Universidade Federal do Rio de Janeiro

Programa de Pós Graduação em Tecnologia de Processos Químicos e Bioquímicos

Estratégias em Indústrias Emergentes: Um Estudo de Empresas Petroquímicas e *Startups* na Bioeconomia

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Rio de Janeiro
2016

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Dissertação de Mestrado apresentada ao programa de Pós-Graduação em Tecnologia de Processos Químicos e Bioquímicos, Escola de Química, Universidade Federal do Rio de Janeiro, como requisito parcial a obtenção do título de Mestre em Ciências (M.Sc).

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Rio de Janeiro
2016

CIP - Catalogação na Publicação

T266e

Teixeira, Leonardo Vieira
Estratégias em Indústrias Emergentes: Um Estudo de Empresas Petroquímicas e Startups na Bioeconomia / Leonardo Vieira Teixeira. -- Rio de Janeiro, 2016.
88 f.

Orientador: José Vitor Bomtempo.
Coorientador: Fábio de Almeida Oroski.
Dissertação (mestrado) - Universidade Federal do Rio de Janeiro, Escola de Química, Programa de Pós-Graduação em Tecnologia de Processos Químicos e Bioquímicos, 2016.

1. Indústrias emergentes. 2. Bioeconomia. 3. Estratégias de inserção. 4. Modelos de negócio. I. Bomtempo, José Vitor, orient. II. Oroski, Fábio de Almeida, coorient. III. Título.

Elaborado pelo Sistema de Geração Automática da UFRJ com os dados fornecidos pelo(a) autor(a).

LEONARDO VIEIRA TEIXEIRA

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Dissertação submetida ao Corpo Docente da Escola de Química da Universidade Federal do Rio de Janeiro – UFRJ, como requisito necessário à obtenção do grau de Mestre em Ciências.

Rio de Janeiro, 30 de setembro de 2016

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Este trabalho é dedicado à minha amada família e a meus queridos amigos

Agradecimentos

Agradeço a meu querido pai, Antonio, que faz tudo em suas possibilidades para cuidar de mim e sempre me apoia. Além de ser o grande inspirador para meu caminho na engenharia.

A minha mãe amada, Nelva, que me acolhe com amor e carinho incondicionais.

A minha irmãzinha Lívia, parceira para todas as horas.

Aos meus orientadores, José Vitor e Fábio, pela paciência infinita, dedicação quase incansável e pela amizade.

A Flávia pela contribuição imensa, paciência, orientação e amizade. Muito obrigado!

Agradeço aos meus amigos de graduação e de vida, Paulinha, My, Irina, Zé e Julia pelas inúmeras horas compartilhadas de felicidade e de sofrimento (que também tem sua graça e inspiram nostalgia!).

Aos amigos de longa data, Maurício, Ivan, Silas, Mauro, Marques, àqueles mais recentes mas não menos importantes, Gabi, Carol, Talita, e de tantos outros que fazem parte da minha vida. Muito obrigado!

Ao CNPQ pelo apoio financeiro durante esse período de mestrado.

Resumo

TEIXEIRA, Leonardo Vieira. **Estratégias em Indústrias Emergentes: Um Estudo de Empresas Petroquímicas e Startups na Bioeconomia**. Rio de Janeiro, 2016. Dissertação (Mestrado em Tecnologia de Processos Químicos e Bioquímicos) – Escola de Química, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 2016.

Indústrias emergentes constituem cenários altamente dinâmicos que apresentam um grande número de novas oportunidades para empresas, mas muitas vezes também, diversas ameaças. Esta dissertação discute as estratégias de inserção de empresas químicas/petroquímicas estabelecidas e *startups* na indústria baseada em matérias-primas renováveis (ou bioeconomia), com o objetivo geral de descrever quais dimensões estão guiando suas respectivas estratégias e as características da indústria que afetam suas escolhas, além de avançar pontos teóricos específicos. Devido à indefinições de quais tecnologias, produtos, matérias-primas e modelos de negócio são os mais adequados, além da variedade de atores de diferentes setores participando no processo de construção da indústria, a mesma apresenta um dinamismo bastante elevado. Considerando as empresas químicas estabelecidas, busca-se avaliar como essas lidam com o acesso a recursos complementares e novas tecnologias. Já no caso das *startups*, discute-se sua flexibilidade na experimentação em modelos de negócio, já que esse tipo de firma tipicamente possui maior liberdade para experimentar. Para tal, foram realizados estudos de casos de firmas selecionadas, nos quais são apresentadas suas trajetórias no contexto da indústria, descritas a partir de literatura específica. Em relação às empresas químicas estabelecidas, identificaram-se diferentes estratégias para gerenciar novas tecnologias, desde uma priorização por incorporar conhecimentos chave, à preferência por acessá-los em um primeiro momento através de parcerias, minimizando custos e gerenciando riscos. Na primeira situação, pode-se indicar uma tendência a transformação de base tecnológica, enquanto a segunda se assemelharia mais a uma adaptação por parte da empresa. Já o estudo de *startups* mostrou que as possibilidades tecnológicas da firma e a natureza dos produtos (*drop-in* ou não *drop-in*) impactam sua flexibilidade para experimentar em modelos de negócio. A escolha entre produzir e/ou licenciar também se mostra uma decisão de modelo de negócio significativa, afetada pelas possibilidades atuais da indústria. Esses aspectos foram resumidos em uma árvore de decisão, que provê uma forma prática para avaliar as oportunidades e desafios de *startups* na bioeconomia. Os resultados indicam desafios bem distintos para esses dois tipos de empresas. Por deterem recursos relacionados à produção, comercialização e aplicação de químicos, a bioeconomia pode representar importantes oportunidades para empresas químicas estabelecidas, porém essas também podem ser afetadas negativamente pela transição de matérias-primas e pelo surgimento de novas tecnologias. Formar parcerias com outros atores tende a ser uma forma hábil de minimizar algumas dessas dificuldades, incluindo parcerias com outras empresas estabelecidas. As *startups*, por sua vez, são criadas para tentar prosperar a partir de inovações tecnológicas, mas se inserem em um contexto de grandes incertezas. A experimentação em modelos de negócio se mostra um fator muitas vezes crítico para a sobrevivência dessas empresas pioneiras.

Abstract

TEIXEIRA, Leonardo Vieira. **Strategies in Emerging Industries: A Study of Petrochemical Companies and Startups in the Bioeconomy**. Rio de Janeiro, 2016. Dissertation (M.Sc. in Chemical and Biochemical Technology Processes) – School of Chemistry, Federal University of Rio de Janeiro, Rio de Janeiro, 2016

Emerging industries constitute highly dynamic scenarios that present a large number of new opportunities for firms, but many times also many threats. This dissertation discusses the insertion strategies of established chemical/petrochemical companies and startups in the industry based on renewable raw materials (or bioeconomy), with the general aim of describing which dimensions are guiding their respective strategies and the characteristics of the industry that affect their choices, besides advancing specific theoretical points. Due to indefinitions of which technologies, products, raw materials and business models are the most adequate, besides the variety of actors from different sectors participating in the process of industry construction, it presents an elevated dynamism. Considering the established chemical firms, there is an interest to evaluate how they deal with the access to complementary resources and new technologies. In the case of startups, this work discusses their flexibility in business model experimentation, since this type of firm typically posses greater freedom to experiment. For this purpose, case studies of selected firms were carried, in which their trajectories in the context of the industry are presented, through the use of specific literature. Considering the established chemical companies, different strategies for managing new technologies were identified, from those favoring the incorporation of key knowledge, to the preference for accessing it in a first stage through partnerships, minimizing costs and managing risks. In the first situation, a tendency of transformation of technological base can be indicated, while the second one would resemble more an adaptation of the company. In turn, the startups study showed that the technological possibilities of the firm and the products nature (drop-in or non drop-in) impact its flexibility to experiment in business models. The choice between produce and/or license also rise as an important business model decision, affected by the current possibilities of the industry. These aspects were summarized in a decision flow chart, which provides a practical way to evaluate the opportunities and threats of startups in the bioeconomy. The results indicate quite different challenges for these two types of companies. Since they hold resources related to the production, commercialization and application of chemicals, the bioeconomy may represent important opportunities for established chemical companies, but they may also be negatively affected by both the raw materials transition and by the emergence of new technologies. Establishing partnerships with other actors tends to be an favorable way to minimize some of these difficulties, including those with other established companies. The startups, in turn, are created to try to thrive from technological innovations, but are inserted in a context of great uncertainties. The experimentation in business models show to be a factor many times critical for the survival of these pioneer companies.

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BDO - *1,4-butanediol*

CA – *Complementary assets*

CEO - *Chief Executive Officer*

CENPES - Centro de Pesquisas Leopoldo Américo Miguez de Mello

DOE – *U.S. Department of Energy*

FAPESP - Fundação de Amparo à Pesquisa do Estado de São Paulo

FDCA - *2,5-furandicarboxylic acid*

FDME - *Furan dicarboxylic methyl ester*

GBL - *Gamma butyrolactone*

HMD - *Hexamethylenediamine*

IEA – *International Energy Agency*

LNBio - Laboratório Nacional de Biociências

NREL - *National Renewable Energy Laboratory*

OECD - *Organization for Economic Cooperation and Development*

PBAT - *Polybutyrate adipate terephthalate*

PBS - *Polybutylene succinate*

PBT - *Polybutylene terephthalate*

PDO - *1,3-propanediol*

PE - *Polyethylene*

PEF - *Polyethylene furanoate*

PET - *Polyethylene terephthalate*

PHA – *Polyhydroxyalkanoate*

PLA - *Polylactic acid*

PP – *Polypropylene*

PTF - *Polytrimethylene furandicarboxylate*

PTT - *Polytrimethylene terephthalate*

PVC - *Polyvinyl chloride*

RBV - *Resource Based View*

R&D – *Research and development*

THF - *Tetrahydrofuran*

UNICAMP - Universidade Estadual de Campinas

USD – *U.S. Dollars*

Sumário

Chapter 1 - Introduction

The industry based on renewable raw materials (commonly called biobased industry) is an emerging industry that has been growing in the last years through the search for products more sustainable, from the economic, social and environmental points of view. Fuels, chemicals, and plastics obtained from renewable feedstocks are some of the products that technology-based startups and companies from distinct sectors, including chemical, petrochemical, oil and gas, food, agribusiness and paper and pulp companies are developing and commercializing (BOMTEMPO, 2013).

Emerging industries are characterized by high technological innovation rates in their initial stages, firstly towards the definition of the products and technologies that are going to become the industry standard (the so-called “dominant designs” or “enabling technologies”) and, then, towards the processes, to reduce production costs (ABERNATHY; UTTERBACK, 1978). The biobased industry is still characterized by major uncertainties, although it already counts with some relevant products in structuring process (such as cellulosic ethanol). Whereas drop-in[1] products emerge as an alternative to minimize impacts on markets and downstream assets, many new products present interesting properties e are gaining increased space. Furthermore, there is a wide variety of technologies and raw materials being tested to obtain such products (BOMTEMPO; ALVES, 2014), without a clearness of which of them will compose the dominant designs. Given these points, the biobased industry may reveal itself as a differentiated emerging industry for allowing the coexistence of different solutions.

