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Sustainable carbonaceous raw materials: A contribution to reduce the negative environmental impacts of chemical industry

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ABSTRACT

Chemicals, a class of global commodities, can be divided into inputs and end-use products, what can include a huge number of characteristics and applicability, encompassing organic and inorganic substances. From this perspective, the chemical industry plays a crucial role in most sectors of regional economies, which has led to innovative, life-enhancing products and technologies that not only support the global economy, but also help people live longer, healthier, more sustainable lives. The use of sustainable raw materials for feedstock of this industry as a transition for the circular economy is a challenge and an opportunity. In this way, sustainable carbonaceous materials (i.e., biomass, CO_2, and recyclable materials) can contribute to the reduction of the negative environmental impacts from the chemistry exploitation. This perspective article, based-on scientific literature and market information, deals with an outlook of the chemical industry, the sources of its negative impacts on the environment, the industrial sources of sustainable carbonaceous materials, and the proposal of sustainable feedstocks in order to promote the sustainable development goals of the United Nations in chemistry.

Introduction of the context for the modern chemical industry

Chemicals, a class of global commodities, can be divided into inputs and end-use products, what can include a huge number of characteristics and applicability, encompassing organic and inorganic substances.

A particularity of the chemical industry is that it provides raw materials for almost every industrial sector. Thus, innovations in chemistry trend to spread to several value and production chains [24].

The chemical industry plays a crucial role in most sectors of regional economies [27], which has led to innovative, life-enhancing products and technologies that not only support the global economy, but also the final consumers. Looking at the market scenario, in 2017, the chemical industry contributed USD 5.7 trillion to global Gross Domestic Product (GDP), equivalent to seven percent of the world's GDP.

Regarding the global context of sustainability, the perspectives offered by climate plans as the EU Green Deal [18] and the US Inflation Reaction Action [59] certainly promotes opportunities in chemical industry not only related to energy decarbonization but to new sources of sustainable raw materials, as the possibilities to use CO_2 by the industry (to be treated in this perspective article). And these opportunities and their exploration should be conducted under the sustainable development goals and their actions preconized by the United Nations [60].

The definition of circular economy as the new model of production of consumption involving sharing, reusing, repairing, refurbishing and recycling existing materials and possible as long as possible, implies reducing waste to a minimum [19]. This model must guide the strategies to pursue eco-friendlier industrial processes of transformation.

Negative impacts of the chemical industry on the environment

The chemical industry, as one of the biggest industries in the world, consumes more than 10% of the fossil fuels produced globally and emits an estimated 3.3 gigatons of greenhouse gas emissions a year [34]; moreover, it can be understood as high-carbon intensive.

Lim [34] also observed that the chemicals sector is the largest industrial user of oil and gas and has the third-largest carbon footprint – behind steel and cement – because only about half of the fossil fuels that the industry consumes are burned for their energy. The rest is used as feedstock for products such as plastics with the emissions released only when these products reach the end of their lives, for example, when

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waste plastic is incinerated.

Here, the application of *decarbonization* term for the chemical industry should be seen with skepticism [7], because the chemical industry needs carbon as raw material for carbon-based products, mainly for organic chemicals.

This issue is not recent. For instance, Dutkiewicz et al. [14] observed in the 1990 decade in Europe the magnitude of the emitted to the air dusts and gases, liquid and solid wastes disposal produced by chemical industry, with the discussion of the impact of chemical industry on the environment. They considered some hazardous agents, occurring in the work environment, morbidity and sickness absenteeism rates, noted among employees in chemical industry. From these statements, the public opinion generally sees the chemical industry as one of the main sources of pollution [1], and this image must be changed.

Naidu et al. [42] observed that the global picture of chemical pollution in the environment is often fragmented. From this point of view, they recommended prioritized strategies for curbing chemical dispersal. Despite this information limitation, Cribb [11] estimated the scale of chemical release to be as high as 220 billion tons per year – of which greenhouse emissions constitute 20%. This estimation can comprise, but not limited to, total disposed waste (e.g., e-waste, hazardous waste), synthetic chemicals, food and biomass waste, mining wastes, carbon, among others.

