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The Materials Transition Quest

Enabling a sustainable energy transition with carbon-based materials

Sanjay Sharma, Vice President, Chemical Consulting

Bertan Enhos, Executive Director, Chemical Consulting

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Introduction: Unveiling the material transformation in energy transition

The ongoing energy transition is an important global effort aimed at reducing our dependence on fossil fuels and fighting climate change. As we adopt renewable energy sources and electric vehicles (EVs), it is crucial to understand that this transition involves not just the energy itself but also the materials that support these advancements.

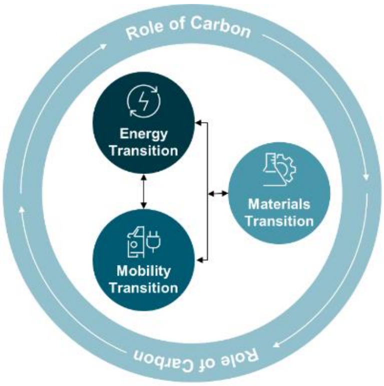
Carbon-based materials: Fueling the future of energy and environmental advancement

Demand for materials, especially carbon-based ones, is increasing as we move away from traditional energy sources to more sustainable options. This creates an interesting paradox: While we aim to reduce oil consumption, the changes in energy and mobility may require more oil-derived materials in various applications to support the transition. As a result, oil demand is expected to remain stable as new materials are developed from petroleum resources, driven by the ongoing shifts in the energy and mobility sectors.

As demand for both traditional and innovative materials continues to rise, the energy transition is giving rise to a significant "materials transition", driven by two primary factors. The first main driver behind the transition is the advancement and manufacturing of new and improved materials that are essential for facilitating the energy transition. This includes critical minerals as well as materials such as engineered polymers and carbon fibers. The second key driver involves shifting from materials characterized by high-energy consumption and emissions to those that are more sustainable, such as low-carbon steel.

Materials play a vital role in reducing energy consumption, optimizing resource use and lowering emissions as we strive for net-zero greenhouse gas (GHG) emissions. They are essential for building wind turbines, solar panels, storage systems, various modes of transportation and the infrastructure needed to cut emissions. Notably, these technologies often require a greater quantity of physical materials to deliver the same energy output compared to traditional options, especially during the construction phase. This reality calls for a thoughtful approach to sourcing and utilizing materials as we progress in our energy transition journey.

Figure 1 The carbon connection: Enabling energy and mobility transitions through materials



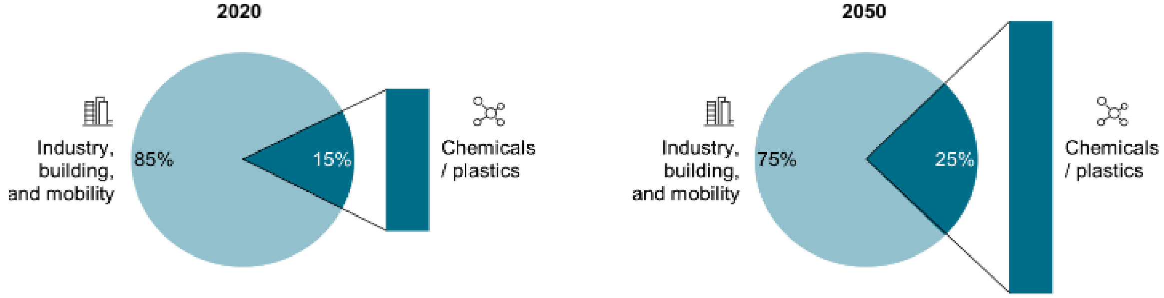
Data compiled Q4, 2024.
Source: S&P Global Commodity Insights.

The chemical industry plays a crucial role in the energy transition, despite its reputation for emissions and negative environmental impacts. While renewable energy and EV sectors enjoy a positive public perception, the materials that support these advancements — primarily sourced from the chemical sector — are often overlooked.