In this context, dispose of certain flexibility to experiment may be a factor that favors the success of firm involvement in the industry, considering that specific opportunities may be economically unfeasible and/or hard to manage. Such flexibility tends to be especially important for startups, recently founded firms that posses limited resources[2] and seek partners to help them to advance innovative technologies.

Another characteristic of emerging industries is the presence of different actors. Incumbent firms are those that already posses established positions in technologies and markets, and that are somehow impacted by new technologies, positively or negatively. New established entrants are companies that posses positions in other industries and that envision new technologies as an opportunity to enter new markets and businesses. Finally, emerging firms are created to explore new technologies, as is the case of startups (HAMILTON, 1990).

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1 Produtos obitdos de fontes renováveis, cujas especificações são idênticas aos produtos de origem fóssil ou àqueles disponíveis de fontes renováveis, mas com baixa disponibilidade.

2 Por recursos, consideram-se tanto aqueles tangíveis, quanto os intangíveis, humanos e capacidades que as organizações possuem, controlam ou tem acesso de forma preferencial (HELFAT et al., 2007, p. 4).

The biobased industry encompasses some complicatings aspects regarding the actors involved. Firstly, it is hard to point out with clearity which group of companies would be the incumbents, since the variety of products that can be obtained from renewable resources is considerably wide (e.g. chemicals, plastics, fuels, functional food ingredients, health care products, etc). For some types of products, chemical/petrochemical companies would be the incumbents, but it is hard to generalize this affirmative to all of them. Moreover, the variety of new established entrants is large, which take advantage of the existence of significant complementarities in the industry. In other words, the resources necessary to structure the offerings are hold by distinct actors, including: access to feedstocks, commercial scale production capability, and sales and commercialization channels, besides technological know-how concerning different steps of production processes. Table 1 summarizes in general terms this distribution within the biobased industry, establishing a distinction between the resources the firm holds and the complementary ones that it needs to access.

Table 1 – Firms profiles and resources in the biobased industry

	Startup	Chemical and petrochemical	Agribusiness	Food ingredients	Oil and gas	Paper and pulp
Resources hold	Technology	Production; commercial	Access to feedstock; logistics	Biomass processing	Production; fuels commercial	Access to feedstocks; biomass pretreatment
Complementary resources	Access to feedstocks; production; commercial	Access to feedstocks; biomass processing and pretreatment; technology (biotechnology);	Technology; production; commercial	Technology; production; commercial	Access to feedstocks; biomass processing and pretreatment; technology (biotechnology)	Technology; production; commercial

Fonte: Adapted from Bomtempo et al. (2014)

This dissertation was developed to help in the comprehension of this complex and uncommon industrial environment, specifically through the study of the insertion of two types of companies in the biobased industry: technology-based startups and established chemical/petrochemical companies. Startups are pioneering companies that posses the required dynamism to advance embrionary technologies, sustained on its innovation capabilities and less strong organizational rigidity. The low entry barriers in the industry are allowing the participation of a great number of such companies. In general terms, established firms hold significant and necessary resources to bring renewable products to markets, but many times deal with dilemma of innovate or prioritize the maintenance of those business that currently constitute their main revenue sources. The chemical and petrochemical companies specifically tend to be substantially affected by the growth of the biobased industry, since many of the new products are to some extent alternatives to those normally obtained from fossil resources. Furthermore, these firms posses access to commercialization channels and hold important assets e capabilities related to the production of chemicals and applications development, which tend to make them critical partners for companies from other sectors.

In this manner, the analysis of insertion strategies of startups is suitable to deepen the knowledge regarding the experimentation flexibility in the industry. The study involving chemical/petrochemical companies, in turn, favors a more detailed view of the matter of complementarity e how mature firms are dealing with the challenges related to renewable based products, mainly considering the development of new technologies and the access to raw materials. The more relevant movements of these established firms within the industry are also highlighted, due to their repercutions in both existing business and in the evolution of the industry.

Since the general objective of this dissertation is to identify and discuss the insertion strategies diversity of established chemical/petrochemical companies and startups, a methodology relying on case studies was chosen, analyzing the movements of these firms in the context of the industry. These two groups of companies are first analyzed separately, in chapters in the format of research papers. Besides providing a practical view of the industry and of their different competitive strategies, these paper advance or revisit specific theoretical discussions. For the purpose of publication, both papers were written in English.

1.1 Dissertation structure and specific objectives

This dissertation is structured in four chapters, with this brief introdution as the first one of them.

Chapter 2 presents integrally the first paper, entitled "*Established firms in emerging industries: innovation strategies in the biobased industry*". This paper deals with the way through which established chemical and petrochemical companies are entering the industry, through the analysis of BASF, Braskem, DSM and DuPont. Its specific objectives are:

1) Analyze how these firms deal with the emerging technologies associated with the industry, with special emphasis on the manner they access innovations through partnerships or develop them internally.

2) Analyze how they are dealing with the access to complementary assets (TEECE, 1986), specially to those related to raw materials supply and processing.

3) Discuss these firms experimentation with new products, in a way to identify different diversification strategies.

Chapter 3 presents, also integrally, the second paper, entitled "*Exploring business model dynamics in emerging industries: the case of the biobased industry*". Discussing the technology-based startups, Amyris, Avantium, BioAmber, Genomatica, Metabolix e Solazyme were the firms selected to be studied, all of which were created around the year 2000. The paper has one main objective, to analyze factors affecting startups flexibility to experiment in business models. Because they are companies with limited resources that try to grow based on specific innovations, having such flexibility in their first years and being able to identify/shape the best opportunities tend to be crucial for their survival. Therefore, the comprehension of these factors is considerably important for startups and to other actors that are involved with them, like venture capital firms, for instance.

From the analysis of these factors, a decision flow chart was developed to evaluate the technological possibilities of startups and how such possibilities may be affected by some of the decisions related to business models.

Finally, Chapter 4 presents the conclusions of the two papers and final comments comparing their approaches. Limitations of the studies and recommendations for future researches are also discussed.

Chapter 2 - Paper 1: *Established firms in emerging industries: innovation strategies in the biobased industry*

Abstract

Despite a number of opportunities, emerging industries encompass an equally vast number of uncertainties. A complex industrial construction process characterizes the biobased industry, where biofuels and bioproducts are produced from renewable feedstocks using innovative technologies. Startups and firms in chemical and petrochemical, oil and gas, agribusiness, food ingredients and pulp and paper sectors, are leveraging their respective technological knowledge and assets in order to establish advantageous competitive positions in the industry. As such, firms' strategic decisions are not solely concerned about developing or accessing technological know-how, but also about complementary assets (CA). We analyze how chemical firms are entering the biobased industry, i.e. how they are managing the necessity of coping with emerging technologies, experimenting with new biobased products, and how they are approaching the issue of CA. We also discuss their market diversification strategies, providing practical insights on the industry and firms co-evolution.

We have carried an empirical multiple case study, focusing on the individual initiatives of 4 chemical companies on bioproducts in the last 20 years, namely BASF, Braskem, DSM and DuPont. In the last 5 years, the authors have been developing a research program aiming at contributing to the literature related to the biobased industry, and to our knowledge this sample is sufficiently diverse to highlight differences in the dimensions we propose. Our study largely dialogues with Hamilton's (1985) work on corporate strategies for managing emerging technologies.

We found that firms still identified with the chemical industry establish partnerships with startups as described by Hamilton (1985), but those willing to deeply incorporate emerging technologies in their business favor internalization of the related knowledge. We also perceived that internalizing know-how associated with renewable feedstocks proven to be challenging for many of these chemical companies, motivating partnerships with food ingredients firms. Finally, firms internalizing new knowledge (especially in biotechnology) are involved with chemicals with sharply growing markets, many times not related to their current portfolio and that are to be licensed. Firms whose main efforts are in matching biobased products with their current fossil-based offerings tend to assume a manufacturing profile, since they are able to easily fit the new offerings within existing operations.

2.1 Introduction

The scarcity of resources, increasing population and environmental concerns are some of the issues challenging our current fossil-based economy, spurring the emergence of the bioeconomy (or biobased industry). It includes sourcing fuels, polymers and chemical from renewable feedstocks, but also the biological manipulation of food products, development of biosensors, personalized medical treatment, etc (WHITE HOUSE, 2012). The large economical potential and societal benefits that the biobased industry is expected to offer is leading to a great mobilization of both public and private sectors, in a way to bring these innovations to market (BOMTEMPO, 2013; OECD, 2009; WHITE HOUSE, 2012).

Despite a number of opportunities, emerging industries encompass an equally vast number of uncertainties. Firms need to find the most suitable strategies in product/market positioning, marketing, servicing, as well as, product configurations and production technologies, while dealing with an innovation-intensive environment (PORTER, 1980). When it comes to producing biofuels or other bioproducts from renewable raw materials, the involvement of startups and firms in chemical and petrochemical, oil and gas, agribusiness, food ingredients and pulp and paper sectors, add complexity to the industrial construction process (BOMTEMPO, 2013). This change in feedstock base occurred previously in the chemical industry in the transition from coal to petroleum, but differently from the biobased industry, the petrochemical industry growth was attributed to the extensive availability of reactive molecules obtained from the petroleum refining to transportation fuels, rather than innovative technologies or market demand (SPITZ, 1988). Consequently, corporate strategies have to be aligned with more uncertain opportunities, taking in consideration the structuring of raw material supply, the design of new business models through experimentation and the access to complementary assets (CA) (TEECE, 1986).

While startups are very important sources of innovation (particularly derived from advanced biotechnology knowledge), many established firms detain important CA, including competitive manufacturing assets and know-how, access to distribution and marketing channels, after-sales and technical services, and complementary technologies and marketing. Therefore, different types of relationships between these technology-based startups and established firms emerge in industries facing radical technological change, which has been a relevant research topic. Arora and Gambardella (1990), for example, analyzed the complementarity of large firms' R&D strategies, in terms of external linkage with new entrants in the biotechnology field. Rothaermel (2001), in turn, studied the economic results of incumbent pharmaceutical firms that are more focused on increasing know-how on a new technology or that remain more distant from the technology (leveraging their advantageous position in CA). Hamilton (1985), in its paper on the advent of biotechnology during the 1970s and 1980s, presented an useful approach for understanding innovation strategies of established firms, highlighting three basic strategies, implemented in a general progression over time: window opening, creating options and establishing positions.

Although these studies elucidate corporate strategies for managing new technologies, different CA in the biobased industry are held by established companies from distinct industries (BOMTEMPO; ALVES, 2014) and the competences required to bring a product to market are vast and spread, which is likely to expand the degree of complexity in selecting partners. Our main goal in this paper is to analyze how established firms, particularly from the chemical and petrochemical industries (for sake of simplicity, from now on referred as "chemical industry") are entering the biobased industry. In other words, how they are managing the necessity of coping with emerging technologies, experimenting with new biobased products, and how they are approaching the issue of CA. We also discuss the role of emerging technologies in these companies' market diversification strategies, providing practical insights on the industry and firms co-evolution. Finally, we hope that our findings are helpful to the understanding of established firms' role in other complex emerging industries.

