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PAPER

Developing new platform chemicals: what is required for a new bio-based molecule to become a platform chemical in the bioeconomy?

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This paper proposes a framework with six dimensions that can be useful for evaluating the potential and the current stage of a bio-based platform chemical. The framework considers the technological and strategic challenges to be fulfilled by a company that intends to lead a platform based on a bio-based chemical. A platform chemical should be an intermediate molecule, with a structure able to generate a number of derivatives, that is produced at a competitive cost, capable of allowing exploitation of the scale and scope economies, and inserted within a complete innovation ecosystem that is able to create value with governance mechanisms that are capable of allowing coordination of the innovation process and facilitation of the value capture by the focal company leading the platform, in our case the producer of the platform molecule. Based on these six dimensions, three potential platform chemicals – succinic acid, butanol and farnesene – are compared and discussed. It is possible to identify important differences concerning the technological dimensions and the strategic dimensions as well. Two of the molecules – farnesene and succinic acid – adhere to most of the conditions required to structure a platform chemical. However, the innovation ecosystem is not complete and the governance mechanisms are still under development, so it is not clear if they will be capable of allowing a favorable position for value capture by the platform leader. Butanol structuring for a platform does not seem promising. The potential of the molecule is apparently not high and the strategic initiatives are in general not focused on innovation ecosystem structuring.

Introduction

Advance of the bio-based industry[1] is driving a great emphasis on the development of platform chemicals, understood as chemical intermediates with the potential to develop new product families. New platform chemicals are an essential opportunity for the bio-based economy. The exploration of

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opportunities related to these molecules is not simple, since it involves a complex development process, including value chain building and market adoption strategies. The literature on platform chemicals is quite rich in details of the technological and market potential,[2,3] but until now has failed to provide an understanding of the critical strategic dimensions involved in platform chemical development. We suggest an exploration of the literature on technological platforms to understand the structuring process of platform chemicals. According to this vast literature,[4,5] a technological platform must present some key characteristics: a modular technological architecture, varied degrees of openness among the interface components, access to innovation agents, regulation by a governance structure, value creation through scope and scale economies, and amenable to coordination to keep competition under control. How do these dimensions fit to platform chemicals? We propose an analytical framework, based on the technological platform literature but adapted to the particular aspects of platform chemicals,[6] which could be useful for evaluating the potential of platform candidates. This framework considers six dimensions related to the molecule and to the strategic dimensions as well: an intermediate position in the value chain, a flexible chemical structure, a wide range of potential derived products at a competitive cost, a well-developed innovation ecosystem, a governance structure and the ability to create value through scope and scale economies. Three different examples in the biobased industry – biosuccinic acid, farnesene and biobutanol – are explored using the framework. It is possible to evaluate if these molecules have the potential to become a platform chemical and to discuss the challenges concerning the value chain structuring. If a new biobased molecule meets the conditions to become a platform chemical, strategic dimensions have to be deployed. During this process, some dilemmas and challenges which are classic in platform development have to be faced: competition or innovation, value capture or openness, scale production or application focus. We conclude that the building of a new platform chemical is a very challenging process. A capacity for coordination of a multivariate environment is crucial for structuring it. The technological development of a potential molecule is an essential step, but it is only the first one. If the key strategic dimensions are not developed in a timely manner, the platform is unlikely to be built.

This paper is organized as follows. First, we present a brief literature review on technological platforms in order to identify the key dimensions that guide platform building. Based on these dimensions and considering the particular aspects of platform chemicals, we propose an analytical framework that could be applied to evaluate the possibility and the present development stage of a potential platform chemical. We examine three potential platform chemicals – biosuccinic acid, farnesene and biobutanol – to illustrate the platform building process. In the last section, we present our concluding remarks, the implications and some open questions that could be interesting research themes.

