, the operational foundation of the sector depends on significantly larger numbers of vocationally trained personnel, technicians and applied-engineering professionals educated through vocational institutions and UASs. These workforce groups support much of the practical industrial implementation required across the raw materials value chain, including industrial operations, maintenance, automation, electrification, environmental management, digital operations and process optimisation.

The workforce structure therefore resembles a skills pyramid in which shortages at any level create bottlenecks for industrial deployment and long-term competitiveness. While highly specialised MSc and doctoral-level expertise remain strategically important, the largest workforce demand increasingly exists at vocational and applied-engineering levels, which form the operational backbone of industrial production, maintenance and deployment of new technologies.

According to the European Centre for the Development of Vocational Training (Cedefop), European labour-market forecasts further indicate particularly strong future demand for science and engineering technicians, electroengineering workers, automation specialists and applied technical professions linked to industrial operations, electrification, maintenance, recycling and circular economy systems. Cedefop projections further suggest that workforce ageing and replacement demand will create substantial long-term recruitment pressures across these occupational groups[5].

Modern vocational and applied-engineering professions increasingly operate in technologically advanced industrial environments requiring competencies related to automation, robotics, AI-assisted systems, remote operations, predictive maintenance, environmental compliance and integrated safety systems. The ongoing digital and green transitions are therefore increasing technical competency requirements across the entire workforce pyramid and challenging outdated perceptions that vocational or operational roles are primarily low-technology occupations.

Educational pathways into the raw materials sector are also becoming increasingly non-linear[6]. European monitoring data indicate that vocational-to-higher-education permeability has expanded significantly across Europe, providing an important foundation for strengthening stackable pathways linking vocational education, applied engineering and higher academic specialisation. In several Member States, the sector increasingly relies on conversion training, industrial reskilling, lifelong learning, workplace-based learning, micro-credentials and professionals transitioning into the sector from adjacent industries.

Future workforce development should therefore be viewed through flexible competence pathways combining formal education, industrial experience, continuous professional development and adaptive lifelong learning. From the perspective of ETP SMR, vocational institutions, UASs, universities, research organisations and industrial partners should increasingly be viewed as interconnected strategic

infrastructures supporting Europe's industrial resilience, sustainability and technological implementation capacity.

Strengthening vocational and applied-engineering education should not be interpreted as reducing the importance of higher academic education and research excellence. On the contrary, Europe's innovation ecosystem ultimately depends on the existence of a sufficiently broad technical and operational workforce capable of implementing, operating and scaling industrial technologies in practice.

Regional Skills Ecosystems and Adaptive Workforce Development

Mining and industrial regions play a particularly important role in securing Europe's future workforce capacity. Regional actors are often best positioned to identify emerging labour-market needs and align educational capacity with industrial development priorities, infrastructure investments and regional innovation strategies. Competence needs within the raw materials sector evolve throughout the lifecycle of industrial projects, from exploration and project planning to construction, operations, automation upgrades, closure and post-closure management.

Regional workforce planning and educational development should therefore incorporate stronger anticipatory approaches capable of identifying future competence gaps and supporting transitions between different industrial lifecycle phases. This is particularly important in regions undergoing rapid industrial transformation linked to critical raw materials, battery value chains, industrial electrification, renewable energy systems and strategic manufacturing.

Future workforce resilience will require stronger integration between industry, universities, UASs, vocational education providers, research organisations and regional authorities. Skills development should therefore be more closely linked to regional industrial priorities, Smart Specialisation Strategies (S3), interregional cooperation platforms such as S3P Mining Regions[7], national raw materials strategies and broader European objectives under the CRMA, the Clean Industrial Deal and the green and digital transitions.

Universities of applied sciences and vocational education providers are especially important for ensuring operational workforce availability in mining and industrial regions. These institutions often maintain close practical cooperation with industry and can respond relatively rapidly to changing labour-market needs through targeted professional training, applied technical education and flexible competence-development models. European evidence further demonstrates that work-based learning and dual-education models significantly improve employment outcomes and labour-market responsiveness, with vocational graduates, who possess substantial workplace-learning experience, often achieving stronger employment outcomes than those without comparable industry exposure[8].