The remainder of this paper is structured as follows. We first present theoretical concepts required to support our analyses. Then, we present both the empirical setting and research methods. In the following section, we present our empirical findings and discussions. We conclude by outlining our contributions and additional research themes that scholars can pursue in the future.

2.2 Literature review

2.2.1 Raw material transitions in the chemical industry and innovation strategies

Prior to discussing the specificities of the biobased industry, it is convenient to briefly introduce how chemical firms evolved during the 20th century in face of the raw material shift from coal to petroleum. This will allow both a contextualization of the current moment of the chemical industry and the identification of general patterns of innovation. Perhaps the main trigger for the shift was the first mass-production of automobiles in the U.S. in the beginning of the 20th century and petroleum refining to produce gasoline, which led to a large and inexpensive supply of by-product molecules, especially olefins[3]. Local industrial dynamics and political issues, including the Second World War, resulted in different rates of petrochemicals development in different countries. The U.S. led the transition in the 1920s/1930s, while Germany switched later, around the 1950s/1960s (BENNETT; PEARSON, 2009).

Between the 1920 and 1960, fundamental research was extensively conducted by the leading chemical firms and resulted in a range of new petroleum-based synthetic products (CHANDLER, 2005). At this time, managers viewed research as necessary to compete and innovate, an idea supported by a number of successful projects. In the late 1960s,

[3] Olefins are important platform chemicals used as starting raw materials for a number of derivatives. Some of the most important olefins are ethylene, propylene and butadiene, employed in the production of the polyethylene and polypropylene plastics, and in synthetic rubbers, respectively.

management view towards fundamental research changed, due to difficulties in finding new products, increased competition in commodities, but also because of the oil crisis of the 1970s. From this point on, the major chemical companies turned to market-oriented research, investing in specialties and fine chemicals. Similarly to commodities, fine chemicals are products that are bought by customers due to their chemical compositions (e.g. food additives, agrochemicals and generic pharmaceuticals). Specialties, in turn, are products that solve specific problems or address certain needs (e.g. high performance plastics and cleaning products). Both of them are produced in low volume, but specialties are higher in margins and not so sensitive to cyclicality (VAN ROOIJ, 2007). Analyzing the evolution of chemical and pharmaceutical firms in the 19th and 20th centuries, Chandler (2005) highlights that these companies often failed to diversify to unrelated markets, as exemplified by DuPont relatively short involvement with pharmaceuticals. The author argues that the knowledge base historically developed by companies plays an important role in diversification strategies.

2.2.2 The biobased industry context

Our study largely dialogues with the insights from Hamilton's (1985) empirical research, since it encompasses a similar industrial scenario. The author analyzed the growing research on biotechnology in the 1970s and 1980s, mainly conducted by small, pioneering biotechnology firms, and how established pharmaceuticals, agricultural and chemical companies coped with this new trend[4]. By the beginning of the 1990s, most innovations using biotechnology commercialized were related to pharmaceuticals (HAMILTON, 1990). In the early 2000s a number of projects emerged with emphasis on biofuels production, spurring a new wave of innovative technologies where biotechnology could play a decisive role. However, although biofuels address the need for sustainable energy sources (primarily through ethanol and biodiesel for motor vehicles) and are demanded in large volumes, they are low value products. A major stream of literature argues that the economic feasibility of biobased products would be more easily achieved if biofuels production was conducted along with other high value biobased chemicals (BOZELL; PETERSEN, 2010; IEA, 2013). The opportunity of integrated production of biofuels and bioproducts rapidly expanded the range of products sought by innovators, which should grow in importance in the near future (COUTINHO; BOMTEMPO, 2011). Considering products innovations, there is a large number of promising molecules that could not be economically produced from traditional fossil raw materials (e.g. succinic acid and 1,3-propanediol), but the search for drop-in bioproducts is very significant as well. The latter are products obtained from renewable sources whose specifications are identical to either their fossil-based counterparts or other naturally occurring molecules with low availability, allowing the replacement of these without major adaptations in distribution infrastructure, transformation or use equipment (TEIXEIRA et al., 2016). There is been research on drop-in alternatives to gasoline, diesel and jet fuel, but also for

[4] An interesting point is that, by that time, DuPont was already investing in biotechnology, focusing mainly on pharmaceutical, but also in agricultural and chemical applications.

traditional platform chemicals used as starting raw materials for a large set of derivatives, including biobased ethylene and butadiene.

Chemical firms can be mostly regarded as incumbent in the biobased industry for being those companies with established positions in the markets to which applications of the new technologies are directed to. Their market skills in chemicals commercialization tend to lead to initial advantages when compared to established firms that are new entrants in the market (HAMILTON, 1990). In fact, to our knowledge, most movements of established firms from other industries in biobased chemicals, such as agribusiness, food ingredients and pulp and paper, are partnering with chemical firms.

Very diverse technological approaches are being pursued, including biochemical routes (relying on biotechnology advancements), thermochemical and chemical processes. Biochemical routes are of great interest, since allow the production of target molecules by engineered microorganisms, but microorganism selection or genetic modification and process scaling-up has proven to be challenging (BOMTEMPO; ALVES, 2014). The use of enzymes (proteins that speed up biological reactions, i.e. biological catalysts) in these new processes also became increasingly important. A major interest of the industry regards developing the so-called second-generation sugar, a potential feedstock in biological processes which derives from lignocellulosic material (e.g. agricultural and forest residues) and would be an advantageous alternative in both economic and environmental terms (BOMTEMPO; ALVES, 2014). The use of the well-established first-generation sugars as feedstock (obtained mainly from sugarcane and corn) is being questioned, due to a possible negative effect on food supplies (SIMS et al., 2008).

Another characteristic of the biobased industry is the change in raw materials base. The new feedstocks require the organization of efficient supply chains, since they are normally residues from other industries and procurement logistics have been accounted as a major component in bioprocesses production costs (MELÉNDEZ et al., 2012). Furthermore, efforts in agricultural technologies and biomass pre-treatment for further conversion are needed to reach economic feasibility. These characteristics generate at least three major issues for chemical companies. The first one is the need to deal with unfamiliar raw materials and with new process constrains, such as the risk of microbial contamination, managing microbial grow and production, recovering products from diluted streams, etc. The second one is that complementary assets (TEECE, 1986) related to feedstocks and some of the technological know-how are detained by companies from other industries (such as agribusiness, food ingredients and pulp and paper). The third one is the differences in prices and markets dynamics of some of important feedstocks (e.g. sugar cane), when compared to petroleum and natural gas.

Hamilton (1985) devised three progressive strategies to manage new technologies. The window strategy concerns mainly identifying and monitoring technological advancements, either through internal R&D or external linkages (e.g. equity investments, research grants). An options strategy would be a next stage, where a firm directs its strategic decisions towards a more restricted number of opportunities for future active participation. It is accomplished by internal programs and more focused R&D contracts, equity investments, licensing arrangements and joint ventures. Finally, a positioning strategy means that firms are staking out their competitive positions in selected technologies and markets. Specific R&D contracts, licensing arrangements, and joint ventures tend to support this strategy. This progression entails a growing resources commitment by the firm, and Hamilton (1985) identified a pattern of increased control over development efforts and reduced dependency on external organizations when uncertainties diminish over time, motivated by economic and managerial incentives. His work is placed in a time when industrial research departed from the centralization of the 1950s-1960s, to a context of more decentralization, increased cooperation and increased focus on the short-term, starting in the 1980s. The higher costs and complexity of technological projects, together with managerial concerns of commercial pay-off, led to industrial research being more linked with the companies' businesses (VAN ROOIJ, 2007).

Considering the wide variety and complexity of competences required in the biobased industry, the patterns identified by Hamilton (1985) regarding managing emerging technologies could have new facets. Chemical firms need to manage the development of new production processes, but there are incentives for agribusiness, food ingredients and pulp and paper companies to engage in biobased products as well, by leveraging their feedstock-related complementary assets and know-how in some of these new processes. Thus, there may be differences in alliances in the biobased industry when compared to the biotechnology advent studied by Hamilton (1985). We are interested in identifying these characteristics and how complementary assets may be important in selecting partners.

The following Section presents our research design and methods.

2.3 Research design and methods

Our research relies in an empirical multiple case studies, focusing on the individual initiatives of established chemical companies to advance bioproducts production and commercialization in the last 20 years. In the last 5 years, the authors have been developing a research program aiming at contributing to the literature related to technology and innovation dynamics in the biobased industry. To support this program, a proprietary data base was assembled from publicly available information, including specialized press (e.g. www.biofuelsdigest.com and www.greenchemicalsblog.com), special reports of governmental and international organizations (e.g. from DOE, OECD and IEA task 42), professional conferences, companies reports (e.g. 10k forms), books describing the companies' history, among others. Specifically for the purposes of this study, a systematic effort was conducted to gather clear and detailed information on each firm under analysis, including: the companies' history and major strategic shifts that indicated their entry in the biobased industry, main business lines, main products and research efforts in bioproducts, how they access required assets in different cases, which modes of partnerships they establish, etc. When it comes to large established companies, there is a multitude of research efforts, many of which are not publicly disclosed. Yet, we deem sufficient for our purposes to identify those that were already reported by the firms (more aligned with options or positioning strategies).

We select a total of 4 companies for this study, namely BASF, Braskem, DSM and DuPont. DuPont and DSM are examples of companies that are apparently conducting more intense reconfiguration to cope with new technologies (in many cases, industrial biotechnology) and to actively participate in the bioeconomy. BASF, in turn, is the largest chemical company in the world in sales and, despite a number of initiatives, seems to be comparatively more conservative. Finally, Braskem is recognized in the industry as a pioneer in bioproducts, with its green polyethylene. One of the advantages of multiple case studies is that it enables comparisons that clarify whether an emergent finding is merely idiosyncratic to one single case or replicated in various cases (EISENHARDT; GRAEBNER, 2007), and this sample is likely to be sufficiently diverse to highlight differences in the dimensions we aim to investigate.

The term bioeconomy still lacks a uniform definition within scientific and societal debates (GOLEMBIEWSKI et al., 2015), but was defined by the European Commission as "*…the sustainable production and conversion of biomass, for a range of food, health, fibre and industrial products and energy. Renewable biomass encompasses any biological material to be used as raw material*" (ALBRECHT et al., 2010). In the present study, we are more interested in the impacts of the bioeconomy in traditional platform chemicals, chemical specialties, polymers and fuels, despite the growing importance of both food and health products for some of the companies under analysis.

2.4 Empirical findings and discussion

2.4.1 Companies overview

Here we present an overview of the firm's trajectories and the most successful biobased products they are engaging in.