Technological platforms

"Platforms are the future – but not for everyone" was quoted in The Economist, May 2016, referring to the wide diffusion of the technological platforms notion over the last 15 years and, as a result, to its overutilization. Many industries, from cars to information technology sectors, have been exploring the idea of a platform as a strategic way to organize and explore new business opportunities. It is important to emphasize that platforms are distinct from conventional products[7] "in that they have the potential to generate positive feedback loops, between the primary product (the platform) and its users as well as with complementary products and services". Positive feedback can create incentives for more users to enter the platform and so to reinforce the ecosystem.

The literature on the subject is now quite vast, from books such as *Platform revolution* and *Matchmakers: the new economics of multisided platforms*,[8,9] which was recently published, to papers in the highest impact economics and management journals. A recent review[4] has identified three different perspectives: market (industrial organization economics), firms (strategic management) and integrative (technology management). Our work uses the technology management viewpoint as a literature reference to present the key dimensions of platforms. In this perspective, platforms are seen as technological architectures which are intended to promote innovation. Nevertheless, Gawer[10] stresses that the interactions between the technological structure and business strategy have to be considered for an integrative perspective.

From this perspective, platforms can be defined[11] as "evolving organizations or meta-organizations that: (1) federate and coordinate constitutive agents who can innovate and compete; (2) create value by generating and harnessing economies of scope in supply or/and in demand; and (3) entail a modular technological architecture composed of a core and a periphery". A typology of technological platforms[11] considers three kinds of platforms: product, supply chain and industry platforms. A supply chain platform is a particular case of internal platform where assemblers and suppliers perform in a quasi-integration way. Thus, we consider in this paper product and industry platforms.

Product or internal platforms[5] can be defined as "a set of assets organized in a common structure from which a company can efficiently develop and produce a stream of derivative products". Industry or external platforms are defined[5] as "products, services, or technologies that act as a foundation upon which external innovators, organized as an innovative business ecosystem, can develop their own complementary products, technologies, or services".

Product and industry platforms can be differentiated[11] by at least five structural characteristics. In product platforms, the constitutive agents are one firm and its constituent sub-units, while in industry platforms, the agents are the platform leaders and the complementors.[12] Complementors are developers and providers of complementary products or services that have to be combined to give a product all the characteristics needed to attain the final users' expectations. Both platforms have a modular architecture organized around a core and a periphery, but the interfaces are closed in product platforms and open in industry platforms. This means that in the first case the interface specifications are defined within the company and they are not known by external agents. In the case of industry platforms, the interfaces are essentially open and are shared with the complementors. Concerning access to the innovative capabilities, product platforms are limited to the company capabilities while with industry platforms, due to the open interfaces, the access is virtually unlimited. Finally, the coordination mechanisms are also diverse. Product platforms are coordinated by an internal authority through the managerial hierarchy. On the other hand, for industry platforms governance mechanisms have to be developed in an innovation ecosystem.

In summary, the above discussion has established a distinction between platforms developed by vertically integrated companies (product or internal platforms) and those developed by companies within innovation ecosystems (industry or external platforms). This last one, to be successful, depends on innovation initiatives from external agents. Nevertheless, notwithstanding the organizational context in which platforms are developed, it is possible to establish, according to Gawer[11] and Gawer and Cusumano,[7] that any platform:

(i) has a modular technological architecture composed of a core and a periphery;

(ii) has technological interfaces, between the core and the periphery, with varying degrees of "openness";

(iii) involves access to innovation agents with varying levels of capabilities;

(iv) involves coordination among constituent agents in order to increase capabilities and control competition;

(v) is regulated by coordination mechanisms which are particular to the platform organizational setting;

(vi) creates value by generating and harnessing economies of scope and scale in supply or/and in demand.

The structuring process of a new platform, based on new bio-based chemicals, for example, challenges companies to deal with an environment where innovation and competition drivers interact. Companies have to manage some key dilemmas in order to conciliate competition and innovation strategies without compromising their economic benefits. They have to consider internal *versus* external platforms and also value capture *versus* the openness degree. There are some technological and strategic challenges to overcome in order to develop the right architecture and interfaces, and to ensure the necessary complements are present to create value as a way to generate demand, develop markets and gain a competitive advantage over the competitors. In the next section, we explore these points for the case of potential platform chemicals. How do these dimensions fit to platform chemicals?