As the world accelerates toward a sustainable future, demand for carbon-based materials is rising, making it imperative to spotlight the chemical industry's vital role in this transformation. Projections indicate that the share of chemicals derived from hydrocarbons could increase significantly, potentially rising from 15% to 25% of the energy mix.

This shift highlights the need for innovative approaches to analyze and communicate the dynamics, emphasizing the critical role of materials within the broader framework of the energy transition.

Figure 2 Increasing share of energy demand by end use

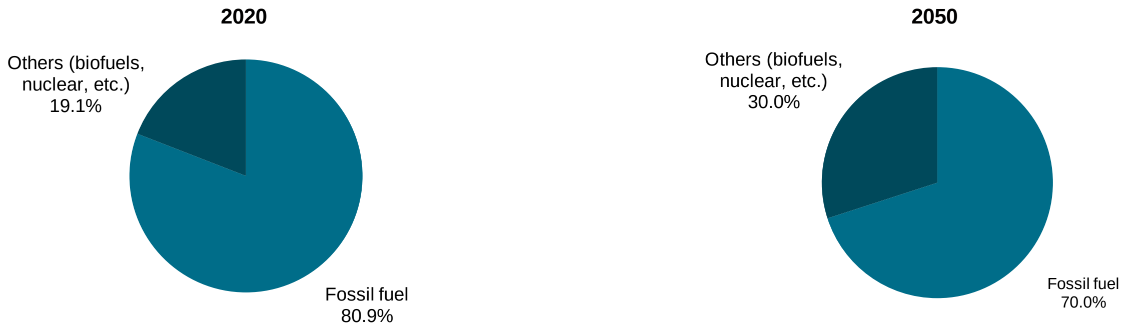


Data compiled Q4, 2024.
Chart is based on S&P Global Commodity Insights Base Case; The energy transition (ET) sectors include mobility, construction and renewable energy.
Source: S&P Global Commodity Insights.

As we look into the future, it is clear that fossil fuels will remain a significant component of our energy landscape, albeit with a shift toward a lighter mix that favors natural gas over oil.

This transition demands a more sophisticated understanding of how hydrocarbons can be employed sustainably, particularly within the chemical sector. By emphasizing the growing demand for carbon-based materials and the indispensable role of the chemical industry, we can cultivate a more balanced narrative that acknowledges both the challenges and contributions of this sector in the ongoing energy transition.

Figure 3 Share of fossil fuels in global energy supply is decreasing, yet their usage is expected to persist



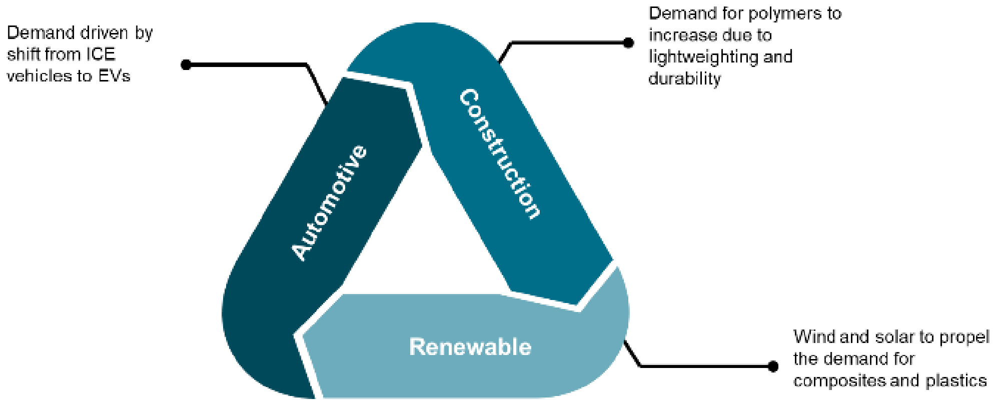
Data compiled Q4, 2024.
Source: S&P Global Commodity Insights.

Fossil fuels, such as oil, natural gas and coal, are expected to remain a significant part of the global energy system through 2050, though their role will gradually diminish. By that time, they are projected to meet approximately 60% to 70% of global energy demand. The fossil fuel mix is anticipated to continue serving as the primary source of energy in the future.