However, we can consider, in theory, the pollution control applied to

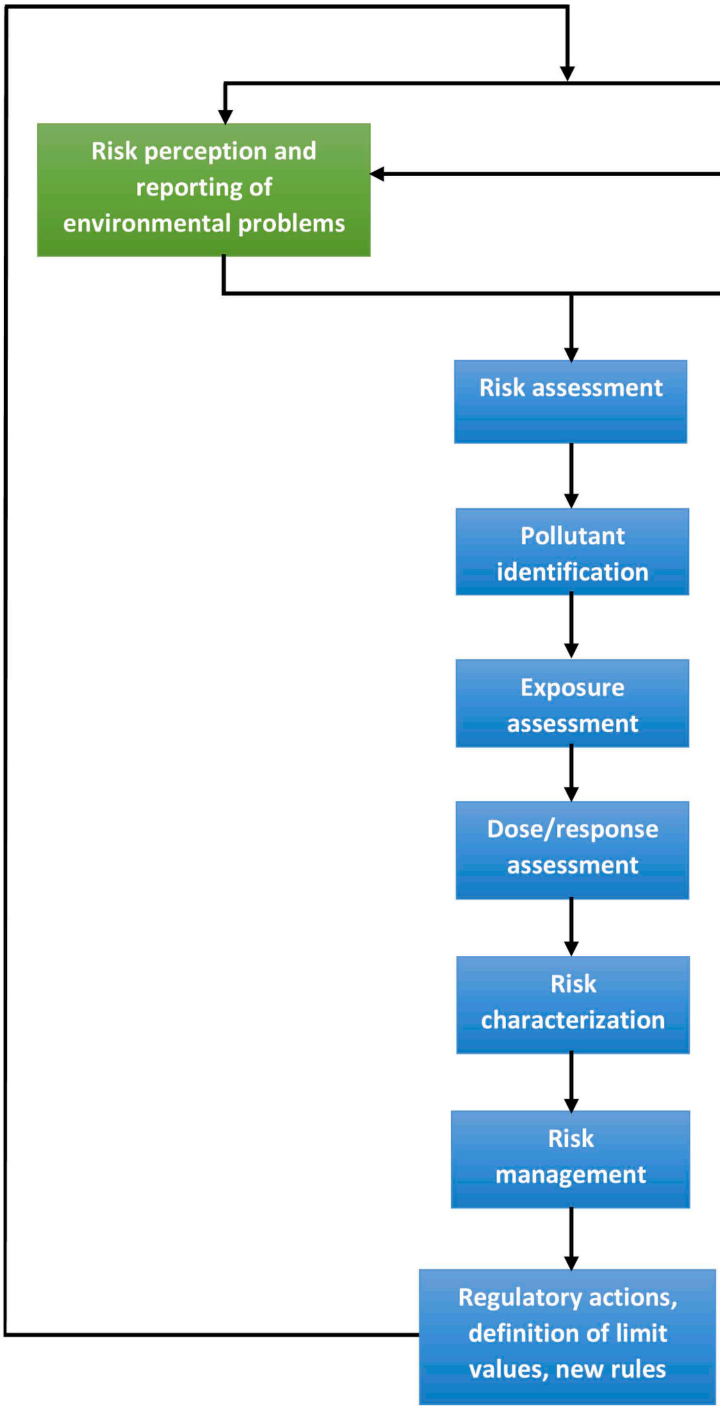

Fig. 1. An environmental risk assessment process for the chemical industry.

the chemical industry by means processes of treatment, reuse, recyclability, etc., which should reduce the quantity of pollutants emitted and dispersed in the environment. In order to proceed to this control, regulation systems as the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) system were created. According to the European Chemical Agency [16], REACH is a European Union regulation adopted to improve the protection of human health and the environment from the risks that may arise from chemicals, at the same time confident to strengthen the competitiveness of the European Union's chemical industry.

The United Nations Educational, Scientific and Cultural Organization [58] sheds light on *emerging pollutants*, which are defined as any synthetic or naturally-occurring chemical or any microorganism that is not commonly monitored or regulated in the environment with potentially known or suspected adverse ecological and human health effects. From this definition the most common emerging pollutants listed are pharmaceuticals, personal care products, pesticides, industrial and household products, metals, surfactants, industrial additives, and solvents. Microplastics – mainly derived from oil - are also a concern by the modern society due their spreading and presence in food chains, especially in humans, with effects not only understood (e.g., suspecting of interfering with endocrine systems) [35]. Obviously, they are derived substances from the chemical industry (i.e., from plastics) and demand special attention with their manufacturing, use and disposal. Fig. 1 depicts a flowchart dedicated to the environmental risk assessment, which can be applied to the chemical industry in order to define priorities for pollution control and treatment.