Platform chemicals

The literature on platform chemicals has remarkably increased in the last ten years. For example, there are more than eight thousand citations referring to platform chemicals or platform molecules within Google Scholar, five thousand within the last three years. However, this vast literature barely explores the technological challenges involved in a platform structuring process, not to mention the strategic challenges. At the same time, companies introduce themselves as exploring bio-based platform chemicals and consultation studies[13,14] frequently emphasize the market opportunity for these molecules as potential platforms.

Most of this literature focus on the technological and market potential of the new bio-based molecules,[2,3,15,16] but until now has failed to provide an understanding of the critical strategic dimensions involved in platform chemical development. So, there is no comprehensive definition of a chemical platform. Most papers do not present any definition, taking for granted the notion of a platform chemical. We can take as a reference the very objective definition by Bozell and Petersen:[2] "Compounds that serve as starting materials for the production of derivatives". This definition emphasizes essentially the ability for the production of derivatives, lacking a broad understanding of the challenges involved in platform development.

The terms platform and building blocks have been used interchangeably by most authors. The DOE Report from 2004 [15] is a remarkable reference on the identification of promising bio-based molecules, which presented twelve well-known high-value bio-based chemicals as building blocks, explaining that "Building block chemicals, as considered for this analysis, are molecules with multiple functional groups that possess the potential to be transformed into new families of useful molecules". This is indeed a good definition of platform chemicals as most of the twelve sugar-based chemicals – 1,4-diacids (succinic, fumaric and malic), 2,5-furan dicarboxylic acid, 3-hydroxypropionic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol – are so called in the current literature.

There is a quite unusual distinction between platform chemicals and building blocks present in the literature. Bozell and Petersen,[2] revisiting the top-10 DOE list from 2004, have proposed a multi-criteria analysis in order to compare and identify the new top bio-based molecules. In Bozell and Petersen's framework, platform chemicals and building blocks are seen as having different criteria. The distinction is based on the idea that a petrochemical refinery is built on a small number of initial building blocks: olefins, BTX, methane, CO. Those compounds that are able to have an analogous role in a biorefinery, as primary building blocks, will be of high importance. Following these criteria, according to Bozell and Petersen, ethanol would be at the same time a good platform chemical and a primary building block. Succinic acid, however, would be a good platform chemical but a poor primary building block. Nevertheless, probably the dominant trend has been to name building blocks as platforms.

We consider in this work that the idea of platform chemicals should not be taken as simply a new way to rename the existing petrochemical building blocks. A platform is taken here as a strategy and a way to organize the business of the industry for at least two reasons. The emergence of the platform concept places the chemical industry within the open innovation[17] paradigm that currently dominates innovation strategies of the most dynamic sectors of the economy. The second reason is due to the idea of the bioeconomy as a system innovation that could lead to a transition to new socio-technical regimes departing from the fossil-based one. This transition[18] can be transformative for the current regime and open opportunities to new forms of business organization.

We suggest then that the so-called platform chemicals are particular cases of technological platforms whose backbone takes the form of a chemical compound. This means that platform chemicals are chemical intermediates capable of giving rise to a wide range of derivatives with diverse final applications. These final products result from specific physical and chemical transformations and are consumed in different markets.

