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Bioeconomy and chemistry

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ABSTRACT

This article explores how bioeconomy can affect the chemical industry. Bioeconomy brings opportunities and challenges for the industry. The trend of using less fossil resources both as feedstock and as energy sources poses a major challenge for the current industrial activities. This context of increasing challenges also opens a large spectrum of opportunities for new research and innovation agenda. The article discusses these challenges and opportunities from the perspective of four key dimensions: feedstocks, technologies, products and business models. Bioeconomy can bring new market opportunities for the chemical industry and at the same time requesting the sector to renew its competences.

INTRODUCTION

Bioeconomy should be seen at the same time as an opportunity and a threat to the chemical industry. In this article, we explore these two angles considering how bioeconomy can affect the chemical industry under the perspective of technology and business.

The trend of using less fossil resources both as feedstock and as energy sources poses a major challenge for the current industrial activities. Petrochemicals are identified (1) as one of the emissions blind spot to be tackled in the next years. In the coming decades, under the decarbonization of transport sector scenario, the industry is supposed to be the main contributor to the increase in fossil resources consumption. Moreover, plastics, probably an icon of the chemical industry achievements in the last century, are under severe attack leading the incumbents to look for a "new plastics economy" (2)

This context of increasing challenges also opens a large spectrum of opportunities for new research and innovation agenda. The adoption of renewable feedstocks under sustainability and economic drivers is a quite challenging goal which could attract new entrants such as technology-based startups and established firms from various industries such as paper and pulp, food ingredients, agroindustry among others, as new products and new market opportunities are quite significant. On the other hand, these new players may compete with the incumbent chemical companies to supply energy, materials, chemicals, food and feed in a biobased economy. This biobased economy has been termed as bioeconomy.

In the next sections we aim to present the bioeconomy innovation dynamics in order to identify and briefly discuss how the chemical industry can deal with the bioeconomy development.

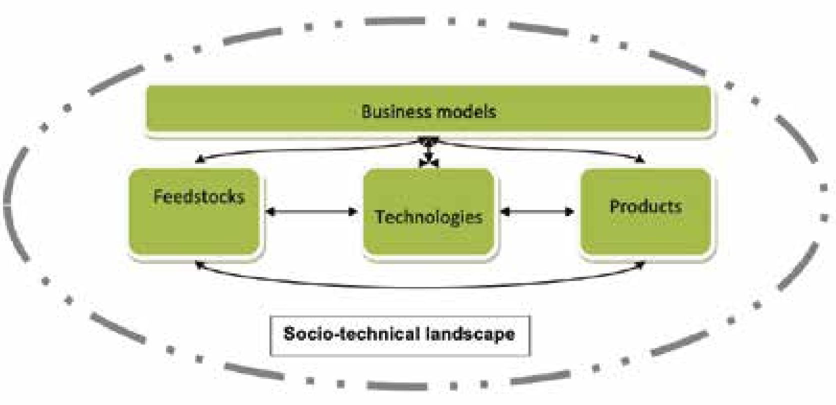

Figure 1. illustrates the innovation dynamics which is central to the bioeconomy evolution.

WHAT IS BIOECONOMY?

In the academic and non-academic literature, there are many definitions for bioeconomy. In this article we assume the European Commission's definition: "The bioeconomy … encompasses *the* ***production of renewable biological resources and the conversion of these resources and waste streams into value added products, such as food, feed, biobased products and bioenergy.*** Its sectors and industries have ***strong innovation potential*** due to their use of a wide range of sciences, enabling industrial technologies, along with local and tacit knowledge" (3). Based on this definition, bioeconomy means the use of **renewable resources** in an **innovative** and **sustainable way.** Therefore, how can we understand the challenges of structuring businesses in the bioeconomy environment?

BIOECONOMY AS A COMPLEX ENVIRONMENT UNDER STRUCTURATION

Competition in the bioeconomy is based on innovation strategies which include not only product and process dimensions but also the ones aimed at shaping new industrial sectors. Since bioeconomy sectors are still emerging and have no defined industrial structure yet, we can see the bioeconomy as an environment under construction (4).