Regarding petrochemicals, despite their relevance for the global economy, we should consider that they are a potential source of pollution of ecosystems and communities due oil exploration, processing and end-use of their related products [34]. Oil spills pollute soil and water and may cause devastating explosions and fires; it is, generally, the result of accidents at oil wells or on the pipelines, ships, trains, and trucks that move oil from wells to refineries [61]. Regarding human contamination, it is worth to cite the presence of plastic particles (i.e., microplastics and nanoplastics) in leaving organisms with induced cellular toxicity in mammals (Benerjee and Shelver, 2020); moreover, the polyaromatic hydrocarbons (PAHs) are well-recognized cancer lung agents [41]. And this statement reinforces the necessity of substitutes for oil-derivatives.

Industrial sources of the sustainable carbon

Carbon-based materials are, probably, the most dominant class of materials available from nature (i.e., biomass from plants) and from industry (i.e., oil-based substances), with a high impact on modern society due their practical uses and very versatile characteristic for a myriad of applications for a carbon-neutral condition [37]. From these statements, it is desirable a holistic view and understanding of positives and negatives impacts in the environmental sphere, especially for an industrial context.

For a didactical purpose, we can consider as carbonaceous sustainable materials those derived from biomass, carbon dioxide (CO_2) and recyclable materials as sources of raw materials for industrial purposes. Fig. 2 depicts this definition. According to this figure, the sources of carbonaceous materials should supply sustainability – based on environmental, social and economic positive impacts [55] – under the circular economy (previously introduced) model.

Biomass for organic chemicals

For this class of sustainable carbon, we can cite some examples of bio-based products. First, we can highlight the bioplastics — typically plastics manufactured from bio-based polymers — which can contribute