Platform chemicals are able to create great commercial value. However, as intermediates in the value chain, in order to actually create that value these chemicals need to be properly transformed into end products and these products need to be adopted by end users. This adoption[19] may depend only on cost competitiveness, in the case of the drop in substitutes for conventional petrochemicals. But if the platform chemical leads to new molecules, a new plastic for example, the innovation adoption depends on market development, which can be very challenging. The platform leader must face not only technological difficulties in order to transform an intermediate molecule into different final products, but also challenges in developing new market applications. The set of technological and managerial competencies that must be mobilized exceeds what is held by a single company, not to mention the financial resources. Except for some fully vertically integrated companies that hold all stages of the production chain and the necessary specific skills and technologies, in general, it is necessary to take advantage of external capabilities. That is, in general, this challenge also involves the need for engagement of complementors, developers and contributors from different and diverse industries. These complementors, as downstream chain actors, are responsible for driving innovation produced by the platform leader to a final use.

Thus, a bio-based platform chemical can be considered an industry platform immersed in an innovation ecosystem that, in this case, is a set of value chains. These value chains are diverse in the sense that the nature of the participating complementors can be distinct, particularly in the extreme downstream positions. Value chains with different end users may demand very different approaches, which means that the innovation ecosystem to be built may be very complex.

The innovation ecosystem, which is so diverse and complex, has to be coordinated by the platform leader for two reasons: to facilitate the value creation and at the same time to find a favorable position for value capture. In this extremely competitive and dynamic environment, focal firms are vulnerable to external innovation efforts and therefore have to deal with technological and behavioral uncertainties.

Considering the identification of these particularities and challenges in the development of chemical platforms and taking them as specific cases for product technological platforms, it is possible to identify the dimensions that will allow us to characterize a given product as a potential platform chemical. In this way, products characterized as a platform chemical necessarily:

(I) are an intermediate in the value chain;

(II) have a flexible chemical structure with functional groups that allow the generation of a set of derivatives;

(III) have interfaces, with varying degrees of openness, that allow their transformation into a wide range of derivatives at competitive cost. These interfaces can be seen as chemical and physical transformation processes that can be integrated by the focal company or performed by external agents;

(IV) are connected to innovation agents with varying levels of competence and diverse interests located at different positions of the value chain and towards different end products, so that they are structured within innovation ecosystems formed by a set of production chains;

(V) are regulated by control and command mechanisms (governance) that vary according to the organizational context. The governance mechanisms should allow a favorable position for value capture by the platform leader;

(VI) create value through scope and scale economies.

The structuring process is challenging as we can see by the conditions presented above. Even if the platform molecule fulfills the technological conditions, the platform leader faces some strategic dilemmas.

Thus, similar to technological platforms, the platform chemicals, in order to be commercially effective, need to overcome some dilemmas that correspond to challenges to be faced by the focal companies, namely:

(I) degree of openness *versus* value appropriation: the platform leader must be able to manage the interfaces in such a way as to allow the generation of value with external collaboration in an open innovation mode, but, at the same time, to prevent this value from being totally captured by these agents;

(II) innovation/collaboration *versus* competition: the platform leader should create relationships of trust and collaboration with the complementors and end users. This is essential for forming an innovative environment. However, the platform leader must be attentive to the opportunistic behavior of other agents;

(III) large-scale production and market application/development: the platform leader must be able to deal with this egg–chicken problem in which network effects define interdependence between these factors. It is necessary to achieve production on a large scale to enter new markets. However, new markets need an application development to persuade end users to adopt the innovation. At the same time, end users usually are not ready to adopt the innovation if large scale production is not available yet.

Comparing biosuccinic acid, biobutanol and farnesene as potential platform chemicals

Biosuccinic acid, biobutanol and farnesene were chosen as cases to apply our framework and discuss the structuring process for new bio-based platform chemicals. They are representative of the new generation of bio-based molecules and have already begun to undergo commercial production, but they are quite diverse concerning their technological and strategic aspects (information on the products is provided by a database organized by the authors, compiling data from company websites, specialized sites and conference presentations).

Succinic acid has been produced only through a petrochemical route. Due to the cost limitations of the petrochemical process, its market is limited to no more than 40 000 tons per year. Bio-based production, potentially cost competitive, could open up the opportunity to develop a wide number of derivatives. There are four important producers currently: Bioamber, Myriant, Reverdia and Succinity. The first two are startups created to explore the opportunity. Reverdia is a joint venture between DSM and Roquette, and Succinity is a joint venture between BASF and Corbion (former Purac).