2.4.1.1 BASF

BASF (USD 78.7 billion in sales in 2014) is a global company with a vast portfolio of products and since 2006 has figured as the world's largest chemical producer in sales (TULLO, 2015). Founded in 1865 in Germany to produce chemicals necessary for dye production, between the 1920s and 1960s, the company relied consistently in its technical and engineering capabilities, producing mainly dyes, fertilizers and basic intermediate chemicals from coal[5]. After the Second World War, BASF initiated a gradual transition to use oil and gas feedstocks to diversify its range of

[5] Between 1925 and 1952, BASF was part of I.G. Farben, the giant German chemical company that was also composed of Bayer, Hoechst and smaller companies. Despite the merger, their organizational structures were basically unchanged, only reporting to a central administration (CHANDLER, 2005).

products, especially in polymers such as polyethylene and polymer-based textile fibers. This transition included joint ventures with Shell and Dow Chemical, and becoming a licensee of polyethylene manufacturingtechnologies from ICI (Imperial Chemical Industries). Despite such diversification and relevant positions in global markets, BASF competitive position depended on its traditional superior technical capabilities, which in the 1960s was being jeopardized by competitors, mostly American. One key solution to both reduce costs and maintain the focus on mass customization was creating large highly-optimized and vertical integrated production plants, a feature that distinguishes BASF until today. Another try was to forward integrate, i.e. move the company into end-use markets including tapes, some plastics and pharmaceuticals, but these initiatives did not succeeded. One of the positive outcomes of forward integration, however, was BASF expansion worldwide, breaking with the company's export tradition (ABELSHAUER, 2004). Path dependency is observed in BASF history and the company basically relies on its long lasting technical capabilities, being nowadays active in Chemicals, Performance Products, Functional Materials & Solutions, Agricultural Solutions and Oil & Gas (BASF, 2016a). Analyzing some of the BASF movements, it can be noticed an increased relevance of sustainability in the development efforts of the company, as shown by the introduction of eco-efficiency analyses in product and process development in 1999 (BASF, 2016a), the "BASF 2015" strategy in 2004, which highlighted the importance of environmental sustainability in the companies' activities (BASF, 2004) and, in 2011, by an update of the company's purpose to "We create chemistry for a sustainable future" (VOESTE, 2011).

One of the company's products with more sustainable appeal is Ecoflex®, the brand name of a polybutyrate adipate terephthalate (PBAT) plastic launched in 1998 by BASF. Ecoflex® is a biodegradable polymer obtained from fossil resources and is sold as an alternative to low density polyethylene (ILES; MARTIN, 2013). As argued by Hamprecht et al. (2011), BASF basically assesses sustainability of its products, so a non-biodegradable product obtained from renewable sources may not be mandatorily the best choice when compared to a biodegradable one derived from fossil resources. In 2003, BASF entered in a research collaboration agreement with Metabolix, a startup that have been developing polyhydroxyalkanoates (PHAs), a type of naturally occurring biodegradable plastic produced by bacteria. The main goal was to assess the incorporation of renewable raw material content to Ecoflex®, but the partnership was ended by BASF in 2004. Later in 2005, BASF introduced Ecovio®, a blend of its Ecoflex® and NatureWorks' polylactic acid (PLA), a biodegradable polymer obtained from corn (ILES; MARTIN, 2013). BASF has made increased research investments on bioplastics in general terms (GUZMAN, 2013), including the expansion in Ecoflex® production capacity in 2011 (BASF, 2011).

BASF produces nylons using biobased castor oil (under the name Ultramid® Balance) (SHERMAN, 2015) and castor-based polyols for flexible foams production, named Lupranol® BALANCE (BASF, 2016b), both of which were launched around 2007. In 2013, BASF became a licensee of a technology from Genomatica (a technology-based startup) for 1,4-butanediol (BDO) production, a chemical that may be used to manufacture polybutylene terephthalate (PBT) polymer. BASF is already a producer of both BDO and PBT from fossil routes (SCOTT, 2016). Furthermore, in 2016 BASF signed a letter of intent with Avantium (a technology-based startup) to establish a joint venture for production and marketing of 2,5-furandicarboxylic acid (FDCA) and polyethylene furanoate (PEF) polymer, which is seeing by the industry as a very promising material to replace PET (polyethylene terephthalate, used in plastic bottles and fibers), especially in food and drink packaging. The plant is to be constructed in BASF's site in Antwerp, Belgium, and after consolidating the technologies for FDCA and PEF, the technology is to be licensed (Scott, 2016).

BASF is also active in succinic acid production, through a joint venture with Corbion Purac (a global leader in lactic acid and its derivatives) called Succinity, formed in 2012. Succinic acid is a widely investigated biobased chemical platform (BOZELL; PETERSEN, 2010), which promptly replaced its fossil-based counterpart (produced in very limited quantities due to cost limitations) and has the potential to be largely demanded in the future (DE ARAÚJO, 2015). The basic technology is based on BASF proprietary bacterium that was first isolated in 2008 and Corbion Purac expertise in insolating succinic acid from the aqueous fermentation solution. Joint development was carried since 2009. A commercial 10,000 ton/year plant was set in 2014 at the Corbion Purac site in Montmeló, Spain, by modifying an existing fermentation facility (BASF, 2014). In recent years, Succinity has been carrying market development activities for its succinic acid, supplying producers of PBS (polybutylene succinate, an emerging biodegradable polymer), polyester polyols and coatings resins. The company indicates the possibility of a second plant, if sufficient market growth is perceived (BIO-BASED WORLD NEWS, 2015).

In the field of lignocellulosic sugars, BASF engaged in a non-exclusive joint development agreement with the American startup Renmatix in 2013, holder of a process for the production of industrial sugars based on lignocellulosic biomass. The parties have agreed to key financial terms for future commercial licenses, which BASF can choose to exercise. This agreement followed a $30 million investment of BASF in 2012 (BASF, 2013).

BASF also acquired in 2013 the biotechnology startup Verenium, specialized in the development of enzymes. Markets targeted by the firm include animal nutrition and petroleum exploration, but also corn grain processing in ethanol production. Although Verenium was small in size, the firm's enzymes library would contribute to BASF initiatives in the industry (NOEL, 2013).

Table 2 summarizes the main biobased products of the company, while Table 3 lists chronologically the main milestones in the last 20 years associated with its business trajectory in the biobased industry (including possible departures from traditional areas).

Table 2 – BASF's main biobased products

Product	Type of product	Type of company involvement	Similar chemicals in the company's current portfolio?	Main knowledge contributions	
				by BASF	by partner(s)
PBAT plastic (non biobased, but with a sustainability appeal)	Non drop-in	Producer	No, PBAT was the first experience with biodegradable materials	Own development	No direct involvement, only supply of bioplastics for blending
Castor oil based materials	Drop-in	Producer	Yes, materials entirely fossil-based	Own development	No direct involvement, only supply of castor oil
Bio-BDO	Drop-in	Producer (tech. obtained from licensing)	Yes, fossil BDO	Plant(s) construction and operation	Technology licensed by Genomatica
FDCA and PEF polymer	Non drop-in	Producer and licensor (joint venture with Avantium)	No	Plant(s) construction and operation	Avantium developed the basic technology
Succinic acid	Drop-in (in established uses)	Producer (joint venture with Corbion Purac)	No	Bacteria used in the process	Raw materials supply and plant operation
Lignocellulosic sugars	Bioprocesses raw material	Joint development and equity investment in Renmatix	No	Process scaling-up	Renmatix developed the basic technology

Table 3 – BASF main milestones associated with the biobased industry

Year(s)	Milestone	Brief description
1998	Product launching	Production of biodegradable PBAT plastic from fossil sources
1999	Organizational change	Introduction of eco-efficiency analyses in product and process development
2003	Supply agreement	Established with Metabolix to find biomaterials for blending with BASF's PBAT (terminated in 2004)
2005	Supply agreement	Established with NatureWorks to find biomaterials for blending with BASF's PBAT
2007	Product launching	Castor oil based materials
2009	Joint development	Signed with Corbion Purac to advance a technology for succinic acid
2012	Joint venture	Formation of the joint venture Succinity with Corbion Purac for succinic acid
2013	License agreement	BASF becomes a licensee of Genomatica's bio-BDO technology
	Joint development agreement	Agreement with Renmatix for lignocellulosic sugars
	Acquisition	Verenium (enzymes company)
2016	Joint venture	BASF signs a letter of intent with Avantium to form a joint venture on FDCA and PEF

2.4.1.2 Braskem

Braskem (USD 19.6 billion in sales in 2014, (TULLO, 2015)) is a Brazilian petrochemical company and the leading thermoplastic resins producer in the Americas (BRASKEM, 2016a). The company was created in 2002 through the integration of Copene and petrochemical assets from the Odebrecht and Mariani groups, later followed by the integration of other Brazilian chemical and petrochemical companies (BRASKEM, 2003). After its inception, Braskem established its Vision 2012, which main goal was to figure between the 10 largest petrochemical companies in the world until 2012 (ODEBRECHT, 2007). This goal was achieved in 2010 and the firm defined its Vision 2020, to become the global leader in sustainable chemistry by 2020, by increasingly incorporating renewable raw materials in its processes, but also improving sustainability aspects (e.g. water usage and energy efficiency) (FDC, 2010). In recent years, Braskem increased both its internal capabilities and the number of external research partnerships related to use of renewable resources to produce chemicals, including the installation of a laboratory for biotechnology research in the State of São Paulo, and cooperation agreements with the State University of Campinas (UNICAMP) and the Foundation for Research Support of the State of São Paulo (FAPESP) (BRASKEM, 2010; INVESTE SÃO PAULO, 2014).

The main driver for Braskem's deeper insertion in the biobased industry can be attributed to the success of its green polyethylene (PE) plastic, produced from ethylene obtained from sugarcane-based ethanol. The basic technology was developed by Petrobras' research center (CENPES) and employed by Salgema[6] to make the ethylene necessary for PVC manufacturing, during the 1980s. In the 1990s, the green ethylene production was ceased due to the loss of competitiveness of ethanol. Later in 2003, a client of Braskem from the car industry contacted the company willing to partner for developing green ethylene, in a strategy to find alternative materials to those sourced from fossil resources. Despite such interest, Braskem engaged in finding other potential buyers for its green plastic before truly investing (OROSKI, 2013). The first samples of the green PE were produced in pilot scale in 2007, receiving the European Bioplastics Award in the category "Best Innovation in Bioplastics" for developing a plastic made 100% from renewable resources (BRASKEM, 2016b). Such acceptance soon motivated the construction of the first green PE plant, announced in 2007 and started-up in 2010, with a 200,000 ton/year capacity. The plant was constructed in one of the company's petrochemical complexes in Brazil, where there were already polymerization facilities in-place. Main investments in assets were related to the ethanol-to-ethylene plant and logistics of ethanol delivering from third party producers. It is worth mentioning that the consolidated ethanol sector in Brazil favored the company's decision to stay apart from ethanol production (OROSKI, 2013). Green PE production continues to date, after expansions in the number of grades available and applications, which currently range from food packaging to personal hygiene products, and gardening applications, to car components (BRASKEM, 2016b).