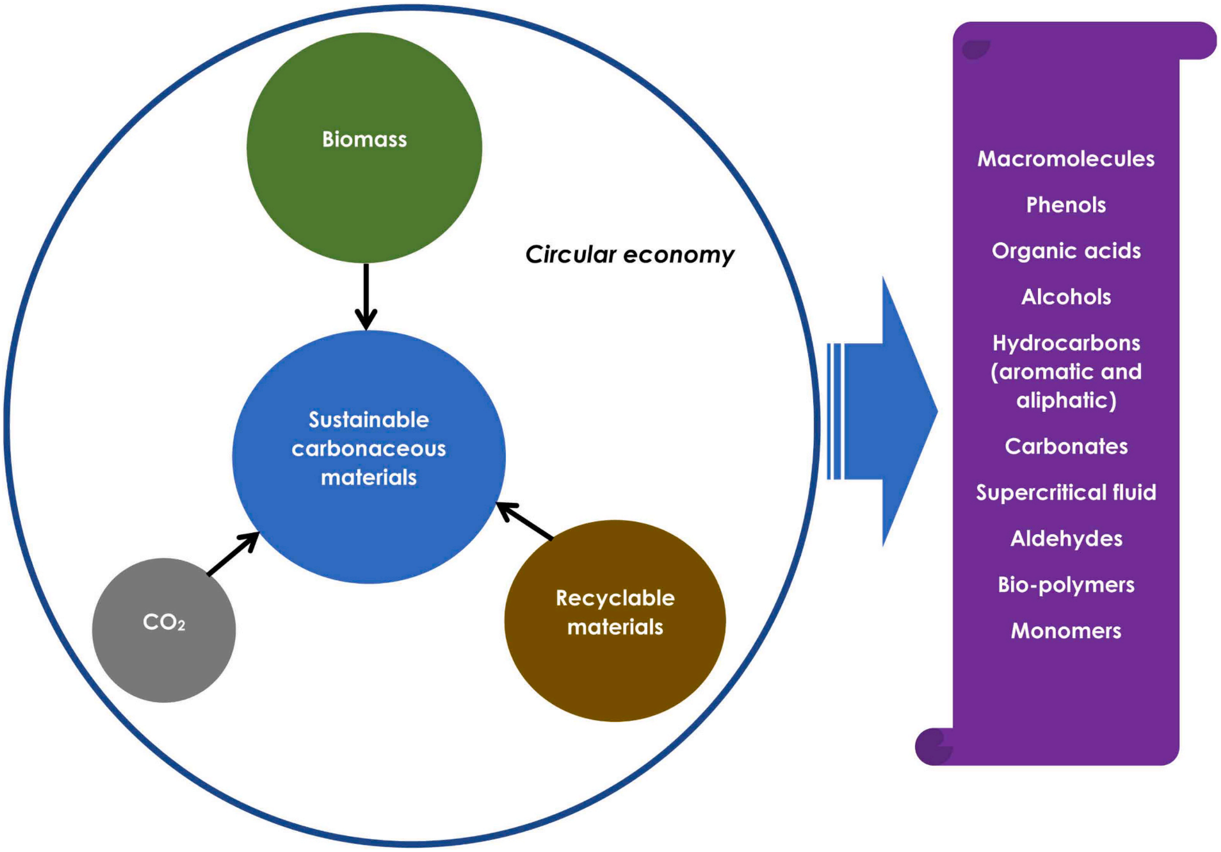

Fig. 2. The definition of sustainable carbonaceous materials (left) and examples of their derived products (right).

to more sustainable commercial plastics as part of a circular economy, in which virgin polymers are made from renewable or recycled raw materials (e.g., a direct replacement for an existing plastic, such as polyethylene (PE), or novel polymers, such as polyhydroxyalkanoates (PHAs)) [49].

The International Energy Agency by means the The IEA Bioenergy Technology Collaboration Programme [57] highlighted as fermentantion innovative products from sugars: itaconic acid, adipic acid, 3-hydroxypropionic acid, aldehyde, isoprene, farnesene, glutamic acid, aspartic acid, 1,4 BDO (1,4-butanediol). And as promising sugar chemical derivatives: levulinic acid, 2,5-furan dicarboxylic acid, mono-ethylene glycol, and methyl vinyl glycolate. Additionally, for lignin products: syngas products, hydrocarbons, phenols, oxidized products, and macromolecules. And promising glycerol derived chemicals: propylene glycol, epichlorohydrin, 1,3-propanediol, 3-hydroxypropionic acid, acrylic acid, and propylene. It is worth to cite that derived molecules from sugars (e.g., ethylene) and lignin (e.g., phenols) can be used as monomers for bio-based plastics. A considerable number of these cited molecule was previously stated by Bozell and Petersen [5] for sugar derivatives and by Ragauskas et al. [48] for lignin derivatives, without remarkable advances in techno-economic aspects from these years of publication until this moment (year of 2023).

From our own experience with the execution of R&D&I projects in biomass fractions (cellulose, hemicellulose and lignin) (Fig. 3), organic acids and alcohols are the most easily obtained by chemical and biochemical conversion routes using C6 and C5 sugars [31,51]; however, it can be expanded to esters and aldehydes [22,51]. For lignins, the use of the macromolecule as carrier for biologically active compounds with or without modifications are the easiest way [28]. For both sugar derivatives and lignin derivatives, we reached the technology readiness level (TRL) [6] at 3 to 6, that means we develop products from laboratory scale to validation and demonstration in relevant environments. Examples of these products are xylitol from D-xylose by catalysis, the development of lignin-based formulation for integrated pest control and the development of a nanocomposite from Kraft lignin and nanocarbonate from CO_2 capture [67,68,69].

Carbon dioxide for organic and inorganic chemicals

Greenhouse gases (GHG), mostly emissions of carbon dioxide (Fig. 4), nitrous oxide and methane, constitutes a global concern due their molecular structure capable of absorbing a certain amount of heat and this capacity configures the effect of global warming, which contribute to, among others, humanitarian emergencies from heatwaves, wildfires, floods, tropical storms and hurricanes with an increasing in scale, frequency and intensity [72]. If the concentration of molecules in these gases is high, the earth's protective blanket is overloaded with heat, causing global warming. Carbon dioxide contributes with 53% to the greenhouse effect (Falci, 2019). Since global warming is a matter of great economic, social and environmental interest, several countries have directed major actions towards mitigating GHG what should involve technologies of carbon capture and use (CCU) for the carbon dioxide molecule [66].

The International Energy Agency by means the The IEA Bioenergy Technology Collaboration Programme [57] highlighted as CO_2-based products: urea, poly(propylene) carbonate, polycarbonate-etherols, formic acid, organic acids, organic carbamates, cyclic carbonates, inorganic carbonates, alcohols, aldehydes, dimethyl ether (DME), and methanol. Moreover, Srivastava and Samanta [52] highlighted the relevance of the several catalytic approaches (i.e., thermocatalytic/photocatalytic/electrocatalytic) in order to reach the conversion of CO_2 to chemicals and fuels.