Fueling transformation: How automotive, construction and renewable energy drive demand

In the changing energy landscape, three sectors emerge as key demand drivers: automotive, construction and renewable energy. Each of these industries is experiencing significant transformations that require a strong supply of materials, especially petrochemical products and carbon-based composites.

Figure 4 Powering change: Automotive, construction and renewable sectors at the forefront of the energy transition



Data compiled Q4, 2024.
Source: S&P Global Commodity Insights.
EV = electric vehicle; ICE = internal combustion engine.

The S&P Global Commodity Insights scenarios examined in this analysis include the Base Case, known as the Inflection scenario, which describes a gradual energy transition; the aggressive energy transition case, called Green Rules, which anticipates a swift move toward sustainability and lower carbon emissions; and the Net-Zero scenario, which targets achieving net-zero emissions by 2050.

For instance, in the power generation sector, wind power exemplifies the role and potential growth of carbon-based materials. By 2050, demand for these materials is projected to increase more than fivefold compared to 2023 under the Net-Zero scenario.

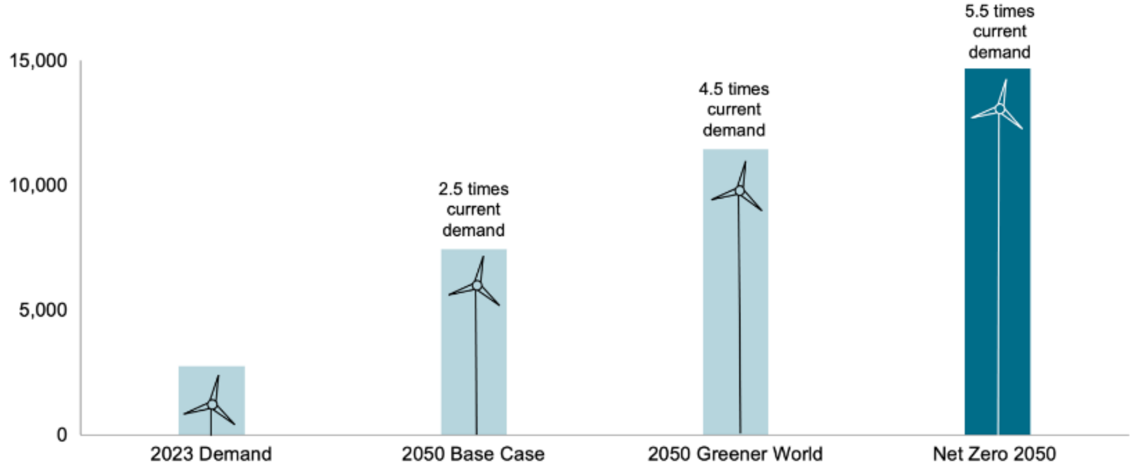
In the three key industries, demand for essential chemicals is set to rise significantly by 2050, with even greater increases projected in a "Greener World" scenario compared to the baseline.

In the automotive sector, whether following the baseline or the greener world scenarios, the long-term demand for polymers will be driven by the shift from internal combustion engine (ICE) vehicles to electric vehicles (EVs) and the overall trend toward lightweighting.

In construction, virgin polymer consumption is anticipated to double by 2050, even in a greener scenario, where the impact of circularity is more pronounced compared to the baseline.

Meanwhile, in renewable power, as per the “Greener World” scenario, the expansion of wind and solar infrastructure is expected to propel demand for plastics and composites to potentially three times the current consumption levels in the sector.

