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Editorial: Green materials, a growing science and industry!

Dr Sylvain Caillol, Editor in Chief

The chemical industry is the industry of industries, upstream of all other industries. And green chemistry will lead to transforming this chemical industry into a green chemical industry, the industry of all the future transformations of industry. These transformations obviously affect the manufacturing of materials, but also the production of energy, the purification of water and the production of food. What are the current trends in these green materials? The global market was valued at \$111.2 billion in 2022 and is expected to reach \$282.9 billion by 2032¹. The green chemicals and materials market is deeply linked to various industrial applications, with emphasis on the use of environmentally friendly and less harmful products compared to their petroleum-based counterparts. This sector is experiencing substantial growth due to increasing focus on sustainability, government regulations and increasing consumer awareness. At the same time, a new policy report² shows that prices of many materials – including aluminum and copper – have reached record levels, driven by the fallout from the Covid-19 pandemic, trade tensions and ongoing consequences of Russia's invasion of Ukraine. Thus, while production and trade of the most critical raw materials have expanded rapidly over the past decade, growth is not keeping pace with the expected pace of demand for the metals and minerals needed to transform the global economy dominated by fossil fuels to an economy dominated by renewable energy. Thus, lithium, rare earths, chromium, arsenic, cobalt, titanium, selenium and magnesium recorded the largest increases in production volume – ranging from 33% for magnesium to 208% for lithium² – over the last decade, but this is still a far cry from the four- to six-fold increase in demand predicted for the green transition. At the same time, global production of some key raw materials, such as lead, natural graphite, zinc, precious metal ores and concentrates, and tin, has actually declined over the past decade. “The challenge of achieving net zero CO₂ emissions will require a significant increase in the production and international trade of critical raw materials,” said OECD Secretary-General Mathias Cormann². Policymakers need to take a close look at how the concentration of production and trade, coupled with the increasing use of export restrictions, is affecting international markets for critical raw materials. We must ensure that material shortages do not prevent us from meeting our climate change commitments. Furthermore, export restrictions on critical raw materials have increased fivefold since the OECD began collecting data in 2009, with 10% of global exports of critical raw materials now facing at least one measure of export restriction. China, India, Argentina, Russia, Vietnam and Kazakhstan imposed the greatest number of new export restrictions over the period 2009–2020 for critical raw materials, and also account for the highest dependence on imports from OECD countries. The OECD believes that the trend of increasing export restrictions could play a role in major international markets, with potentially significant effects on the availability and prices of these materials.

This transition will also be within the reach of Africa, which has crucial resources and is developing technologies for the future. Indeed, while the world is witnessing a gradual easing of inflationary pressures, Morocco is seizing new opportunities, with the aim of strengthening the recovery and resilience of the national economy, declared King Mohammed VI³. The new plan is in line with instructions from King Mohammed VI relating to the need for a faster transition to a carbon-neutral economy. The OCP Group, a major fertilizer producer and main exporter of phosphate fertilizers, has been striving for years to increase investments in green energy production and carbon-neutral projects. The new strategy aligns with directives from King Mohammed VI aimed at accelerating the transition to a carbon-neutral economy. OCP Group is working diligently to increase investments in environmentally friendly energy production and carbon-neutral initiatives. The OCP Group relies on the research and development capabilities of the Mohammed VI Polytechnic University (UM6P) to

seize technological opportunities and optimize production. One of the main objectives of the plan is to improve fertilizer production capacity while achieving carbon neutrality before 2040 through increased use of renewable energy. The OCP Group is targeting massive investments in solar and wind energy to power its industrial facilities by 2027. In addition, green energy will be used to power new seawater desalination capacities, meeting the water needs of the group and supporting the surrounding areas with drinking water and irrigation water. The plan also calls for reducing OCP's dependence on imported ammonia, a critical component in fertilizer manufacturing, by switching to green hydrogen to meet ammonia needs.

With these aspects in mind, this issue of *Green Materials* follows the principles of green chemistry, particularly with the use of renewable resources, the substitution of harmful chemicals and an environmentally driven approach.

The underlying idea of the study reported in first paper⁴ concerns the reduction of wastes generated by pressure-sensitive adhesives (PSAs). PSAs are a kind of viscoelastic material with the viscous properties of liquids and the elastic properties of solids that can adhere to the surfaces of various substrates only under light pressure without phase change. PSAs derived from petroleum-based materials are generally non-biodegradable and disposable; therefore, a large amount of waste is generated from PSA products. Preparation of PSAs using renewable vegetable oil as a raw material is an effective way to reduce dependence on petrochemical resources and environmental pollution. This paper summarizes the recent progress on vegetable-oil-based PSAs.

Cement is an essential construction ingredient, and the demand for it has increased multifold during the last couple of years due to various construction activities. For the manufacturing of cement, limestone is a key component, which is a major source of carbon dioxide (CO₂) emission. Moreover, municipalities all over the world have long been concerned about the disposal of sewage sludge. Due to increased generation of sewage sludge, urgent alternative solutions are required for sludge disposal, one of which is recycling of waste into construction materials. The second paper⁵ studied production of low carbon dioxide cement containing sewage sludge ash as mineral mixture.

Poly(3-hydroxybutyrate) (PHB) is a well-known member of the polyhydroxyalkanoate family of biopolymers, and it has been extensively investigated as an environmentally benign replacement for petrochemical-based polymers. The practical application of PHB in the biomedical field and in packaging has been limited because of its relatively narrow processing window, high brittleness and low thermal stability. In the third paper⁶, a melt flow extrusion plastometer was used to investigate the processability of PHB by evaluating its melt flow rate and the mechanical properties of its monofilament extrudates. The results of this study will be useful in selecting appropriate conditions for producing PHB-based blends/composites with desirable properties for a wide range of applications.

At present, most carbon fibers are made from non-renewable polyacrylonitrile. Substantial efforts have been made to replace petroleum-based precursors for carbon fiber production. Interestingly, lignin is a carbon fiber precursor material that is cheap, highly available and sustainable. Submicron-scale lignin-based carbon nanofibers are used in numerous areas, such as electronic devices, batteries, supercapacitors and low-cost, high-performance structural composite materials. Trackspinning (TS) technology offers a way to scale-up the versatile, but inefficient contact drawing technique to produce small-diameter lignin fibers from environmentally friendly aqueous solutions. The fourth paper⁷ investigated the effects of TS based on probe drawing of low-concentration lignin nanofibers blended with poly(ethylene oxide) and glycerol in sodium hydroxide (NaOH) solution.

These findings support the potential to utilize TS to produce small-diameter lignin fibers using a simple aqueous solvent approach.

Taken together, the articles in this issue reveal not only the growing attention paid to the use of renewable resources and the substitution of harmful substances, following the trends in society, but also all the interest and promises of this chemistry for the improvement of current materials and the design of new green materials.

¹ Acumen Research and Consulting, Green Chemicals and Materials Market 2023 - 2032", 2023

² OECD, Raw materials critical for the green transition production, international trade and export restriction, OECD trade policy paper, April 2023 n°269

³ Jihane Rahhou, Morocco World News, July 29, 2023

⁴ 10.1680/jgrma.22.00061

⁵ 10.1680/jgrma.21.00004

⁶ 10.1680/jgrma.22.00026

⁷ 10.1680/jgrma.23.00037