Again, from our own experience executing R&D&I projects related to CCU, mineral carbonates are the easiest product to be obtained [28].

Fig. 3. Agroindustrial biomass: A) sugarcane bagasse (lignocellulosic biomass); B) corn (starchy biomass); C) sugarcane (saccharide biomass); D) soybean (oleaginous biomass).
(a) Source: adapted from Vaz Jr [64]. (b) Reprinted with permission from Elsevier.

Fig. 4. CO_2 emission chimney at a sugarcane ethanol production plant in the southeast region of Brazil.

Recyclable materials for organic chemicals and materials

Undoubtedly, plastics can be considered the main source of recyclable carbonaceous materials with more than 380 million tons of them are produced worldwide every year. Unfortunately, just 16% of plastic waste is recycled to produce new plastics or to use their monomers for other application (Fig. 5), while 40% is sent to landfill, 25% to incineration and 19% is dumped [33].

Plastics are the pollutant most commonly found in the oceans and terrestrial environments – sometimes as microplastics, an emergent pollutant of environmental concerning [62]. Furthermore, microplastics – plastic pieces with size less than 5 mm – can be observed in soil, surface water and groundwater [73], spreading its pollution potential.

In order to build a bridge between the sustainable sources of carbon and the 12 fundamental principles of green chemistry [26], we can consider: i) designing safer chemicals: chemical products should be designed to affect their desired function while minimizing their toxicity; ii) use of renewable feedstocks: a raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable. Besides, the reuse of these type of carbonaceous raw materials depends on the application of several advanced analytical techniques (e.g., chromatography, spectroscopy, electrochemistry, microscopy, thermal analysis, process analytical technologies, artificial intelligence), which can be explored using the green chemistry principles [65].

Outlook for research & development & innovation related to sustainable carbonaceous materials

An outlook into the R&D&I trends is paramount to construct a future scenario related to the main opportunities for the exploration of renewable carbonaceous materials by the chemical industry, according to the circular economy model.

Firstly, regarding to these trends for biomass for chemicals and materials, Queneau and Han [47] observed as challenges to be overcoming specific catalysts to work in highly oxygenated media, the solvent design (e.g., ionic liquids, deep eutectic solvents) able to dissolve highly bound and polar solids, process engineering able to manage liquid and solid-phase processes associated to target molecules separation, theoretical chemistry and spectroscopy to inform about the reaction mechanisms and the most promising pathways, the development of organic synthesis for building blocks and innovative chemicals. Indeed, Yang et al. [75] corroborate to the relevance of synthetic approaches for biomass-derived carbonaceous materials, highlighting as synthetic strategy the hydrothermal carbonization (HTC) due its energy efficiency and ability to synthesize carbonaceous materials for use in a wide range of applications (e.g., environmental, catalytic, electrical, biological).

Regarding to CO_2 for chemicals and materials, its use considers the capture as the initial step involving biological (e.g., engineered biosystems, enzyme engineering and immobilization), geological (e.g., oil & gas reservoirs, clathrates, minerals), chemical (e.g., carbonization,

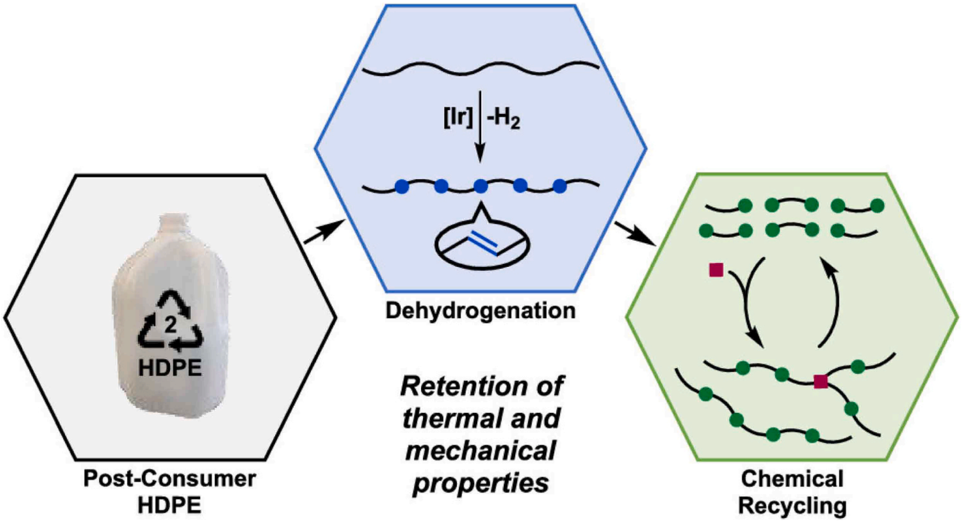

Fig. 5. The chemical recycling approach for post-consumer high-density polyethylene (HDPE).
(a) Source: Arroyave et al. [3]. (b) Reprinted with permission from the American Chemical Society.