Figure 5 Carbon-based materials required for wind turbines (thousand tons)

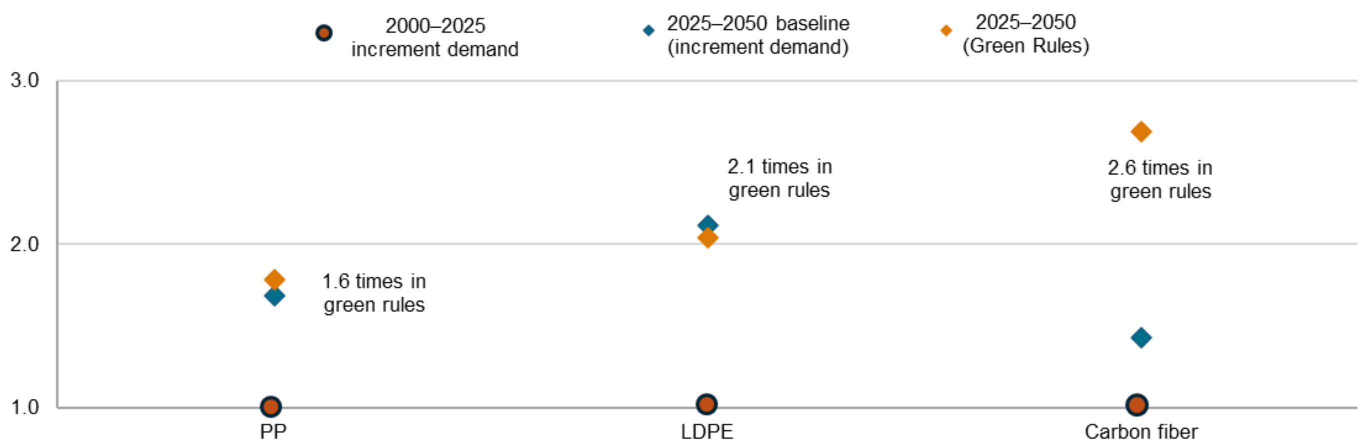


Data compiled Q4, 2024.
Source: S&P Global Commodity Insights.

The findings from this analysis reveal a significant rise in demand for composites as the world hastens its shift toward greener technologies. In both scenarios, the dependence on materials like plastics and chemicals is projected to increase substantially. These materials are not just functional; they offer vital durability and efficiency in applications that are crucial to the automotive, construction, and renewable energy sectors.

For example, plastics typically exhibit a higher or similar emissions intensity compared to steel, with emissions of 2 kg CO_2e per ton for plastics compared to 1.4-2 kg CO_2e per ton for steel during production. However, materials such as polypropylene are significantly lighter than steel, often requiring less material for various lightweight applications. Consequently, replacing steel with polypropylene in the automotive industry for lightweighting can lead to substantial enhancements in fuel efficiency and a reduction in GHG emissions during vehicle operation.

Figure 6 Demand for petrochemicals to surge in the next 25 years



Data compiled Q4,2024.
LDPE = low-density polyethylene; PP = polypropylene.
Source: S&P Global Commodity Insights.

The above figure depicts the demand increment for polypropylene (PP), low-density polyethylene (LDPE) and carbon fiber in the green rules scenario.

Durability: Paving the way for tomorrow

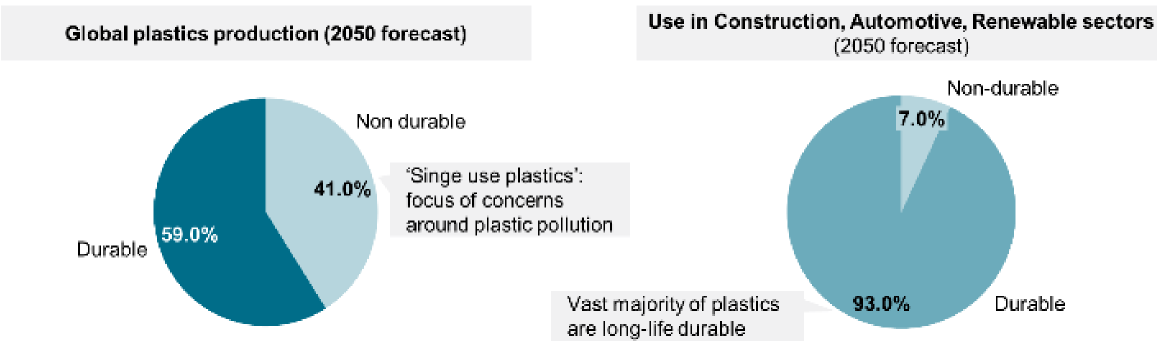
Durability is becoming a crucial aspect of sustainability in the automotive, construction and renewable energy sectors, largely due to the widespread use of plastics and carbon-based materials. These materials are engineered for longevity, often remaining effective for 20 to 30 years across various applications. This extended life span enables them to function as carbon sinks throughout their life cycle, effectively capturing carbon and helping to reduce overall greenhouse gas emissions.