At the same time, Europe faces a structural mismatch between the speed of industrial transformation and the responsiveness of formal educational systems. While educational institutions can often react rapidly

through short courses, micro-credentials and targeted professional training, adapting full degree structures and curricula may require several years due to accreditation, governance and administrative processes. This creates growing pressure for more agile educational cooperation models capable of combining long-term academic education with flexible industrial upskilling, workplace-based learning and rapid competence responses to emerging technological and operational needs.

Closer integration between industry, research organisations and educational institutions is therefore essential to ensure that educational content reflects real industrial needs and evolving operational environments. Pilot environments, industrial demonstrators, testbeds and joint development platforms can provide important mechanisms for accelerating competence transfer between research, innovation and operational deployment while simultaneously improving the attractiveness and practical relevance of raw materials education.

Sustainable development principles should also be integrated throughout the workforce ecosystem and organisational culture. Responsible operations are not delivered solely through management systems or reporting frameworks, but through the everyday actions, communication and operational behaviour of employees at all organisational levels. Strengthening sustainability competence, environmental awareness, safety culture, stakeholder interaction capabilities and responsible operational behaviour across the workforce is therefore essential for improving public trust, societal acceptance and the long-term attractiveness of the sector.

Europe's competitiveness cannot ultimately be strengthened solely through financing instruments and industrial policy frameworks. Competitiveness depends equally on Europe's ability to maintain the workforce, engineering, operational and innovation capacity required to implement strategic industrial objectives in practice.

Sustaining Europe's Long-Term Raw Materials Education Capacity

Within the broader workforce ecosystem, higher education remains strategically important for maintaining Europe's long-term technological and innovation capacity in critical raw materials. Sustainable support for specialised raw materials education programmes must therefore be ensured across all educational levels, including vocational education, applied engineering education and higher academic education.

Several established European programmes operating within the EIT RawMaterials ecosystem and broader European cooperation frameworks have already demonstrated strong European added value by contributing to international competence development, industrial cooperation and cross-border workforce mobility[9]. However, many strategically important educational initiatives continue to rely heavily on short-term project-based funding instruments, particularly within Erasmus+ and temporary programme structures. While these mechanisms have enabled important progress, they do not provide sufficient long-term continuity for maintaining strategically important educational capacity across Europe.

Educational evaluation and funding mechanisms also do not always sufficiently recognise previously demonstrated excellence, industrial relevance, established cooperation networks or long-term workforce impacts when programmes reapply for funding. This may create structural uncertainty even for well-performing programmes that have already established strong European competence ecosystems and industrial partnerships.

From the perspective of ETP SMR, Europe requires **more stable** and **strategically coordinated long-term support mechanisms capable of sustaining educational ecosystems across the entire mineral raw materials value chain**. This includes not only research-intensive university programmes, but also vocational education providers, universities of applied sciences, technical institutes, lifelong learning platforms and industrial reskilling initiatives.

Future workforce development should also be understood as an ecosystem-level challenge rather than solely an institutional one. Europe's ability to secure strategic raw materials value chains increasingly depends on whether educational institutions, industrial actors, regional authorities and innovation ecosystems can evolve together in response to changing technological, environmental and geopolitical conditions.

The growing importance of automation, artificial intelligence, industrial digitalisation and sustainability transformation further increases the **need for continuous competence development throughout professional careers**. Workforce development can therefore no longer rely solely on traditional front-loaded education models completed during early adulthood. Continuous learning, professional adaptation and industrial reskilling are becoming permanent structural requirements across the raw materials sector, reinforcing the importance of flexible educational pathways between vocational education, applied engineering, industrial practice and higher academic specialisation.

From the perspective of Europe's industrial resilience and long-term competitiveness, r**aw materials education and competence development** should therefore be recognised not merely as educational activities, but as **strategic European capacity supporting industrial competitiveness, technological sovereignty, operational resilience and economic security**.