Butanol has been produced through a petrochemical route and also through a biochemical one, called ABE. The petrochemical process was able to be used to obtain an important market of more than 3 million tons per year, essentially for chemical uses such as solvents and plasticizers. The bio-based production is aimed at drop-in substitutions but also new markets, to provide renewable fuels for gasoline, diesel and jet fuel applications, and new bio-based chemicals such as *p*-xylene, used as a PTA precursor for PET production. There are three important players: Gevo, Butamax and Green Biologics. Gevo and Green Biologics are startups while Butamax is a joint venture between Du Pont and BP.

Farnesene was not produced at a commercial level until an innovative biochemical route was proposed by Amyris, a startup created to explore the potential uses of farnesene and other similar isoprenoids. Farnesene itself has no market, but its derivative applications are quite diverse: from drop-in diesel and jet fuels to use in a variety of specialty markets within the chemical, cosmetic and food ingredient industries. Amyris is the only farnesene producer.

How are these molecules performing as potential platform chemicals? Starting with the basic condition – to be an intermediate –, it is fulfilled by the three molecules. Concerning the chemical structure, which must be adequate for performing transformations to a wide range of derivatives, important differences can be found among the three molecules. This issue is normally considered in publications on promising bio-based molecules. Chemical functionality can be based on the number of potential derivatives that can be synthesized through chemical and biological transformations. Simply, a candidate with one functional group will have a limited potential for derivatives, while candidate molecules with multiple functional groups will have a much larger potential for derivatives and new families of useful molecules. We propose having at least two functional groups as the basis for a platform molecule.

A platform chemical should have at least two functional groups. The nature of the functional groups – equal or different, easy or difficult to access – can improve the quality of the starting molecule. A diacid, such as succinic acid, fulfills this condition with two equal functional groups. Farnesene has four double bonds, which open up transformation possibilities. But butanol, with only one functional group, provides considerably less options. It should be converted to butene in order to increase its functionality and open up possibilities for new derivatives.

The derivatives have to be cost competitive. This is probably a very difficult evaluation to conduct mainly in the first stage of development, where the learning curve is still in its first stages. Many factors have to be considered to give a platform candidate a good position for cost competitiveness. We propose that a first proxy could be the biomass utilization efficiency,[20] which can be evaluated using the theoretical yield of sugar. This theoretical yield should be compared with the industrial yield. But as a general rule it is possible to consider that 90% should be the limit achieved at the mature industrial scale.

Succinic acid has a clear advantage at this point: with a CO_2 absorbing fermentation the theoretical yield of glucose is 100%. Butanol has a theoretical yield of 41% and that of farnesene is around 30%.

The availability of derivatives at a competitive cost depends also on the number of steps needed to obtain the final product. Each step represents not only additional capital expenditure (Capex) but also a lower final yield. The productivity measured in g per liter per hour is another factor that can strongly influence the Capex cost of fermentative processes.

Accumulated knowledge on the molecule could also contribute to its competitiveness. Taking the number of papers cited on Web of Science as an indicator, butanol is by far the molecule with more accumulated knowledge. There are almost 25 000 papers cited on Web of Science. Succinic acid has less than 8 000 and farnesene has less than 1 500 papers cited on the same database. Trying to overcome this situation, Amyris started to sell *via* the internet small quantities of farnesene to promote more research and experiments using the molecule. The same strategy to increase knowledge on succinic acid molecules has been proposed by Reverdia.

The ability to create value through scope and scale economies is directly related to the number of derived products (economy of scope) and their market volume (economy of scale). A platform chemical will be successful only if its final markets are a combination of commodity and specialty applications. If there are only a couple of commodities, the value chain tends to involve very small numbers of actors, probably with vertical integration by commodity producers. On the other hand, if there are only specialty applications, the lack of scale makes it difficult to produce the platform molecule at a cost low enough to multiply the applications.

