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New perspectives for green and sustainable chemistry and engineering: Approaches from sustainable resource and energy use, management, and transformation

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ABSTRACT

The special volume on green and sustainable chemistry and engineering has fourteen papers that were considered relevant to the present day issues and discussion, such as adequate use of raw materials and efficient energy, besides considering renewable sources for materials and energy; and changing economical canons towards circular economy. Businesses, governments and Society are facing a number of challenges to tread the sustainability path and provide wellbeing for future generations. This special volume relevance provides discussions and contributions to foster that desirable future. Chemicals are ubiquitous in everyday activities. Their widespread presence provides benefits to societies' wellbeing, but can have some deleterious effects. To counteract such effect, green engineering and sustainable assessment in industrial processes have been gathering momentum in the last thirty years. Green chemistry, green engineering, eco-efficiency, and sustainability are becoming a necessity for assessing and managing products and processes in the chemical industry. This special volume presents fourteen articles related to sustainable resource and energy use (five articles), circular economy (one article), cleaner production and sustainable process assessment (five article), and innovation in chemical products (three articles). Green and sustainable chemistry, as well as sustainable chemical engineering and renewable energy sources are required to foster and consolidate a transition towards more sustainable societies. This special volume present current trends in chemistry and chemical engineering, such as sustainable resource and energy use, circular economy, cleaner production and sustainable process assessment, and innovation in chemical products. This special volume provides insights in this direction and complementing other efforts towards such transition.

1. Introduction

This special volume on green and sustainable chemistry and engineering addresses the adequate use of raw materials and the relevance to use in an efficient energy; the discussion and analysis to consider renewable sources for materials and energy in the

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chemical industry is considered; the recent importance for changing economical canons towards circular economy will be commented, finally innovation in chemicals shall be discussed, specifically in this case about ionic liquids.

Chemicals are ubiquitous in everyday activities. The chemical industry has generated considerable wealth and economic growth during the last two centuries (Arora et al., 1998). The Centre for Industry from the University of York reported, for 2013 and 2014, total sales of chemicals of 3.57 and 3.56×10^{12} US dollars for 2011 and 2014 respectively; located in China, Europe, rest of Asia and North America, these regions represent 82.3% and 76.5% of total sales for 2011 as given in Lozano et al. (2016); and the more recent data of 2014 in Healthon (2015). While the top 50 worldwide chemical companies had sales of 961 and 775×10^9 US dollars in 2014 and 2015 respectively; though there is a sales decrease of 10.8%, profits actually increased for 2015 with a value of 96.7×10^9 US dollars representing an increment of 15.1% (Tullo, 2015).

The widespread presence of chemicals provides benefits to societies' wellbeing, but can also have some deleterious effects. The industry has produced new materials that have helped Society enjoying a better life quality, such as better fuels, pharmaceutical drugs, plastic polymers, silicon wafers for microcircuits; but also there has been toxic dispersion such as mercury, pesticides, plastics dumping, chlorofluorocarbons that destroy tropospheric ozone, to mention a few. To counteract such effects, green engineering and sustainable assessment in industrial processes have been gathering momentum in the last thirty years. The European Chemical Industry Council (CEFIC) made a clear commitment towards sustainability across the value chain and the World Business Council for Sustainable Development (WBCSD) has a specific project first addressing the Life cycle metrics for chemicals (WBCSD, 2014), the project Chemicals to provide collaboration and harmonisation regarding sustainability measurement (WBCSD, 2015); and including the social dimension where the social impact for chemicals is taken into account (WBCSD, 2016).

Innovation in the chemical industry has been a foundation for its evolution highlighted in the centennial anniversary of the American Institute of Chemical Engineers a list of 100 market innovations related to chemicals (Chemical Engineering Progress, 2008). A comprehensive and detailed account for the evolution of the international chemical industry, based on scientific breakthroughs during the 19th century and continuing with innovation in the 20th century, is presented by Aftalion (2001). There have been many examples of such innovations, such as in the energy, chemicals, and process sectors (including thermal cracking of heavy oil to produce gasoline, synthetic jet engine lubricants, high energy lithium batteries, anaerobic bioreactors for cleaning up wastewater in the production of terephthalic acid), and in products (e.g. Teflon and polycarbonates). Such innovations have also been fostered by political, social, and public policy support (Horstmeyer, 1998).