ETP SMR Call for Action 1

To strengthen Europe's long-term industrial resilience, strategic autonomy and mineral raw materials implementation capacity, ETP SMR calls for the **establishment of a coordinated European raw materials skills ecosystem supported through sustained long-term cooperation mechanisms covering vocational education and training, applied engineering education, higher education, lifelong learning and industrial reskilling across the full raw materials value chain.**

ETP SMR calls on the European Commission and Member States to **strengthen vocational, technical and applied-engineering** competences supporting **exploration, mining, mineral processing, metallurgy,**

refining, recycling, industrial digitalisation, automation, environmental management and circular economy systems, recognising that these workforce groups form the operational foundation of Europe's industrial implementation capacity.

Future workforce-development frameworks should support substantially **stronger integration** between **industry, vocational institutions, universities of applied sciences, universities, research organisations and regional innovation ecosystems** to ensure that educational content reflects evolving industrial, technological and societal needs.

ETP SMR further calls for **stronger support for flexible and modular educational pathways**, including lifelong learning, industrial reskilling, conversion training, workplace-based learning and micro-credentials, recognising that educational pathways into the raw materials sector are increasingly non-linear and interdisciplinary.

Improving the attractiveness and visibility of technical, industrial and raw materials-related careers among younger generations should be recognised as a strategic European priority, including stronger communication on the sector's essential role in enabling Europe's green transition, digital transition, energy systems, industrial resilience and technological sovereignty.

ETP SMR further highlights the **importance of pilot and learning environments, industrial demonstrators, testbeds and operational development platforms** as mechanisms for accelerating competence transfer between research, innovation and industrial deployment while simultaneously strengthening workforce development and educational attractiveness.

To **reduce fragmentation and strengthen continuity across Europe's raw materials workforce ecosystem**, ETP SMR calls for stronger long-term coordination between initiatives such as the Raw Materials Academy, Erasmus+, EIT RawMaterials, Just Transition Funds, the Pact for Skills and future European competitiveness and innovation instruments.

ETP SMR also recommends the **development of harmonised European monitoring indicators capable of better capturing vocational, applied-engineering and UAS-level educational pathways relevant to strategic industrial value chains**. Current European statistical systems still provide limited visibility into applied-engineering pathways, UAS-level transitions and applicant-level workforce attractiveness indicators relevant for industrial implementation capacity.

Workforce Capacity and Industrial Competitiveness

ETP SMR emphasises that workforce capacity, technological capability and industrial deployment capacity are fundamentally interconnected. Europe cannot strengthen domestic raw materials production or strategic industrial value chains without simultaneously investing in the workforce, research, innovation and industrial ecosystems required to implement future technologies and operational systems in practice.

The implementation of Europe's strategic industrial objectives will require not only access to raw materials, but also sufficient workforce capacity across mining, processing, refining, recycling, automation, digital operations, environmental management and industrial deployment. Without skilled vocational personnel, technicians, applied-engineering professionals and higher-level experts, Europe risks developing financing, permitting and industrial-policy frameworks without the operational workforce needed to implement them successfully.

The growing geopolitical importance of mineral raw materials further increases the strategic significance of workforce resilience. Dependency risks are linked not only to access to raw materials themselves, but also to shortages in industrial competence, processing capacity, technological deployment capability and operational expertise.

From the perspective of ETP SMR, strengthening **Europe's raw materials workforce ecosystem should therefore be recognised as a strategic policy instrument for reducing dependencies, strengthening industrial competitiveness, supporting regional resilience and securing sustainable European value chains** in the context of the green, digital and defence transitions.