The two final dimensions in our framework are strategic ones, which depend on management approaches: the innovation ecosystem and governance.

The term innovation ecosystem[21] refers to the set of innovative actors – upstream suppliers, buyers and downstream complementors – normally organized into a network. This set of actors provides products and services in order to create value and enable market diffusion of an innovation produced by a central organization called the leader or focal firm. The challenge for the platform chemical leader is to identify the set of actors and to mobilize their capabilities to contribute to the platform development. As long as the platform leader is able to combine the existing capabilities and induce the development of new ones, the innovation ecosystem works in an open innovation mode through a high level of collaboration among the actors. In this context, it is required[22] that the leader has the ability to organize and participate in an innovation process that combines a very diverse set of actors performing at the various stages of this innovation process.

Nonetheless, to develop a platform, the ecosystem must be coordinated. That is, some kind of governance must be in place. The term innovation ecosystem refers to the comprehensiveness of the competencies that have to be mobilized; the ecosystem must involve the complete set of competencies necessary to develop the platform innovation. So, an innovation ecosystem is critical to achieve innovation. On the other hand, governance refers to the way that relationships are organized and how the focal firm manages these relationships. An innovation ecosystem is essential for creating value and governance is critical for enhancing the value creation but also for defining the value capture, which means that these dimensions are interrelated.

It is possible to identify five types of global value chain governance[23] – hierarchy, captive, relational, modular, and market – which range from high to low levels of explicit coordination and power asymmetry. These types are used to try to categorize the variety of network forms and particularly those between the traditional poles: hierarchy and market coordination. Platform development involves very intensive coordination efforts in order to enable contact among the producers, a quite varied range of complementors, and end users or brand owners. This coordination aims at the same time to diffuse information and knowledge about the product, to acquire knowledge from the network and to combine this knowledge to create or co-create product applications to be adopted by end users. At the present stage, bio-based platform chemicals are still immature and under development. Thus the governance is essentially relational.

Relational value chains[24] "arise when product specifications cannot be easily codified, products are complex and supplier capabilities are high; this leads to frequent communication between buyers and suppliers within the framework of a certain degree of mutual dependence, which may be regulated through reputation, social ties and/or spatial proximity". Sturgeon[25] emphasizes that the access to expertise and competencies is a strong motivation for developing and maintaining external relationships.

Previous stories of the introduction of new molecules to the market can illustrate the nature of the relational competencies that innovating firms had to develop to get new applications adopted by end users. This was the case, for example, with GE Plastics in the 1980s when the firm innovated in the engineering plastics segment to provide a series of new applications.[26,27] However it is important to understand that although relational governance prevails in the development phase, it will probably evolve later to market or hierarchical governance, depending on the nature of the value chain. In that situation, the platform chemical producer could become a simple commodity supplier with low, if any, value capture from the derived products. At this point, it is important to distinguish another possible outcome: a wide range of new applications is developed based on the bio-based molecule but at the end of the day the molecule producers do not have a relevant position for value capture. In other words, value created by the innovation system may, depending on the governance and coordination mechanisms, be captured by other actors and not by the producer at the platform origin. Thus, it is critical that molecule producers, aiming to profit from a platform chemical, are involved in the platform structuring process, particularly in the innovation ecosystem organization and in the governance coordination.

How are biosuccinic acid, biobutanol and farnesene producers performing at the innovation ecosystem and governance level?

Farnesene has only one producer, Amyris. The ecosystem is vast and involves actors from very different industries and knowledge bases: chemistry, fuels, lubricants, cosmetics, flavors and fragrances. There is apparently a perception that the way to value farnesene for the market depends strongly on the nature of each market. Amyris has different business models from a joint venture with minority participation (with Total for biofuels) to a joint venture with equal participation (with Cosan for lubricants), a vertical integration from farnesene to a final market in cosmetics, and R&D cooperation with Braskem and Michelin. These different business models could be interpreted as a strategy to adapt the value creation and value capture to the particularities of each business.