mineralization), and material (e.g., adsorption, absorption, membrane separation) technologies [76]. For the industrial usages, Sun et al. [54] proposed the integration of capture and utilization processes by means dual functional materials (DFMs; e.g., 5% Ru,10% CaO/γ-Al_2O_3) for industrially applicable CO_2 hydrogenation, with the interaction between adsorbents and catalysts, promoting industrial advantages such as the reduction of overall cost and the possible post-processing requirements. Furthermore, Park et al. [44] described CO_2 conversion routes utilizing supercritical conditions and dry ice, and electrochemical reactions; these conversion routes can transform CO_2 into carbon materials as graphene for hydrogen adsorbent, supercapacitor and electric material (by dry ice route), porous carbon for Li-ion storage and diamond (by supercritical fluid route), and porous carbon, graphene, carbon nanotube, carbon nanosphere, and carbon nanofibers (by electrochemical route).

Regarding the recyclable materials, Coates and Getzler [10] observed the existence of impediments to the recycling of commodity polymers including separation, impurities and degradation of the macromolecular structures, all of which can negatively affect the properties of recycled materials in order to be reused by the industry; however, an alternative to these technical restrictions is turn back polymers to their monomers by the chemical recycling (e.g., polyolefin thermolysis and nylon 6 ring-closing depolymerization). Xu and Wang [74] observed that chemically recyclable polymers as polyesters, polythioesters, polycarbonates, polyacetals, and polyamides are suitable for polymerization–depolymerization cycle to access chemically recyclable polymers by means the recuperation of their monomers. In this regard, Qin at al. [46] proposed the use of reversible amidation reaction to reach the closed-loop chemical recycling of cross-linked polymers as strong elastomers with a tensile strength of 22.3 MPa and rigid plastics with a yield strength of 38.3 Mpa. Additionally, the application of life cycle assessment to thermochemical processes of chemical recycling should quantify the environmental performances according to the best overall sustainability, as for the hydrogen production by gasification from mixed plastic waste [2].

Thus, we can observe several efforts related to R&D&I in order to turns renewable carbonaceous materials able to be, in fact, explored in a sustainable way by the chemical industry. Moreover, is it possible to prove that the circular economy is not restricted to processes related to the recycling of materials already used by modern society. In addition, it is expected that the conversion processes reach the metrics for greenness, especially those related to life cycle assessment [13], in order to meet a circularity performance for production and value chains [56].

Barriers (technological, economic, societal) to using sustainable carbonaceous raw materials

Bio-based chemicals are widely used as substitutes for fossil fuels. However, many substitutes are produced in small and expensive quantities and do not always provide significant environmental benefits. Some processes for converting carbonaceous feedstocks into sustainable products, such as bioplastics or biofuels, are energy-intensive and represent a technological barrier due to the inefficiency of the conversion processes, slowing the technology adoption. Examples of this barrier for emerging technologies are the fact that fast pyrolysis and gasification still face technical challenges and high implementation costs [32,45], and research is needed to optimize these processes.

The availability of suitable feedstocks can also be a technological barrier, as finding abundant and sustainable sources of carbonaceous feedstocks is a major challenge. The development of bioplastics from biomass, such as corn, requires the reallocation of land that could be used for agriculture to produce plastics instead of food [29]. In addition, the increased use of agricultural land for the production of biofuels and bioplastics could lead to higher food prices, affecting other productive sectors and society as a whole [15]. The production of bioplastics from organic waste rather than dedicated feedstocks could address some of these constraints to the expansion of the bioplastics industry [12].