ETP SMR Call for Action 2

To ensure that Europe's strategic raw materials ambitions can be implemented in practice, ETP SMR calls for substantially **stronger and better coordinated European support mechanisms linking workforce development, industrial competitiveness, technological deployment and innovation capacity across the full raw materials value chain.**

ETP SMR emphasises that future **European competitiveness depends not only on scientific excellence and technological breakthroughs, but also on Europe's ability to deploy, operate and scale strategic technologies through a sufficiently skilled industrial workforce**. Workforce development should therefore be recognised not solely as an educational policy issue, but increasingly as a strategic industrial capability essential for Europe's competitiveness, resilience, sustainability and long-term economic security.

ETP SMR calls on the European Commission and Member States to **strengthen long-term coordination between workforce-development instruments, industrial policy frameworks, research and innovation programmes and future European competitiveness mechanisms supporting strategic value chains**. Future European support mechanisms, including Horizon Europe and follow-up programmes, should ensure that workforce development, industrial innovation and regional implementation capacity evolve together across the full raw materials value chain, from exploration to recycling and circular economy systems.

ETP SMR further calls for **stronger integration between educational institutions, research organisations, industrial actors and regional innovation ecosystems through long-term European support frameworks**

rather than fragmented short-term initiatives. Particular attention should be given to strengthening capabilities in mineral processing, metallurgy, refining, recycling, industrial digitalisation, automation and operational deployment, where Europe currently faces both technological and workforce bottlenecks relative to global competitors.

ETP SMR also highlights the **growing importance of vocational, technical and applied-engineering competences in enabling industrial transformation**. Existing European battery-sector initiatives already demonstrate that workforce bottlenecks increasingly emerge at vocational and applied-engineering levels related to manufacturing, electrification, process technologies and industrial scale-up rather than solely within research-intensive disciplines.

The accelerating transition toward AI-assisted industrial systems, automation, remote operations, predictive maintenance and digital-twin-enabled industrial environments further reinforces the **need for multidisciplinary competence combinations** integrating engineering, digitalisation, sustainability, systems thinking and societal interaction capabilities throughout the workforce ecosystem.

ETP SMR stands ready to collaborate with the European Commission, Member States, regions, industrial partners, research organisations and educational institutions in operationalising these priorities and strengthening Europe's future raw materials workforce ecosystem.

Concluding Remarks

Europe's ambitions to strengthen strategic autonomy, industrial resilience and sustainable raw materials value chains will depend not only on policies, financing instruments and technological development, but also on the availability of a sufficiently skilled workforce capable of implementing these objectives in practice.

The raw materials sector is undergoing profound transformation driven by geopolitical pressures, industrial decarbonisation, digitalisation, automation and changing societal expectations. At the same time, Europe faces growing workforce challenges linked to demographic change, declining STEM participation, regional labour shortages and increasing global competition for skilled professionals. Without decisive long-term action, workforce and competence shortages risk becoming a major bottleneck limiting implementation of the CRMA and related industrial strategies.

From the perspective of ETP SMR, **strengthening Europe's workforce ecosystem requires a long-term and systemic approach integrating vocational education and training, applied engineering education, higher education, lifelong learning, industrial reskilling and regional innovation** ecosystems. Particular

attention should be given to **vocational and applied-engineering education capacities**, which form the **operational backbone of Europe's raw materials sector and industrial implementation capability**.

Europe's future competitiveness depends not only on scientific excellence and technological innovation, but equally on the availability of skilled technicians, operators, maintenance personnel and applied-engineering professionals capable of deploying, operating and maintaining increasingly advanced industrial systems. Modern raw materials operations increasingly require combinations of technical, digital, environmental and societal competences, while automation and AI-assisted industrial systems further increase the importance of human expertise, communication, responsibility and multidisciplinary cooperation.

Europe's raw materials workforce ecosystem should therefore be recognised as strategic infrastructure supporting industrial competitiveness, technological sovereignty, economic security and long-term societal resilience.

ETP SMR stands ready to support continued cooperation between the European Commission, Member States, regions, industrial actors, research organisations and educational institutions in strengthening Europe's future raw materials workforce ecosystem and ensuring that Europe possesses the operational and technical capacity required to implement its strategic ambitions successfully.

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