Succinic acid is a very interesting case due to the strategic diversity of the players. Bioamber and Myriant, both startups with no capabilities other than succinic acid technology, have been trying to diversify their relationships in order to build an innovation ecosystem. But it is less clear whether the producers have been able to coordinate the ecosystem in their favor. Reverdia, a joint venture between DSM and Roquette, combines a strong chemical company, able to provide R&D and production expertise, with Roquette which has expertise in the supplying and processing of renewable feedstock. At the same time, Reverdia has been partnering with players in the downstream side of the value chain. Through this action, Reverdia shows a clear strategy to build a governance form in its favor. There is explicitly a proposal to license the technology to key users of succinic acid that has the potential to generate captive consumers. But the licensee cannot commercialize any succinic acid if the production is in excess of the captive use. The fourth player, Succinity, a joint venture between BASF and Corbion, has a very different strategy. Even if the company suggests a strategy for platform building, no alliance or relationships have been announced up to now. It is possible to suppose in this case that Succinity, considering that the competencies of BASF and Corbion are sufficient to develop the succinic acid platform, has decided to develop a product platform and not an industry platform.

Butanol is a particular case due to two important aspects: there is an efficient petrochemical production route and the technological barrier for entry to bio-based production is not high. As a result, many companies have been trying to enter the business. Three of them – Gevo, Butamax and Greenbiologics – are the most important. Gevo and Greenbiologics are startups and Butamax is a joint venture between Du Pont and BP. The platform vision of these companies seems less developed compared to farnesene and succinic acid. Their focus is apparently on butanol production, and less on the creation of new applications. Butamax has an explicit strategy to license its technology to potential producers of biofuels, particularly within the gasoline market. Gevo and Greenbiologics have some initiatives for building a platform vision. Gevo has been building an innovation ecosystem with a focus on jet fuels and resins (a renewable *p*-xylene for the production of drop-in PET in cooperation with Coca-cola). Some commercial partnerships are also in place. Greenbiologics' targets are solvents for various types of paints and adhesives, flavorings, fragrances, cosmetics and personal care. Its network is not very well developed.

Concluding remarks

We have explored the concept of technological platforms, which is currently applied in many industries, in the particular case of bio-based platform chemicals. Platform chemicals have been frequently mentioned within the specialized literature as a key development, being one of the most promising innovations for the bioeconomy. Taking the literature on technological platforms as a reference and the particular aspects involved in platform chemicals, we have proposed an analytical framework with six dimensions that we present as a tool for better understanding of the platform structuring process. The key dimensions, involving technological and strategic issues, are that the chemical should: be an intermediate molecule, have a flexible structure to make a wide range of derivatives possible, be cost competitive at the level of the platform molecule and at the level of the derivatives, be capable of generating scale and scope economies in the value chain, be organized within an innovation ecosystem and have associated well-developed mechanisms of governance. Through applying the framework to three bio-based platform chemicals – succinic acid, farnesene and butanol – we have discussed their current status and possible outcomes. Two of these molecules – farnesene and succinic acid – adhere to most of the conditions required for structuring a platform chemical. However, the innovation ecosystem is not complete and the governance mechanisms are still under development, so it is not clear if they will be capable of allowing a favorable position for value capture by the platform leader. Butanol structuring for a platform does not seem promising. The potential of the molecule is apparently not high and the strategic initiatives are in general not focused on innovation ecosystem structuring.

The framework should be further elaborated, particularly concerning the definition of clearer and more precise criteria for each dimension. This is a development that should be made so that the analytical framework may possibly be useful to help with the decision making of research and business personnel.