Spurred by the success of green PE, Braskem also envisioned the possibility of making green polypropylene (PP) plastic and announced a commercial plant in 2010. Development partnerships dated back to 2008, including one with Novozymes, a world leader in enzymes and biotechnology solutions (GUZMAN, 2010). However, in 2013, the firm decided to at least temporarily freeze investments in new bioplastics plants to focus in

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[6] This company was a former polyvinyl chloride (PVC) producer whose assets were also incorporated when Braskem was created.

building traditional petrochemical facilities with a view to increase cash generation, also putting on hold the plans for a second green PE plant announced in 2011 (BERESFORD, 2013). The development partnership with Novozymes was eventually terminated due to difficulties in achieving technical milestones (NOVOZYMES, 2014).

In 2014, Braskem joined the partnership of Michelin and Amyris (a technology-based startup) initiated in 2011, dedicated to developing a technology for isoprene from renewable sources, a chemical used in synthetic rubber. Braskem is already a producer of isoprene via petrochemical route and participate in the joint development focusing on the extraction/purification of isoprene obtained through Amyris' bioprocess. Braskem will share with Amyris the rights to commercialize the technology, while Michelin maintain certain preferential, but not exclusive, access to the isoprene produced from such technology (MICHELIN, 2014).

Since 2013, Braskem is also in a partnership with Genomatica, to find biological routes to produce butadiene, a platform chemical produced by Braskem from fossil sources and used in synthetic rubbers. Braskem was held responsible for funding the construction and operation of pilot and demonstration-scale plants using the technology, in return for exclusive license rights to use the process in the Americas. Genomatica will receive fees and royalties for each licensed commercial plant, besides financial and resources contributions from Braskem to advance the technology (GENOMATICA, 2013). In the last years, the companies conducted joint screening efforts to find the most advantageous route and in 2015 were producing butadiene in laboratory scale (GENOMATICA, 2015a; ISTOÉ, 2015).

Table 4 summarizes the main biobased products of the company, while Table 5 lists chronologically the main milestones in the last 20 years associated with its business trajectory in the biobased industry (including possible departures from traditional areas).

Table 4 – Braskem's main biobased products

Product	Type of product	Type of company involvement	Similar chemicals in the company's current portfolio?	Main knowledge contributions	
				by Braskem	by partner(s)
Green PE plastic	Drop-in	Producer	Yes, fossil-based PE	Own development	No direct involvement, only supply of ethanol
Green PP plastic	Drop-in	Joint development with Novozymes (terminated) and universities	Yes, fossil-based PP	Not well specified	Not well specified
Bio-isoprene	Drop-in	Joint development with Amyris and Michelin	Yes, fossil-based isoprene	Contributes with product separation and purification	Amyris developed the basic technology, supported by Michelin
Bio-butadiene	Drop-in	Joint development with Genomatica	Yes, fossil-based butadiene	Microorganism selection, plant(s) construction and operation	Genomatica uses its simulation capabilities to develop the basic technology

Table 5 – Braskem main milestones associated with the biobased industry

Year(s)	Milestone	Brief description
2007	Product launching	Production of pilot quantities of green PE, followed by the announcement of a commercial plant
2008	Joint development agreement	Established with Novozymes for green PP production
	Research agreement	Cooperation with UNICAMP University and with FAPESP, both towards bioplastics
2013	Joint development agreement	Signed with Genomatica to advance a technology for bio-butadiene
2014	Joint development agreement	Braskem joins Amyris and Michelin to advance a technology for bio-isoprene
	Joint development agreement terminated	Partnership with Novozymes terminated due to difficulties in achieving technical targets
	Construction of research laboratory	Corporate laboratory in LNBio facilities, in the State of São Paulo, Brazil, main projects concerned production of bio-propylene (used in PP production), bio-butadiene, microorganisms engineering and continuous improvement of the green PE technology

2.4.1.3 DSM

Royal DSM (USD 12.3 billion in sales in 2014, (TULLO, 2015)) is a global company founded in the Netherlands in 1902 as a coal-mining company that initially engaged in the chemical industry through fertilizers in the 1930s, acquiring the technology from third parties. DSM did not figured as a pioneer in the chemical industry and corporate R&D only begun around this date. After the Second World War, the firm diversified further in the chemical industry, with intermediates of nylon, other intermediates and plastics. In the 1960-1970s, DSM also invested in the exploitation of oil and natural gas, and in forward integration, participating in plastic products, textiles and construction, for example. With the decline of its coal business and the limited value of the chemical commodities produced (suffering from increased competition), around the 1980s DSM turned its efforts to high value-added products, including high-performance materials and fine chemicals (VAN ROOIJ, 2007). A more profound involvement with the biobased industry started around the mid-1990s, when the company decided to focus on both the life sciences (mainly concerning nutrition and pharmaceuticals) and the materials sciences (performance materials), grounded on its Vision 2005 plan. Such plan included the selling of DSM's petrochemical business to SABIC in 2002 and a number of acquisitions related to health and nutrition areas, including Roche Vitamins & Fine Chemicals in 2003 (JEANNET; SCHREUDER, 2015). Research on biotechnology was already present in the 1980s, mostly through collaboration agreements with other companies and research institutes, focusing on fine chemicals (e.g. amino acids) and agro solutions (e.g. in biological nitrogen fixation as an alternative to fertilizers). Yet, its short-term effect was minimal, as no new business developed from these efforts (VAN ROOIJ, 2007). Aligned with its Vision 2010 portfolio transformation plan, DSM declared innovation as fundamental for achieving sustainable growth and took actions to enhance innovation within the company (ICIS CHEMICAL BUSINESS, 2005; SCHREUDER, 2012). From 2010 onwards, DSM undergoes the strengthening of its operations in health, nutrition and materials by establishing a number of partnerships and conducting specific acquisitions (DSM, 2010, 2016a), but also entering partnerships with the ultimate aim of exiting specific areas, such as pharmaceuticals and polymer intermediates (e.g. caprolactam, acrylonitrile and composite resins) (DSM, 2015).

Currently, DSM Biobased Products & Services is one of DSM's three Emerging Business Areas that the firm established in the last 5 years, along with DSM Biomedical and DSM Advanced Surfaces (that encompasses solutions for solar energy) (DSM, 2015). Perhaps the main product targeted by DSM in the biobased field is cellulosic ethanol, a biofuel obtained from crop residues. The company seized this opportunity by establishing a joint venture with POET, an ethanol, food and feed products manufacturer, forming POET-DSM Advanced Biofuels in 2012. POET's efforts in developing a cellulosic ethanol technology date back to 2001, when the company started bench-scale tests (POET, 2016), and included a USD 80 million grant of the U.S. Department of Energy (DOE). DSM's engagement in turn was more focused on enzymes and yeasts enhancement, including DOE grants for enzymes development in 2008 (CURTIS, 2008), licensing of a modified yeast from TU Delft and the Kluyver Centre (BIOFUELS JOURNAL, 2011) and acquisition of C5 Yeast Company B.V. (DSM, 2011), the last two occurring in 2011. Back in 2009, POET was already intending to begin the construction of a cellulosic ethanol plant in its Emmetsburg site, in Iowa, USA, scheduled to be operational in 2011. With the joint venture, the companies were able to combine their own developments and the Emmetsburg facility eventually began operation in 2014, with continued funding of the DOE (WARD, 2015). POET-DSM Advanced Biofuels currently offers its technology for licensing, but also intends to incorporate it in existing POET's ethanol facilities. Meanwhile, DSM still provides enzymes and yeasts to other companies interested in producing cellulosic ethanol (BIOFUELS DIGEST, 2012; GRANBIO, 2012).

Another major product pursued by DSM is succinic acid. The firm was already a producer using traditional chemical routes, but established a joint venture in 2010 called Reverdia with the French company Roquette Frères to produce succinic acid from renewable raw materials. Roquette is a starch and starch-derivatives manufacturer and the beginning of their relationship was associated with the launching of the BioHub™ program in mid-2006, which was promoted by the Industrial Innovation Agency of France and coordinated by Roquette to spur technologies for isosorbide, isosorbide diesters and succinic acid (ROQUETTE, 2015). The partnership begun officially in 2008, followed by the opening of a demonstration plant in France in 2009 and, subsequently, by the startup of a commercial plant at the end of 2012, in Cassano Spinola, Italy, in a Roquette site (REVERDIA, 2016). In rough terms, this joint venture brought together Roquette's expertise in bioprocessing with DSM's downstream position and growing expertise in industrial biotechnology. Reverdia is currently pursuing direct sales of its products and conducting market development activities, but also offers its bio-succinic acid technology for licensing. In these licensing arrangements, besides the royalties paid by the licensees, succinic acid that is not directly used by the licensees to produce derivatives must be sold to Reverdia (LUBBEN, 2016), which guarantees the company some control over this growing market.

DSM is also incorporating biobased content to some of its materials. In 2013, the company tested bio-BDO as a replacement to fossil BDO, used in its thermoplastic copolyester elastomer Arnitel®. Rapeseed oil derivatives were already used to confer biobased content to the material, launched in 2010, but the bio-BDO would increase it. DSM plans to incorporate bio-BDO when commercial supply becomes available (DSM, 2013). Similarly, DSM's EcoPaxx polyamide 410 launched in 2010 is derived from castor oil, with up to 70% biobased content (DSM, 2016b).

Further details on other bioproducts previously sought by the company, including bio-caprolactam, bio-adipic acid and bio-butanol (ICIS CHEMICAL BUSINESS, 2011; SIJBESMA, 2008) were not recently disclosed.

Table 6 summarizes the main biobased products of the company, while Table 7 lists chronologically the main milestones in the last 20 years associated with its business trajectory in the biobased industry (including possible departures from traditional areas).

Table 6 – DSM's main biobased products

Product	Type of product	Type of company involvement	Similar chemicals in the company's current portfolio?	Main knowledge contributions	
				by DSM	by partner(s)
Cellulosic ethanol	Drop-in	Producer and licensor (joint venture with POET)	No	Enzymes and yeasts enhancement	Raw material, plant operation and its own development efforts
Succinic acid	Drop-in (in established uses)	Producer and licensor (joint venture with Roquette Frères)	Yes, fossil-based succinic acid	Mainly in biotechnology	Bioprocesses expertise
Materials with biobased content	Drop-in	Producer	Yes, materials entirely fossil-based	Own development	No direct involvement, only supply of plant oils

Table 7 – DSM milestones associated with the biobased industry

Year(s)	Milestone	Brief description
Mid-1990s	Organizational change	Corporate focus on life sciences and materials science
2002	Organizational change	Selling of DSM's petrochemical business
2008	Internal research efforts	DSM awarded with grants for enzymes and yeasts development for cellulosic ethanol
	Joint development	Partnership with Roquette Frères to advance succinic acid technology
2010	Joint venture	Formation of the joint venture Reverdia with Roquette Frères for succinic acid
	Product launching	Castor oil and rapeseed oil based materials
2011	License agreement	Modified yeast from TU Delft and the Kluyver Centre associated with cellulosic ethanol
	Acquisition	C5 Yeast Company B.V., associated with cellulosic ethanol
	Organizational change	Partnership with Sinochem related to exiting pharmaceuticals (DSM, 2015)
2012	Joint venture	Formation of the joint venture POET-DSM Advanced Biofuels with POET for cellulosic ethanol
2014	Organizational change	Partnership with Patheon related to exiting pharmaceuticals (DSM, 2015)
2015	Organizational change	Partnership with ChemicalInvest related to exiting plastics intermediates and composite resins (DSM, 2015)