In our previous works on bioeconomy and innovation (4,5,6), we have identified four key dimensions which coevolve in this structuring process: feedstocks, technologies, products and business models. These dimensions are embedded in the macro environment that the transition literature identifies as the socio-technical landscape (7).

Feedstocks, technologies and products are combined in many different business models which represent the way innovating firms try to compete in the bioeconomy environment. In the following sections, we focus on the three basic dimensions – feedstocks, technologies and products - considering the chemical industry perspective.

Feedstock and its structuring role in the chemistry industry
Renewable feedstocks are very challenging to chemistry science and technology developed and used for long period by the chemical industry. After almost a century exploring oil and gas as feedstock, chemistry must learn how to deal with a new and very variated material. As pointed out by Spitz (8), the feedstock exerted a crucial structuring role in the chemical industry history. From the coal-based chemical in the 19th century to the petrochemical industry in the 20^{th} century, Spitz identifies the feedstock availability as the key structuring variable, more important than technology and market factors.

At industry level, the bioeconomy requires that new supply chains and logistics must to be developed, in order to use biomass as feedstock. These developments are very complex and ask for competencies that are not found in the chemical industry. In some cases, such as agri-food and urban residues, biodiversity specialties and new energy crops, the supplying market is not yet organized. Biomasses are usually solid, not fluid as oil and gas, functionalized and with complex molecular structures not hydrocarbons, compete with food and feed, are seasonal and not scalable at usual oil and gas levels.

As a result, apart from supply chain and logistics challenges, well established technologies dealing with fluids can't be applied to solid biomass. The well-known problems with the use of lignocellulosic materials for ethanol production illustrate the know-how gap in biomass handling and processing. Finally, the feedstock-integrated model, predominant in the petrochemical industry, must be reexamined as a strategy by chemical firms entering the bioeconomy.

Technology challenges
At the technology dimension, two relevant challenges can be identified. The first one is related to the feedstock treatment and conversion technologies. Many technological options have been developed over the last two decades looking for the best routes to convert renewable starting molecules such as sugars, cellulose, lignin, glycerin, CO2 into valuable products. Among these options, chemical and thermochemical routes are quite important but new routes such fermentative and enzymatic ones tend to become most prominent in the bioeconomy. A very challenging and promising topic is synthetic biology. Synthetic biology, an advanced biotechnology field, is predicted to foster very innovative conversions from sugars to complex molecules in one step. But as a very new field, R&D efforts have to be made to get the potential results in time with competitive costs. A good example of funding programs to accelerate the synthetic biology is *Agile BioFoundry*, a DOE supported program that aims to identify and propose solutions to reduce time and cost of industrial exploitation of synthetic biology-based products (9). Biobased conversion requires costly separation processes which, in addition to increasing the facility capital cost, require high energy consumption for product separation and concentration steps. Process intensification has been developed as a technological innovation of great importance to the chemical industry and the bioeconomy, being fundamental both to make many enzymatic or fermentative processes economically viable and to give them better environmental performance (less energy consumption, less effluents). The intensification of processes still allows the compaction of plants, which contribute to relevant changes in scales and location strategies of the industrial units. There are, thus, many new research topics that the industry has to become familiar with in order to be competitive in the bioeconomy.

The second challenge is related to biorefineries as a new plant concept, very different from conventional chemical and petrochemical plants. Considering the nature of the feedstocks and the type of treatment and conversion technologies, the conventional wisdom in plant concept concerning scale, scope, localization and integration is challenged. Biorefineries should have a regional embeddedness which is quite contrasting with the petrochemical centralized model. Biorefineries tend to adopt a kind of "distributed manufacturing" concept (10).
This concept, not yet fully developed, implies the building of an innovation ecosystem in which the biorefinery is inserted.