In the automotive industry, for example, lightweight composites improve fuel efficiency and decrease total emissions throughout a vehicle's life span. Consequently, the use of durable materials not only facilitates the energy transition but also aligns with wider sustainability objectives. In construction, durable materials play a crucial role in extending the life span of buildings, minimizing the need for frequent replacements and the associated waste. This strategy not only conserves resources but also promotes a more sustainable built environment.

As previously noted, carbon-based materials such as plastics, resins and composites are vital in driving the energy and mobility transitions. However, public discussions and regulations have largely focused on the challenges posed by plastic waste and its environmental consequences. It is important to distinguish between single-use plastics, which must be urgently phased out, and other types of plastics. Currently, about 59% of polymers globally are converted into durable products — long-lasting materials that can make a significant contribution to sustainable solutions.

Examples of products that incorporate durable, carbon-based components include wind turbines, batteries, electric vehicles and pipes for hydrogen transportation. By 2050, it is projected that 93% of plastics in key sectors will be durable. Embracing durable materials in these critical areas not only aids in the ongoing energy transition but also promotes a more sustainable future by minimizing waste and encouraging responsible resource utilization.

Figure 7 Durable plastics will drive material transition



Data compiled Q4, 2024.
Sources: Plastics Europe; S&P Global Commodity Insights.

Substitution's impact: Understanding Scope 4 emissions

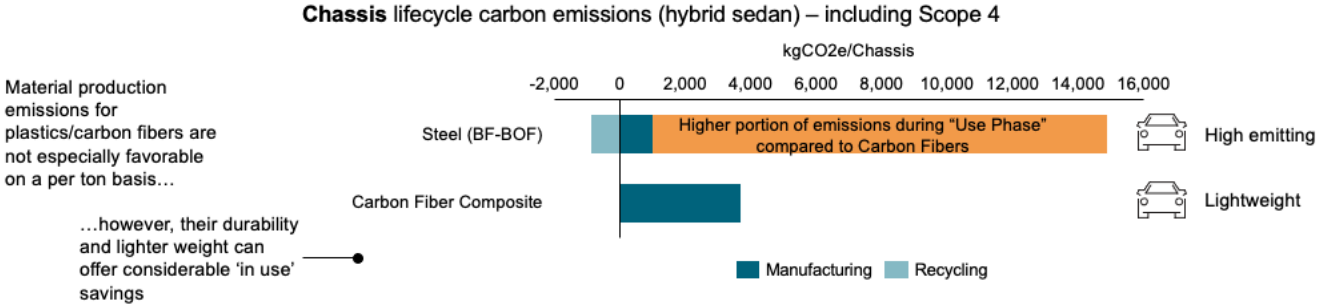
Material substitution is crucial in the discussion of emissions and sustainability. Carbon-based materials, like carbon fibers, typically have lower emissions throughout their life span, even though they may have higher emissions during initial production. For instance, carbon fiber chassis for internal combustion engine (ICE) vehicles may produce more emissions during manufacturing than traditional steel, but their lighter weight and durability lead to significant emissions reductions during operation, highlighting the importance of a life-cycle perspective.

In this context, understanding emissions scope, particularly Scope 4, which refers to avoided emissions during a product's use, is essential. A comprehensive life-cycle analysis (LCA) allows stakeholders to assess the full environmental impact of material choices, factoring in both production emissions and operational savings.

The core takeaway is the significant impact of material substitution when considering Scope 4 emissions. By acknowledging the emissions saved through the use of more efficient and durable materials, we can truly grasp the vital role that innovative solutions play in advancing sustainability.