References

1 J. V. Bomtempo and F. C. Alves, *Chem. Biol. Technol. Agric.*, 2014, **1**, 19.
2 J. Bozell and R. Petersen, *Green Chem.*, 2010, **12**(4), 525–728.
3 J. Becker, A. Lange, J. Fabarius and C. Wittmann, *Curr. Opin. Biotechnol.*, 2015, **36**, 168–175.
4 D. P. Mcintyre and A. Srinivasan, *Strat. Manag. J.*, 2017, **38**, 141–160.
5 A. Gawer and M. A. Cusumano, *J. Prod. Innovat. Manag.*, 2014, **31**(3), 417–433.
6 M. Araujo, J. V. Bomtempo, F. Alves and F. Oroski, *ALTEC 2015*, 2015, http://www.altec2015.org/anais/altec/papers/608.pdf.
7 A. Gawer and M. A. Cusumano, *International Encyclopedia of the Social & Behavioral Sciences*, 2nd edn, 2015, vol. 3, DOI: 10.1016/B978-0-08-097086-8.73012-1.
8 G. G. Parker, M. W. Van Alstyne and S. P. Choudary, *Platform revolution*, W W Norton & Company, 2016.
9 D. S. Evans and R. Schmalensee, *Matchmakers: The New Economics of Multisided Platforms*, Harvard Business Review Press, 2016.
10 A. Gawer, *DRUID Summer Conference 2010*, 2010.
11 A. Gawer, *Res. Pol.*, 2014, **43**(7), 1239–1249.
12 A. Brandenburger and B. J. Nalebuff, *Coopetition*, Currency Doubleday, New York, 1997.
13 S. R. O. Weastra, *WP 8.1. Determination of market potential for selected platform chemicals: itaconic acid, succinic acid, 2,5-furandicarboxylic acid*, Report for BioConSepT FP7 project, 2013, http://www.bioconsept.eu/wp-content/uploads/BioConSepT_Market-potential-for-selected-platform-chemicals_report1.pdf.
14 E4tech, RE-CORD and WUR, *From the sugar platform to biofuels and biochemicals*, Final report for the European Commission, contract No. ENER/C2/423-2012/SI2.673791, 2015.
15 Department of Energy, *Top Value Added Chemicals from Biomass Volume I—Results of Screening for Potential Candidates from Sugars and Synthesis Gas*, 2004.
16 J. S. Luterbacher, D. Martin Alonso and J. A. Dumesic, *Green Chem.*, 2014, **16**, 4816.
17 H. Chesbrough, *Open Innovation: the New Imperative for Creating and Profiting from Technology*, Harvard Business School Press, Boston, MA, 2003.
18 F. W. Geels, F. Kern, G. Fuchs, N. Hindererc, G. Kungl, J. Mylan, M. Neukirch and S. Wassermann, *Res. Pol.*, 2016, **45**, 896–913.
19 F. Oroski, J. V. Bomtempo and F. Alves, *J. Bus. Chem.*, 2014, **11**(1), 131–138.
20 K. Iffland, J. Sherwood, M. Carus, A. Raschka, T. Farmer and J. Clark, *nova paper#8 on biobased economy*, 2015, http://www.biobased.eu/novapapers.
21 R. Adner and R. Kapoor, *Strat. Manag. J.*, 2010, **31**(3), 306–333.
22 J. West and M. Bogers, *J. Prod. Innovat. Manag.*, 2014, **31**(4), 814–831.

23 G. Gereffi, J. Humphrey and T. Sturgeon, *Rev. Int. Polit. Econ.*, 2005, **12**(1), 78–104.
24 P. Gibbon, J. Bair and S. Ponte, *Econ. Soc.*, 2008, **37**(3), 315–338, DOI: 10.1080/03085140802172656.
25 T. Sturgeon, *Industry Studies Association Working Paper Series*, 2008, From Commodity Chains to Value Chains: Interdisciplinary Theory Building in an Age of Globalization.
26 J. V. Bomtempo, D Sc thesis, CERNA, École des Mines de Paris, 1994.
27 J. T. Coe, *Unlikely Victory: How General Electric Succeeded in the Chemical Industry*, American Institute of Chemical Engineers, New York, 2000.