Green chemistry, green engineering, eco-efficiency, and sustainability are becoming a necessity for assessing and managing products and processes in the chemical industry, as well as contributing to more sustainable societies. In brief, for the purposes of this introduction: green chemistry can be used as a basis for assessing chemical processes in their early conceptual and design stages (Anastas and Warner, 1998); green engineering can help in selecting appropriate chemical processes that can help modulate decision making (Anastas and Zimmerman, 2003); while eco-efficiency can help evaluate environmental and economic issues for goods and services in businesses (OECD, 1998; Verfaillie, 2000).

There are numerous examples of application of the deliberate drive to measure progress towards more sustainable chemical processes. The Institute of Chemical Engineers from the United Kingdom has a set of sustainability metrics for assessing a process (IChemE, 2002). The chemical company BASF has presented the method used to assess Eco-efficiency within the company (Saling et al., 2002), also published a detailed account for the protocol validating the Eco-efficiency analysis (Bradlee et al., 2009); and complementing economic and environmental dimensions, they have introduced and used SEEBALANCE® that includes the social dimensions to assess processes and products (BASF, 2015). A similar concept, cleaner production, has been used in preventing leaks and redesigning processes based on resources efficiency (UNIDO, 2017).

The progress on reducing the footprint of the chemical industry has been in areas that are key to the production of chemicals and their sustainability: sustainable energy and resources, circular economy, cleaner production and sustainable process assessment, and innovation in chemical products.

An important element for the chemical industry is its energy use. Energy is a key a factor for production, in the same terms as capital and labor. Oil, Coal, and Natural gas consumption for 2015 (BP, 2016) was 11,306 million metric tonnes of oil equivalent, far larger than iron ore and grains for food. In 2015 worldwide consumption of fossil fuels was 11,306 million tonnes oil equivalent (which includes oil, natural gas, and coal) (BP, 2016), which corresponds to 245 million barrels of oil equivalent per day.

Energy has also been linked to economic growth, through fossil fuels since the 18th century, particularly through their substitution of human and animal labour (Ayres and van den Bergh, 2005). Energy inputs, as represented by "useful work", meaning the product of energy by conversion efficiency, have promoted development from the onset of the first industrial revolution to the present.

Some of the fossil fuels are inextricably linked in their manufacture to chemical processing, where a paradigm change is needed related to green and sustainable chemistry. Worldwide chemical markets and economies rely on large materials flows, where energy is embodied (Laitner, 2013). According to Ayres et al. (2009) though energy is a small fraction of GDP, is a very important factor of production and the way our present economies function, without energy countries' economies would stall. Realising this fact businesses have started to take notice of the issue, the World Business Council for Sustainable Development has considered the present day energy facts to discuss the trends that need to be taken into account (WBCSD et al., 2004). Furthermore a detailed report were several scenarios to study pathways for energy generation, to achieve the IPCC (Intergovernmental Panel on Climate Change) carbon dioxide levels are presented by (WBCSD et al., 2005) with a combination of various energy technologies. Shutting down the material flow of fossil fuels would bring World economies to a standstill. In this regard energy efficiency forms part of the path towards a low-carbon economy. Considering the commitment to extract as much as possible usable energy from fossil fuels becomes a necessity and can be considered as a mandate.

The European Commission (2011), in its Roadmap to a Resource Efficient Europe, asked to have proper and efficient use of resources, as well as consideration of sustainable production and consumption. For example, the European Union Ecodesign Directive set requirements for energy-related products and according to (Dalhammar et al., 2014) takes into consideration resource efficiency, they analyse advantages and disadvantages when applying the directive, as well as providing recommendations for future actions. The European Ecodesign Directive emphasises the focus on