In terms of economic barriers, high production costs and lack of scale are obstacles to the production of sustainable products from carbonaceous feedstocks. Biorefinery research aims to establish large-scale processes for converting lignocellulosic biomass, such as wheat straw and sugar cane bagasse. These agricultural residues are generally inexpensive, but require additional pretreatment steps to release fermentable cellulose and hemicellulose sugars. Greater efficiency in the production processes present in biorefineries is needed to achieve competitive costs and green chemistry principles, including the use of non-toxic chemicals and lower energy consumption [49].

The article by Rosenboom et al. [49] discusses the stagnation in the recycling of non-fibrous plastics since the 1980 s. Chemical recycling is a process in which the polymer is first depolymerized to recover the monomers, which, after proper separation, can be repolymerized to yield high-value materials. However, these processes are almost always complex and costly, especially in the implementation phase, which requires greater financial incentives [49].

Another economic barrier is the fluctuating price of raw materials, which can affect the viability of processing sustainable products. Recently, the economic sanctions imposed on Russia and the corresponding retaliatory measures have had a significant impact on global markets. The prices of oil, gas and certain agricultural products have risen significantly, creating inflationary pressures and threatening food security in several developing countries. Price increases and scarcity of raw materials have affected various industrial sectors, with strong implications for the transition to a green economy [43].

On the other hand, there are also social barriers related to cultural resistance to the use of sustainable products. Many consumers are still unaware of the benefits of sustainable carbon-based raw materials, making it difficult to change established consumer behaviors and habits. The study by Filho et al. [21] identified consumer attitudes and concerns about the use of bioplastics. The study found that just over half of the participants used bioplastic products on a regular basis, mainly for food packaging and containers, cutlery and toys. Respondents also reported that factors limiting the use of bioplastics include limited access, high cost of the products, and lack of information about their properties, design and quality.

The work of Moshood et al. (2022) describes the presence of social barriers related to regulations and policies that are unfavorable to the use of sustainable carbonaceous feedstocks. The global bioplastics industry lacks structured support policies. There is no international standard to support the use of these materials, with the exception of the single-use bag ban strategy, which has recently received significant attention. As a result, there are problems with the supply, marketing and pricing of raw materials, which puts the biomaterials and bioplastics industry at risk [40].

Efficient waste management by economies requires, for example, the allocation of responsibilities between producers and collectors. The variety of alternative plastics on the market requires precise identification and selection of materials in the recycling process. This separation greatly facilitates the sorting of materials. Therefore, increasing customer awareness of bio-based and biodegradable plastics would definitely have a positive impact on the bioplastics market [53].

Overcoming these barriers will require the combined efforts of governments, industry, researchers, and society at large. Technological development, public awareness and appropriate policies are all essential components in the transition to a more sustainable economy based on carbon-based feedstocks.

Future scenarios

With regard to carbonaceous raw materials, one of the trends highlighted in research [71,4] is their use in two-dimensional structures such as graphene. The global graphene market was valued at $175.9 million in 2022 and is expected to grow at a CAGR of 46.6% between 2023 and

2030. The market is driven by the growth of electronics industry in emerging economies and applications in various segments. The graphene industry is also expected to witness significant growth due to the research and development being conducted by institutes and multinational companies [25].

Another trend is carbon nanotubes, which continue to have potential applications in electronics, nanotechnology, and composites. The carbon nanotubes market size was valued at USD 800 million in 2022 and is expected to grow at a CAGR of more than 19.5% between 2023 and 2032. Increasing global demand for energy will drive the overall business growth. Increasing emphasis on renewable energy sources has led to the adoption of carbon nanotubes on a global scale [23]. With excellent mechanical properties, carbon nanotubes have the potential to revolutionize the construction industry and architecture in the future, although there have been only small-scale applications to date. Verma and Yadav [70] discuss the innovation of nanomaterials and their application in architecture.

The value of the global carbon market reached a record $909 billion in 2022, up 10% from 2021 (Reuters, 2023). The emissions trading system is an instrument that sets a cap on emissions and allocates emission allowances to participating actors. This limits the amount that countries or companies can emit, with the possibility of buying licenses from third parties.

In terms of biomass, the size of the global biorefinery market will reach $135.43 billion in 2022 and could reach $328.04 billion by 2032 (Precedence Research, 2023). The current supply of bio-based chemicals and materials to EU biorefineries was 4.6 million tons in 2019. It is estimated that supply to new or expanding biorefineries could exceed 3.1 million tons by 2030 in a high growth scenario. In a low-growth scenario, supply would be much lower, at around 1.1 million tons [17]. Globally, the high depletion of conventional resources such as natural gas, oil and coal has favored the growth of biorefinery markets (Precedence Research, 2023).