2.4.1.4 DuPont

DuPont (USD 29.9 billion in sales in 2014, (TULLO, 2015)) is a global company founded in the USA in 1802 to produce black powder and other explosives, which were the company focus until the beginning of the 20th century, when it departed from explosives and begun to produce specialty chemicals. DuPont's growth was truly sustained on its pioneering research on polymers and plastics, starting with nylon in the

1930s. In the 1960s, when the firm noticed both the maturation of its major products and increased competition (especially in textile fibers), there was an attempt to develop products for markets that were new to DuPont, but it proved unsuccessful as most products were extensions of existing fields, rather than bold moves into new areas. Following more defensive strategies during the global economic downturn in the 1970s, DuPont decided in the 1980s to focus its exploratory research on the life sciences, which included agricultural chemicals, pharmaceuticals and molecular biology (HOUNSHELL; SMITH, 1988). In the early 1990s, the firm was involved with chemicals, fibers, polymers and oil, besides pharmaceuticals (CHANDLER, 2005). But in the beginning of the 2000s, with its new CEO Chad Holliday, DuPont established its Sustainable Growth Goals, in which 25% of revenues were to be derived from businesses not requiring depletable raw materials and 10% of the company energy needs would be derived from renewable resources by 2010 (KURIAN, 2005). Additionally, DuPont created and deployed a strategy focusing on integrated science, knowledge intensity, and productivity improvement, in a way to keep or enhance shareholder value while reducing quantities of products (HOLLIDAY, 2001). Aligned with these changes, the firm exited the energy and textile fibers sectors in the following years (ICIS CHEMICAL BUSINESS, 1998, 2003). Competing with long-established pharmaceutical companies also proved to be challenging and DuPont sold its recently founded pharmaceutical business in 2001 (CHANDLER, 2005).

Until 2010, DuPont was mainly focused on 7 segments, namely Agriculture and Nutrition, Electronics and Communications, Performance Chemicals, Performance Coatings, Performance Materials, and Safety and Protection. Despite a number of efforts in biobased products in the 2000s, only after the acquisition of Danisco in 2011, Industrial Biosciences became one of the main business segments of DuPont. The Danisco transaction included specialty food ingredients, but also Genencor, Danisco's enzymes division (DUPONT, 2010). Other acquisitions followed, including Verdezyne's Xylose Isomerase Technology in 2012 to enable microbial consumption of sugars with 5 carbons (C5) (VERDEZYNE, 2012) and Dyadic's biotechnology assets related to enzymes production (DUPONT, 2015a). In 2013, DuPont indicated a major R&D campaign in the company to replace over 50% of its plastic portfolio with biobased versions within the next 15 years (PLASTICS TECHNOLOGY, 2013). By the end of 2015, DuPont announced a merger with Dow Chemical, the second largest chemical company in the world (USD 58.2 billion in sales in 2014, (TULLO, 2015)), which will be followed by the separation of their combined businesses in three companies, focused on agriculture, specialty products and material science, respectively (DUPONT, 2015b). The real impact of such decision to the companies' portfolio is yet to be seen.

DuPont Industrial Biosciences deals with biomaterials, process technologies and enzymes for different purposes (including biomass processing for biofuels production, detergent enzymes for cold-water washing and enzymes for animal feed) (DUPONT, 2015c). Biomaterials were one of the first movements of DuPont in the biobased industry context, back in the 1990s with 1,3-propanediol (PDO) and its derivative polytrimethylene terephthalate (PTT) polymer. PTT is said to have more advantageous properties over

PET and some nylons (used in fibers, films and shapes), but the absence of low cost PDO from fossil sources hindered its production (KURIAN, 2005). To find a more sustainable source of PDO, DuPont entered a partnership with Genencor to develop and enhance microbial production of PDO in 1995 (ILES; MARTIN, 2013) and later, in 2000, established a joint development agreement with Tate & Lyle (a leader in carbohydrate processing and provider of specialty food ingredients) for developing the manufacturing process (TATE & LYLE, 2000). The later relationship evolved in the following years and the DuPont Tate & Lyle Bio Products joint venture was formed. After the construction of a pilot plant, in 2006 the joint venture built a commercial PDO plant in Tate & Lyle's Loudon site, in Tennessee, USA, which is supplied with corn sugar raw material (CHEMICALS TECHNOLOGY, 2016). Although PTT is still the main application of PDO (MARKETSANDMARKETS, 2016) and was initially the main target of DuPont, over the years different uses of PDO other than in polymers manufacturing started to gain space, including cosmetics and personal care products, engine coolants, food and flavors (DUPONT TATE AND LYLE BIO PRODUCTS, 2016). Additionally, PDO is being used to increase biobased content in some of DuPont's materials, such as Hytrel® RS thermoplastic elastomer launched in 2009 (SHERMAN, 2015), and to create new materials, including Cerenol® polyols launched in 2007 (DUPONT, 2016).

In biobased materials, DuPont is also using castor oil as a raw material for biobased nylon resins, named Zytel® RS, which was launched in 2009. Different grades are available with renewable content from 20-100% (SHERMAN, 2015). In biobased isoprene, a collaborative research agreement between Goodyear and Genencor (later acquired by DuPont) was established in 2008, but no recent news were found. Additionally, in 2016 DuPont entered a development partnership with ADM, a leading agricultural processor, to produce furan dicarboxylic methyl ester (FDME), a monomer for polytrimethylene furandicarboxylate (PTF) and polyethylene furanoate (PEF) polymers (SCOTT, 2016).

Another important bioproduct of DuPont is cellulosic ethanol. Since the beginning of the 2000s, the firm started working with DOE's National Renewable Energy Laboratory (NREL), focusing in developing an improved bacterium for fermentation of biomass sugars into ethanol and also a pretreatment process suitable for corn stover residues. More than 10 joint DuPont-NREL U.S. patents were issued in these two areas (DOE, 2015). In 2008, the DuPont Danisco Cellulosic Ethanol[7] joint venture was formed, bringing together Genencor (a division of Danisco) enzyme technologies and the work carried by DuPont and the NREL (GREEN CAR CONGRESS, 2008). Since 2000, Danisco was involved in developing a technology for producing ethanol from biomass (DANISCO, 2006). In a joint project with the University of Tennessee Research Foundation, DuPont built a demonstration plant in Vonore, Tennessee, USA, to research ways to make cellulosic ethanol from switchgrass and other crops. The facility was inaugurated in 2010 and closed in 2015, following the opening of DuPont's Nevada (Iowa, USA) facility, the world

[7] DuPont Cellulosic Ethanol dropped the "Danisco" portion of its name after the acquisition of Danisco by DuPont, in 2011.

largest cellulosic ethanol plant (THE DAILY TIMES, 2015). For this new plant, DuPont managed to contract local farmers to gather, store and deliver corn stover (PROVINE, 2014) and partnered with the company Pacific Ag, specialized in collecting excess crop residue from growers and operating the required equipment (PETTIT, 2015). The Nevada facility is a commercial-scale demonstration of both the cellulosic technology and the challenging feedstock supply chain, which are incorporated in DuPont's licensing strategy[8]. A first licensing agreement was already announced with the Chinese company New Tianlong Industry (BIOFUELS DIGEST, 2015a).

DuPont also have a joint venture with the oil & gas company BP, called Butamax. It was formed in 2009 aiming at licensing isobutanol technology to existing ethanol producers. Isobutanol has the potential to be a fuel blend and would be an interesting alternative for ethanol producers aiming at diversifying their products. A facility was constructed for an ethanol producer, but it is not in operation (BIOFUELS DIGEST, 2015b).

Table 8 summarizes the main biobased products of the company, while Table 9 lists chronologically the main milestones in the last 20 years associated with its business trajectory in the biobased industry (including possible departures from traditional areas).

[8] DuPont offers feedstock supply consulting along its cellulosic ethanol technology, including feasibility studies, planning and execution (PROVINE, 2014).

Table 8 – DuPont's main biobased products

Product	Type of product	Type of company involvement	Similar chemicals in the company's current portfolio?	Main knowledge contributions	
				by DuPont	by partner(s)
PDO	Drop-in (in established uses)	Producer (Joint venture with Tate & Lyle)	No	Microbial enhancement	Raw material and manufacturing process
PDO-based materials	Non drop-in	Producer	Only those in which PDO replaces fossil content	Own development	None
Castor oil based materials	Drop-in	Producer	Yes, materials entirely fossil-based	Own development	No direct involvement, only supply of castor oil
Bio-isoprene	Drop-in	Joint development with Goodyear	No	Not well specified	Not well specified
FDME monomer, PTF and PEF plastics	Non drop-in	Joint development with ADM	No	Not well specified	Not well specified
Cellulosic ethanol	Drop-in	Joint development with Genencor (later acquired)	No	Bacterium for fermentation and biomass pretreatment	Enzymes and process advanced by Genencor
Isobutanol	Drop-in	Joint development with BP	No	Not well specified	Not well specified

Table 9 – DuPont milestones associated with the biobased industry

Year(s)	Milestone	Brief description
1995	Joint development	Partnership with Genencor to develop and enhance microbial production of PDO
1998	Organizational change	Selling of DuPont’s textile fibers business
2000	Joint development	Established with Tate & Lyle for developing the manufacturing process for PDO
	Joint development	Established with DOE’s NREL, focusing on cellulosic ethanol
	Organizational change	Establishment of DuPont’s Sustainable Growth Goals
2001	Organizational change	Selling of DuPont’s pharmaceutical business
2003	Organizational change	Selling of DuPont’s energy business
2004	Joint venture	Formation of the joint venture DuPont Tate & Lyle Bio Products with Tate & Lyle for PDO
2007	Product launching	Plastics based on PDO produced by DuPont Tate & Lyle Bio Products
2008	Joint venture	Formation of the joint venture DuPont Danisco Cellulosic Ethanol with Danisco
2009	Product launching	Plastics based on PDO produced by DuPont Tate & Lyle Bio Products
	Joint venture	Formation of the joint venture Butamax with BP for isobutanol
	Product launching	Castor oil based materials
2011	Organizational change	Acquisition of Danisco (including Genencor) and formation of DuPont Industrial Biosciences
2012	Acquisition	Verdezyne’s Xylose Isomerase Technology, to enable microbial consumption of sugars with 5 carbons

Table 9 – DuPont milestones associated with the biobased industry (cont.)

Year(s)	Milestone	Brief description
2015	Acquisition	Dyadic's biotechnology assets related to enzymes production
	Organizational change	Merger with Dow Chemical
2016	Joint development	Partnership with ADM for FDME monomer, PTF and PEF plastics

2.4.2 Forms of accessing knowledge in the biobased industry

In general terms, there are a number of interfirm synergies that can arise from strategic alliances, including managing risk and uncertainties, cost sharing, low cost entry into new markets (especially in foreign countries) and into new industries, etc. (BARNEY, 2007). In the cases previously presented, there are limited examples of established firms carrying technology or product development on their own. BASF developed its biodegradable plastic without remarkable partnerships, but using conventional fossil raw materials. The firm later partnered with the startups Metabolix and NatureWorks aiming at producing polymer blends, but the initial effort to produce Ecoflex® was mainly from BASF itself. The green PE of Braskem is another example. The company took advantage of a technology already available and managed it in a way to minimize costs, using existing polymerization assets and buying the ethanol raw material from third party producers.