Figure 8 Chassis life-cycle carbon emissions (hybrid sedan), including Scope 4 (avoided) emissions (kg CO_2e/chassis)

Plastics and composites enable the lightweighting of vehicle components, leading to fuel savings during the use phase in automotive vehicles; this results in lower life-cycle emissions compared to conventional steel components



Data compiled Q4, 2024.

1. BF-BOF stands for Blast Furnace-Basic Oxygen Furnace, a conventional steelmaking process where iron ore is reduced to molten iron in a blast furnace and then refined into steel using oxygen in a basic oxygen furnace.
2. Carbon fiber composite includes 50% of epoxy/ester.
3. 'Use of Product' emissions are based on a relative assessment.

Source: S&P Global Commodity Insights.

While carbon fibers have a much higher emissions intensity than steel, as illustrated in the figure above, the overall life-cycle comparison tells a different story. An automobile with a carbon fiber chassis emits significantly less than one with a steel chassis. This stark contrast highlights the importance of evaluating materials through their entire life cycle.

For instance, the replacement of metal or steel in chassis and monocoque with carbon fiber, which is stronger and lighter. The BMW i3 and advanced sports cars have used carbon fiber for these components, where safety is paramount. Carbon fiber helps in overall vehicle weight reduction, improving the vehicle's mileage. It leads to a much lower carbon footprint during the vehicle's life cycle (use phase).

This illustrates how chemical-based materials contribute to emissions reduction through Scope 4 emissions, highlighting their overall life-cycle impact.

Unlocking value: Carbon, a catalyst for new value chain opportunities

In the context of the energy transition, carbon-based materials are not merely a burden but a valuable resource that can enable new value chains. These materials can serve as carbon sinks, contributing to sustainability efforts while supporting the development of advanced technologies. Rather than focusing solely on decarbonizing industries, we must emphasize the need to decarbonize emissions associated with material production and use. The lessons learned from our transition journey suggest that incorporating more carbon-based materials into energy transition initiatives can lead to a reduction in overall carbon emissions. By adopting a holistic approach that values carbon as a resource, we can create a more sustainable future.

Automotive industry: Abating material emissions is the next focus

The automotive industry plays a vital role in reaching net-zero global emissions by 2050, which is essential for keeping global warming within 1.5 degrees C above preindustrial levels. In response to this challenge, numerous original equipment manufacturers (OEMs) are establishing ambitious decarbonization goals.

Given that 65%-80% of an automobile's emissions come from tailpipe emissions, along with additional indirect emissions from fuel supply, the automotive industry has rightly concentrated on electrifying powertrains. However, to fully realize the potential for automotive decarbonization and attain the goal of a zero-carbon vehicle, industry stakeholders must now also focus on addressing material emissions. New solutions for energy and mobility transitions require more carbon than conventional technologies. For instance, electric vehicles (EVs) require more lightweight materials for fuel efficiency, and larger wind blades can be built with high-performance carbon-based materials that can generate more power.

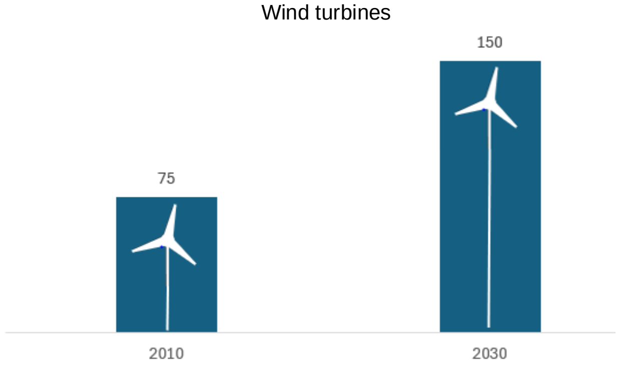
Focusing on decarbonizing material emissions: A shift in industry priorities

Materials will be essential in decarbonization efforts and the electrification of the economy as we shift from fossil fuels to renewable energy sources such as wind and solar power, along with battery- and fuel-cell-based EVs and hydrogen production. Just as there are multiple pathways for the global economy to limit warming to 1.5 degrees C, various combinations of technologies and raw materials will have distinct implications. Regardless of the chosen decarbonization route, significant shifts in demand are inevitable, transforming the metals and mining sector and creating new value opportunities.