Products and their dilemmas
Following the adopted bioeconomy definition, the main market opportunities have been identified in four sectors: biofuels, biochemicals, biomaterials and food. The first generation (ethanol and biodiesel) biofuels market is around 140 billion liters per year, with an annual growth rate of 4% in the last years. But according to IEA, biofuels production is expected to be 10 times greater in 2060 compared to 2015, if we consider the 2°C scenario (11). To meet these projections, it is expected a large contribution of advanced biofuels which are not fully developed yet.
Biochemicals are probably a key opportunity if we consider the chemical industry capabilities. According to (12), there is a potential to replace two third of fossil-based chemicals being 60% of them chemical specialties. In line with this perspective, the Roadmap for the Chemical Industry in Europe towards a Bioeconomy (13) considers a 25% share of bio-based chemicals in the European chemical industry by 2030. The roadmap signs a diversification trend moving from biofuels to a scenario also composed by biobased chemical specialties. The specialty segment, in addition to traditional chemical specialties (additives, surfactants, dispersants, etc.), has attracted the attention of companies that develop new products for use in markets such as human and animal nutrition, cosmetics and other high-value markets. In the food market, plant-based proteins are estimated to reach 10% of market share in 10 years (14).
Opportunities in bioplastics are also seen as very promising. According to recent reports, bioplastics market share is currently no more than 1% of global plastics demand with a value of 2,960 bi US$. This value is projected to reach around 3,9 bi US$ in 2023 (15). Considering the European market, bioplastics are now at around 1,2 mi t/y compared to a 70 mi ton/y of fossil-based plastics. There is therefore a large room for growth if bioplastics are able to meet the demands of a circular economy.

Despite the high potential, the choice of which new biobased product to develop and launch in the market is a strategic decision to be made by the chemical industry. Our works (16, 17) have shown that there are at least three dilemmas to be considered. The bioproducts may be final or intermediate; commodity or specialty and drop-in or non-drop-in. Each of these dilemmas derive major challenges for innovators in bioeconomy.

The chemical industry is certainly familiar with the two first dilemmas, even if in the biobased case they may show some particularities. As observed for intermediate fossil-based products, the intermediate biomolecules also depend on derivates development efforts to its demand flourish.
While commodities rely on scale and competitive costs, specialties require long term efforts to develop market applications. But the dilemma drop-in or non-drop-in is the first one the industry has to face to comprehend some specific challenges imposed by the bioeconomy.

Drop-in bioproducts are those chemically identical to their fossil counterparties. It results in minor adjustments along the value chain concentrated on the earlier stages as feedstock supply and treatment and conversion since the material obtained is identical to the petrochemical version. This adoption depends on the competitive costs to petrochemicals and availability. For example, brand-owners that use plastics in their products such as food, beverages, cosmetics and hygiene and cleaning materials will request a supply which attend their volumes and they can trust. Non-drop-in bioproducts are novel molecules which bring opportunities to offer new functionalities and to develop new markets. As novel products, their diffusion means great challenges in terms of application developments. Their adoption in most cases leads to major adjustments along the latter stages of value chain as observed in plastics such as PLA. The PLA trajectory exemplifies how difficult it is to introduce a new material in the market (17). Non-drop-in bioplastics involve downstream complementors in the production chain (additive producers, converters), and end-user application development efforts. Existing complementary assets must be adapted, or new ones must be built to reach the end markets and effectively diffuse the new bioproduct.

CONCLUSIONS

Bioeconomy represents a great opportunity for the chemical industry, but its development addresses many challenges which should be better understood by the industry. In this article, we have explored how the bioeconomy can bring new market opportunities for the chemical industry and at the same time requesting the sector to renew its competences. Contrary to what some experts may think, the challenges are not restricted to the technology dimension. We proposed the understanding of four key dimensions: feedstocks, products, technologies and business models. In terms of feedstocks, the bioeconomy requires the development of new knowledge on biomass handle and treatment associated to the structuring process of biomass supply. The technology dimension means the incorporation of new knowledge basis such as advanced industrial biotech and of course, a time to develop and to apply these new routes in industrial scales. The product dimension will demand product lines' redefinition considering the dilemmas involved and the efforts related to their adoption by the market. Finally, the decision about these three dimensions will push the chemical industry to business model innovations. If the chemical industry desires to take advantage of the many opportunities the bioeconomy brings, it should create spaces for learning and adapting its decades-old business models.

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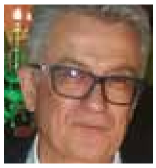

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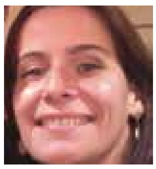

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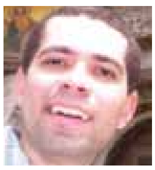

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