Far more common though, especially in the scenario of an emerging industry as the biobased, are chemical firms seeking strategic alliances to access new technologies, many times with startups. In a similar fashion as described by Hamilton (1985), some established firms assume positioning strategies in new promising technologies by joining efforts with these startups. Examples include: BASF license agreement with Genomatica for the bio-BDO technology and its future joint venture with Avantium; Braskem partnership with Amyris and Michelin for isoprene (where Michelin's main goal would be to later incorporate renewable content in its products), and with Genomatica to produce butadiene. Interestingly, neither DSM nor DuPont maintain technological alliances with startups, at least not in those technologies that currently encompass their main efforts in the biobased industry. These companies seem to have rather a stronger focus on enhancing their capabilities related to industrial biotechnology. For instance, DSM became a licensee of TU Delft and the Kluyver Centre modified yeast and acquired C5 Yeast Company B.V., both aiming at cellulosic ethanol. DuPont, in turn, acquired its long-time partner Genencor and Dyadic's biotechnology assets related to enzymes production. For DuPont, partnering with biotechnology startups (as Genencor was in the 1980s) led to early involvement in the industry (with PDO in 1995), while DSM was only lightly involved with these pioneering companies in the 1980s and no businesses developed from these relationships in the short-term.

Therefore, technological alliances with startups in positioning strategies, as described by Hamilton (1985), may be more suited for companies that are in a process of adapting to emerging technologies, i.e., when the existing technologies and businesses are favored, as BASF and Braskem seem to do. Firms that, in face of the rise of the biobased industry in the beginning of the 2000s acknowledged these new technologies as major part of its current and future businesses may be rather more motivated to internalize some of the related knowledge to find new innovation paths, the cases of DSM and DuPont. It does not prevent, however, other forms of strategic alliances with startups such as equity investments, but they are more characteristic of window and options strategies (HAMILTON, 1985). In fact, both companies have corporate venturing arms investing in startups, as well as BASF. We will discuss the matter of technology base adaptation and transformation later in this paper.

Internalizing know-how associated with renewable raw materials proven to be challenging for many of these chemical companies. Most initiatives analyzed already in commercial phase are the result of partnerships with firms from agribusiness or food ingredients sectors. In succinic acid, BASF is in a joint venture with Corbion Purac, a company with long term experience in fermentation technologies that targets food ingredients, biochemical and innovations in the biobased industry such as polylactic acid (PLA) (CORBION, 2016). DSM is in a joint venture with the ethanol producer POET for advancing cellulosic ethanol technology and in a joint venture to produce succinic acid with Roquette Frères, a starch and starch-derivatives manufacturer. Finally, DuPont developed PDO through a joint venture with Tate & Lyle (a leader in carbohydrate processing and provider of specialty food ingredients). In all these cases, the commercial facilities are placed in the partner's sites, taking advantage of existing raw material supply (and other common industrial requirements, such as steam, cooling water and other utilities). Furthermore, the production processes were a result of a combined expertise, where the chemical firms contributed especially with the microorganisms (i.e., a focus on industrial biotechnology) and the partners with biomass processing, product recovery, etc.

The efforts of DuPont in cellulosic ethanol share some similarities, such as the joint venture with Danisco in 2008, a food ingredients and enzymes company, but there was also a relevant participation of governmental organizations (the DOE and NREL). Governmental policies are viewed as very important to promote innovation and commercialization in the biobased industry (GOLEMBIEWSKI et al., 2015). Moreover, differently from the other chemical companies, DuPont strategy was to develop feedstock management know-how in order to offer it as part of its licensing package. This is aligned with the firm strategy of providing solutions across the biomass value chain, from seed technology and crop protection, to cellulosic ethanol technology (PROVINE, 2014).

As expected, there are usually large incentives in the biobased industry context for agribusiness and food ingredients firms to participate in new processes development, leveraging their capabilities, but the case of Braskem's green PE showed that it is possible for chemical companies avoid these partnerships if conditions are favorable (such as the availability of ethanol supply in Brazil). From the chemical companies' side, these partnerships have proven to be an interesting way to both advance technologies and take advantage of interfirm synergies, like managing risk and cost sharing. Joint development agreements followed by joint ventures are apparently the preferred modes of partnerships in these cases. Even so, chemical companies may take strategic decisions towards increasing their knowledge regarding feedstock management in a way to better position in the industry, as demonstrated by the DuPont strategy in cellulosic ethanol.

2.4.3 Insights on companies' strategies

Despite these differences, all companies recognize the growing importance of biological sciences for the future of the chemical industry and are investing in knowledge building. It favors a better understanding of opportunities associated with these new technologies and the propensity to innovate, through the renovation of technological trajectories (QUINTANA-GARCÍA; BENAVIDES-VELASCO, 2008).

Among the chemical companies analyzed, it can be noticed different insertion strategies in the biobased industry. On one side, Braskem is mostly engaging in products aligned with its current business, favoring biobased versions of chemicals produced from fossil sources, usually referred as "drop-in". These are products obtained from renewable raw materials that can integrally use the CA in-place and follow the same specifications of their fossil-based counterparts (TEIXEIRA et al., 2016), i.e., demanding minimum adaptations downstream. Green PE and the researches on polypropylene, butadiene and isoprene, all of which are already produced by the company, support this affirmative. Braskem tends to assume a manufacturing and commercialization profile, since it is able to easily fit the new offerings within its existing operations.

On the other one, both DSM and DuPont are promoting more profound changes to their capabilities and placing biotechnology as a key feature of their biobased insertion. An interesting finding is that such knowledge is being used to develop technologies for chemicals not currently produced by the companies, which many times are to be licensed. DSM positioned as a licensor of both cellulosic ethanol and succinic acid[9] technologies, while DuPont has a significant effort in cellulosic ethanol. Investing in important drop-in products and in those with major potential (such as cellulosic ethanol and succinic acid, respectively) would be a way to promote short- to medium-term leading technological positions. In the situations where chemical firms are not incumbents in specific markets, the cases of DSM and DuPont entering the biofuels business, a technology licensing strategy minimizes expenditures with CA.

[9] Although DSM was a producer of succinic acid, production through fossil route is very limited and the emerging markets for bio-succinic acid are significantly different from the traditional ones.

In an intermediate strategic approach, BASF seem to position in both ways. The company chose to invest in a fossil-based polymer (PBAT) with a value proposition associated with sustainability, similarly to biobased polymers of other companies, but taking advantage of its current position in chemicals and petrochemicals. Becoming a licensee of Genomatica's technology for bio-BDO, a drop-in product, also permit an easier fit with the assets in-place. Yet, BASF entered relationships aiming at position in emerging markets, like in succinic acid and in the FDCA/PEF partnership with Avantium. Whereas the latter is being drafted as a partnership for licensing the FDCA/PEF technology, the former entails a producing strategy.

2.4.4 Technology base adaptation or transformation

The question of whether the form of accessing knowledge (partnering with startups or internalizing) is a good indicative of firm technology base adaptation or transformation deserves further discussion, since it is related to the firms' strategies when entering the biobased industry, their innovation paths and diversification strategies. First of all, companies are more or less inclined to transform themselves depending on their historical of technological shifts. BASF is a company that hardly changed their target markets during the years, expanding based on well-established technological competences. Braskem, perhaps due to its comparatively shorter life, does not indicated major shifts from its commodity petrochemicals business since its formation. DSM, in turn, begun as a coal-mining company, entered the chemical industry in fertilizers, diversified in commodity chemicals, and in the mid-1990s turned to the life sciences and material sciences, selling its petrochemical business. Similarly, DuPont started in chemicals used in explosives, pioneered in plastics in the 1930s, advanced in petrochemicals and in textile fibers, and, in the 1980s, turned to the life sciences. DuPont's commitment to the new field was supported by the selling of its energy and textile businesses. As their histories indicate, DSM and DuPont seem more prone to commit to the biobased industry. Yet, it is worth noting that these emerging opportunities are aligned with the so-called life sciences. Nutrition and health are sectors increasingly relying on biotechnology techniques, and some synergies between those and the production of biobased chemical products through biochemical routes may be expected. Therefore, for DSM and DuPont opportunities related to the biobased industry seem to be emerging along with favorable internal contexts.

At this point, Freeman's (1997) discussion on firms innovation strategies comes to hand. The author proposes 6 alternative strategies, of which the offensive, defensive and imitative are the 3 crucial ones. An offensive innovation strategy is designed for a company to achieve technical and market leadership by being the first to introduce a breakthrough product. Due to the risks, this is often the exception than the rule. A firm pursuing a defensive innovation strategy does not attempt to be the first, but follow the leaders close behind, trying to appropriate and, if possible, improve the new product. Although an offensive strategy encompasses significant investments in research, so does the defensive strategy. Defensive innovators may be less prompt to assume the risks of being the first, may lack capabilities required for more original innovations and/or may be simply outpaced by more successful competitors. Finally, a firm pursuing an imitative strategy is mainly focused on diversifying, but minimizing costs, and does not attempt to catch up with the leaders. These strategies are considered a spectrum of possibilities rather than clearly distinguishable forms (FREEMAN, 1997).

The biobased industry presents some important innovative products, such as PEF replacing PET in bottles and food packaging and succinic acid that can be an important chemical platform in the future, but also drop-in alternatives including cellulosic ethanol. Freeman (1997) argues that large multi-product chemical firms will contain elements of both offensive and defensive strategies in their various products lines. The author highlights DuPont's offensive strategy in nylon development during the 1930s, as well as, I.G. Farben (of which BASF was part of between 1925 and 1952) with PVC plastic. Considering the variety of biobased products envisioned by chemical companies, the 4 companies we have analyzed may also transit between offensive and defensive strategies, depending on their available capabilities and willingness to be market and technology leaders.

However, early investment in knowledge internalization rather than partnering with startups until technology and market uncertainties diminish, as identified by Hamilton (1985), would indicate a tendency towards offensive strategies, enabled by in-house technological capabilities. This transformation of technology base reflects a commitment to the opportunities brought by this emerging industry and an attempt to review established innovation paths, both of which have implications to the portfolio of biobased products. This becomes clear with DSM and DuPont being active in cellulosic ethanol, even after they have sold their respective oil and gas businesses (see Table 6 and Table 8). In the current moment of the industry, leading positions may mean investing in technologies for products that have already a concrete demand, despite not being particularly aligned with other of the companies' products. A tendency to defensive strategies seems to be the case of Braskem. Partnering with selected startups that pursue biobased products identical to the firm petrochemical portfolio indicates an adaptation of technology base and prioritizing the existing business. BASF may also be more defensive than offensive, due to the number of partnerships with startups, but it seem more open to transform its technology base if the opportunities are favorable. The partnership with Renmatix on lignocellulosic sugars and the acquisition of Verenium supports this affirmative, since these sugars tends to be a very important raw material for a number of bioprocesses and enzymes a crucial input.