As for recyclable materials, Khalid et al. [30] comment that the transition to a circular economy, where recycling and reuse are relevant, is largely due to the development of high-value materials from recycled materials. This research is being conducted using advanced chemical recycling technologies, such as pyrolysis and hydrogenation, which allow complex plastics and wastes to be reused more efficiently. Unfortunately, there is not a well-established market information for this type of carbonaceous materials in chemical industry.

Sustainable feedstocks for the chemical industry

Especially in the case of biomass components, sustainable raw materials can rise as alternative feedstocks for chemicals and materials derived from oil which meets the principle 7 of green chemistry (use of renewable feedstocks) [26]. In addition, CO_2 can be considered also a renewable feedstock from the green chemistry perspective.

Chemicals, materials, biofuels, among other possibilities of green products, can be obtained by means several technologies based on chemical, biochemical and thermochemical routes applied to convert sustainable raw materials [63], which promote the development of new value chains and leverages sustainable carbonaceous materials.

As an example, aromatic compounds – e.g., benzene, toluene, ethylbenzene and xylenes (BTEX) – can be obtained by means the catalytic cracking of lignin [50] which can be a substitute to oil-derived BTEX although they are toxic and ecotoxic compounds [8]. Second, methane from biogas can be converted into green hydrogen by means catalytic reforming [39].

To increase the possibilities of new chemical technologies towards sustainable chemicals, Cheon et al. [9] proposed the use of CO_2 through photo- and electrochemical processes of conversion to obtain products that can replace fossil fuels as a source of carbon, by means the improvement of product selectivity, reaction rate, and energy efficiency. Lopez et al. [36] proposed new green carbon feedstocks to defossilise the production of large volume organic chemicals; for instance, the electricity-based methanol (e-methanol) and biomass-based methanol (bio-methanol) could contribute to this goal. Furthermore, Fantke et al. [20] proposed the use of digitalization and digital tools to optimize the management of entire chemical life cycles, in order to reach a more sustainable chemical industry, including their feedstocks and end-products; this digitalization process can impact positively, for instance, on the design of chemicals and materials and on the understanding of chemicals-environment-health interactions.

Going in this direction, the application of life cycle analysis (LCA) and its related parameters, e.g., carbon footprint, can boost the market perspectives of new value chains. For instance, this type of assessment for value chains was described by Meiinrenken et al. [38] observing the relevance to reliably quantify carbon emissions.

And from the application of the Sustainable Development Goals of the United Nations [60] to the carbonaceous raw materials and their industrial usages we can establish the follow contributions: i) to the Goal 1 (zero hunger), by means waste recovering and treatment as a way to create new jobs; ii) to the Goal 6 (clean water and sanitation), by means of no generation of wasting water and by means avoiding the release of chemical additives and microplastics; iii) to the Goal 7 (affordable and clean energy), with the use of energy-efficient systems and with the possibility to use biomass as source of renewable electricity; iv) to the Goal 9 (industry, innovation and infrastructure), with the change to renewable and sustainable feedstocks that promote new chemicals and materials allied to green conversion processes; v) to the Goal 12 (responsible consumption and production), with the recycling of materials; and vi) to the goal 13 (climate action), with the direct reduction of CO_2 emission by means carbon capture and use.

Conclusions and perspectives

As easily noted, the chemical industry plays a crucial role in most sectors of regional economies, which has led to innovative, life-enhancing products and technologies that not only support the global economy, but also help people live longer, healthier, more sustainable lives.

The use of sustainable carbonaceous raw materials by the chemical industry can bring a new evolutive step in chemistry related to the circular economy and the green chemistry principles, under the premises of the Sustainable Development Goals. Furthermore, it can establish new value and production chains based on biomass, CO_2 and recyclable materials.

This demand comes from the potential pollution to the environment from chemicals and their manufacturing processes, and should be understood as the opportunity to develop more sustainable products and processes in order to improve the quality of life of the modern society.

Of course, it is not so easy change a fossil-based economy to a sustainable and circular economy, but with global efforts and commitment we can reach this new model of economy.

Ethical statements

Not applicable.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Prof. Dr. Silvio Vaz Jr. reports was provided by Brazilian Agricultural Research Corporation. Prof. Dr. Silvio Vaz Jr. reports a relationship with Brazilian Agricultural Research Corporation that includes: employment. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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