Road transport and power generation have made notable advancements in reducing greenhouse gas (GHG) emissions. However, achieving a low-carbon economy and decreasing emissions intensity in these sectors will require a substantial amount of materials. For example, generating one terawatt-hour of electricity from solar and wind sources may demand 300% and 200% more metals, respectively, compared to a gas-fired power plant, measured on a copper-equivalent basis. This transition still results in a significant reduction in emissions intensity, even when accounting for the emissions associated with material production.

The figure below highlights the increasing demand for materials in wind turbines, emphasizing the significant role that chemicals will play.

Figure 9 Material consumption in wind turbines (metric tons per megawatt)



Data compiled Q4, 2024.
Source: S&P Global Commodity Insights.

Boosting material intensity: The key to cutting emission intensity in low-carbon technologies

When it comes to developing new power generation capacity or manufacturing vehicles, the carbon footprint of each technology hinges on a variety of factors beyond mere material intensity. Emissions are generated throughout the entire life cycle of the technology, from burning fossil fuels for power generation to the electricity consumed by battery EVs.

The choice of materials, such as steel versus aluminum, significantly influences emissions intensity as well. Moreover, even identical materials can exhibit varying carbon footprints depending on their suppliers, highlighting the importance of sourcing in determining environmental impact. Additionally, each sector has its own unique characteristics; for instance, renewable power sources often operate with lower capacity factors compared to fossil fuels, necessitating greater generation capacity — and consequently, more metals — to produce the same amount of electricity. Understanding these complexities is key to driving meaningful change in our pursuit of a sustainable future.

Conclusion: A balanced perspective on the energy transition

Numerous strategies exist to forge a more sustainable global materials supply system, essential for driving the energy and mobility transitions. Some approaches deliver immediate benefits, while others lay the groundwork for lasting change. From proactive policies and financial sector initiatives to groundbreaking technologies and a commitment to sustainability in product design, these multifaceted strategies are paving the way for a greener future. It is time to harness these innovative solutions and transform our materials landscape, ensuring it not only meets today's demands but also supports a sustainable tomorrow.

Valuable resource perspective: Carbon-based materials should be viewed as valuable resources that can enable new value chains, rather than as burdens on the environment. This shift in perspective is crucial for promoting sustainability and innovation in various sectors.

Role as carbon sinks: The durability and longevity of carbon-based materials allow them to act as effective carbon sinks, contributing positively to sustainability efforts while supporting the development of advanced technologies.

One planet, two realities: Realizing energy transition in emerging economies: The growth of carbon-based materials and their applications may be undermined by the demand centers of the emerging economies. Addressing the specific needs and challenges faced by these regions is essential for fostering equitable growth and ensuring that the benefits of carbon-based materials are realized globally. Understanding challenges in these economies will be key to navigating and charting a successful energy transition. International cooperation and support are essential to unlock the full potential of developing countries in tackling climate change to meet Paris Agreement climate goals.

New technological advancements: We are beginning to observe an expanding role for carbon materials beyond traditional plastics, venturing into a wide range of advanced applications. Second-generation carbon fibers (2GCF), a new class made from carbon nanotubes (CNT), offer improved electrical and thermal conductivity, potentially transforming the industry. As a result of their importance in facilitating this transition, the global market for conventional carbon fibers is experiencing double-digit growth.

Similar to 2GCF and CNT, graphene is an emerging high-performance form of carbon that is gaining popularity in various applications. Technologies currently being developed for large-scale CNT production could also be adapted for graphene, which would help reduce production costs and make graphene more accessible for a broader range of applications as it becomes more affordable.

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CONTACTS

Europe, Middle East, Africa: +44 (0) 203 367 0681
Americas: +1 800 332 6077
Asia-Pacific: +60 4 296 1125

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