2.5 Conclusions

With the present study we aimed at discussing chemical companies' strategies when entering the biobased industry. Consonant with the observations of Hamilton (1985) in its paper on advent of biotechnology in the 1970s and 1980s, we noticed that companies that are still identified with the chemical industry (BASF and, most of all, Braskem) explore partnerships with startups to cope with emerging technologies. However, we identified that established companies willing to incorporate them as a fundamental part of their business favor internalization of the related knowledge (the cases of DSM and DuPont), but it does not prevent partnering with startups in window and options strategies. So, the management of emerging technologies when dealing with startups may assume different characteristics depending on the firm long-term business focus, and its willingness to quickly position itself, which is also affected by the success in technological shifts in the firms' histories. For these firms, capabilities building through specific acquisitions tend to be a preferred positioning strategy, rather than joint ventures, license agreements and specific R&D contracts with startups, as described by Hamilton (1985). It also alludes to more offensive innovation strategies, due to growing in-house technological capabilities (FREEMAN, 1997).

We further qualify Hamilton's (1985) findings arguing that companies facing changes in their raw materials base will have difficulties in developing new production processes on their own, and there are strong motivations for partnering with other established firms that have both capabilities and assets related to these feedstocks. Therefore, technological alliances between chemical and food (or agribusiness) firms became common in the biobased industry, instead of mostly between established companies and startups. Generally speaking, technological alliances between established companies in environments of great uncertainty may be an interesting way to share costs and manage risk, taking advantage of their respective distinct capabilities and assets in-place.

We were also able to devise different general strategies among the companies analyzed when it comes to the biobased industry, which have practical implications. Firms with a strong focus on matching biobased products with their current offerings sourced from fossil sources tend to assume mostly a manufacturing and commercialization profile, since they are able to easily fit the new offerings within existing operations. Those firms that, on the other hand, embrace emerging technologies as an important part of their future, do not need to commit entirely to products aligned with their current portfolio and may position as technology providers for markets that are sharply growing. Finally, mixed strategies may occur, balancing diversification and finding biobased alternatives to existing products.

We are able to recognize some limitations of the present study. It is focused on a specific emerging industry, which may hinder the generalization of our conclusions. Although we were able to collect and analyze a great number of data, all findings are inferred from publicly available information and misinterpretations could occur. To minimize that issue, we have employed a multiple case study of reasonably different companies, cross-checked crucial information and tried to properly picture companies' history of strategic decisions by searching data from the time specific movements occurred, i.e., eliminating possible biases associated with companies' current strategies.

Our future expectation is to better understand which characteristics of complementary assets and technological capabilities favor partnerships between established firms, instead of vertical integration and internalization of know-how. We also envision the possibility of deepen our findings regarding technology base transformation and adaptation, by focusing on efforts less dependent on acquisitions (mostly regarded as windows strategies (HAMILTON, 1985)). They are keys to guide acquisitions and provide the firm with absorptive capacity for external knowledge. Patenting patterns may also indicate efforts not widely disclosed in the specialized press and the rate of technological change.

Chapter 3 - Paper 2: *Exploring business model dynamics in emerging industries: the case of the biobased industry*

Abstract

Emerging industries constitute a complex selection environment where competitive patterns are not yet defined. To grow and sustain long-term business performance, startup firms need to simultaneously surpass technological challenges and experiment in business model design. The biobased industry is an interesting setting for analyzing business model dynamics, since a number of recently founded technology-based firms are able to participate in the industry construction. Our aim is to identify and describe the factors that impact startups flexibility in business model design within the biobased industry, a research topic with special relevance for decision-makers, but with limited examples in the related literature.

Our research relies on multiple case studies of firms with different profiles and in large evidence within the industry – Amyris, Avantium, BioAmber, Genomatica, Metabolix and Solazyme. We have already been studying these firms insertion in the biobased industry, but we dedicated special effort to gather and organize clear information on their business trajectories from secondary sources.

We found that the technological possibilities of the firm and the product nature (drop-in or non drop-in) affect the flexibility in business model experimentation, while the assumed firm profile (producing or licensing) stands as an important business model decision that must be weighted by existing constrains of the industry. We draw from our results a new decision flow chart that can give firms a concise view on how to sequentially evaluate these three aspects when designing a business model. Our analyses also dialogues with the dynamic capabilities literature, supporting that sensing dynamic capabilities are also present when designing a business model, not only seizing ones.

3.1 Introduction

In recent years, factors such as climbs in oil prices, limited supplies of fossil resources, consumer awareness and demand for environmentally friendly products, and population growth have been stimulating the structuring process of a new industrial sector, commonly referred as bioeconomy or biobased industry (BOMTEMPO, 2013). This industry includes sourcing fuels, polymers and chemicals from renewable feedstocks, but also employing biological sciences for tailoring food products, personalizing medical treatments based on a patient's own genomic information and real-time monitoring of the environment with novel biosensors, for example (WHITE HOUSE, 2012). The large economical potential and societal benefits offered by the biobased industry, has led to a great mobilization of both public and private sectors to meet the vast number of uncertainties in this transition period, with special attention to finding low carbon alternatives for the current fossil base (BOMTEMPO, 2013; OECD, 2009; WHITE HOUSE, 2012).

Emerging industries constitute a complex selection environment where competitive patterns are not yet defined and technological innovation is still in a fluid phase (ABERNATHY; UTTERBACK, 1978). Moreover, companies in emerging industries need to find the most adequate strategic approaches regarding product/market positioning, marketing, servicing, as well as, product configurations and production technologies (PORTER, 1980). As such, the biobased industry conceals intense product and process innovations, low entry and exit barriers, coexistence of innovators from different knowledge backgrounds proposing multiple concepts and constructing diverse technological trajectories (BOMTEMPO; ALVES, 2014), being a very interesting setting for analyzing the dynamics behind business model design.

Despite a number of publications on bioeconomy with a socio-economic approach (e.g. in sustainable business models (ILES; MARTIN, 2013; NAIR; PAULOSE, 2014)), addressing technology and innovation management (e.g. (GOLEMBIEWSKI et al., 2015; VAN LANCKER et al., 2016)) or concerning the industry innovation dynamics (e.g. (BOMTEMPO et al., 2014; BOMTEMPO; ALVES, 2014)), there is limited studies on business model dynamics in this context. One interesting type of company to be analyzed in terms of business model experimentation comprises the technology-based startups, recently-founded companies that try to grow their businesses based on innovative offerings. They need to simultaneously surpass technological challenges and experiment in business model design in order to be successful, and the emerging biobased industry does set a challenging business environment for these firms. In a recent empirical paper on startups' business models dynamics, Alves et al. (2014) highlights that different strategic focuses impact the firms' flexibility in business model design. These focuses are: (1) exploration and manipulation of technologies to yield different products, (2) exploration of the potentials of a platform chemical and (3) exploration of the potentials of final products (ALVES et al., 2014). Although identifying such relationship between strategic focus and flexibility constitutes a valuable insight, the authors' analysis is rather preliminary and also lacks a deeper look in other factors that may affect business model design. In this paper, we address these issues, analyzing technology-based startups that engage in biobased products directly affecting the chemical and petrochemical industries. Besides identifying factors impacting business model experimentation flexibility, we draw from our results a new decision flow chart that can give firms a concise view of how to sequentially evaluate their technological possibilities and how they may be constrained by some of the firm's business model choices.

The remainder of this paper is structured as follows. We first present both the empirical setting and research methods. Then, we present the theoretical concepts required to support our analyses. In the following section, we present our empirical findings and discussions. We conclude by outlining our contributions and additional research themes that scholars can pursue in the future, mostly related to the context of emerging industries.

3.2 Research approach

The work of Alves et al. (2014) does set an interesting starting point for the present paper. As one of the strategic focuses highlighted by the authors, platform chemicals may be defined as chemical intermediates capable of yielding a large set of derivatives through specific physical and chemical transformations, targeting several distinct end-uses (DE ARAÚJO, 2015). Bozell and Petersen (2010) list some biobased products that exhibit potential as platform chemicals, all of them not yet intensely explored on a commercial scale (such as succinic acid or levulinic acid, for example). Another strategic focus devised is the exploration of the potential of final products. For the purposes of this study, we define final products as a chemical or a mixture of chemicals that will not be subjected to further chemical transformations before its end-uses, which includes, for example, resins, fuels, base oils and solvents, chemicals used in formulations and as food ingredients. Typically, these final products are in the interface with other industries, such as converters, pharmaceutical, personal care, etc., all of which detains expertise considerably different from the biobased industry. With the last strategic focus, the exploration and manipulation of technologies to yield different products, the main feature of the startup is not a specific set of products, but the ability to provide different ones according to market or customers' demands.

Similar to the work of Alves et al. (2014), our research is based on multiple case studies exploring the business strategies of startups in the biobased industry. In the last five years, we have been developing a research program aiming at contributing to the literature related to technology and innovation dynamics in the biobased industry. To support this program, a proprietary data base was assembled from publicly available information, including specialized press (e.g. www.biofuelsdigest.com and www.greenchemicalsblog.com), special reports of governmental and international organizations (e.g. from DOE, OECD and IEA task 42), professional conferences, companies reports (e.g. 10k forms), among others. Specifically for the purposes of this study a systematic effort was conducted to gather clear and detailed information on each startup under analysis, including the companies' background, their main assets and how they access complementary assets[10], disclosed partnerships, products and markets targeted, their current business strategies, possible strategic shifts during time, etc. Two startups were selected for each of the three strategic focuses and have their main products[11] briefly described in the table below. We deepen the work of Alves et al. (2014) by including startups they have study, namely Solazyme, Amyris and Metabolix. The other companies were selected based on their relevance, since they are commonly

[10] Complementary assets includes competitive manufacturing assets and know-how, access to distribution and marketing channels, after-sales and technical services, and complementary technologies and marketing (TEECE, 1986).

[11] The products presented are those strictly related to the biobased industry, as some of these companies also participate in the medical field (e.g. Amyris) or providing catalysis solutions (e.g. Avantium), for example. Although such background contribute to the set of companies' capabilities, they are not likely to contribute to the comprehension of the drivers behind business model dynamics in the biobased industry.

placed by the specialized press among the most important companies in the industry (BIOFUELS DIGEST, 2016).

Table 10 – Summary of startups selected according to their profile

Strategic focus	Company	Main products currently focused
Technology manipulation	Genomatica	Intermediate chemicals technologies, notably for 1,4-butanediol and butadiene
	Solazyme* (now TerraVia)	Triglyceride oils and other bioproducts using microalgae as biocatalyst
Platform chemical	Amyris	Farnesene, its derivatives and other isoprenoids
	BioAmber	Succinic acid and its derivatives
Final product	Avantium	PEF polymer, FDCA and levulinics
	Metabolix	PHA biopolymers

One of the advantages of a multiple case analysis is that it enables comparisons that clarify whether an emergent finding is merely idiosyncratic to one single case or replicated in numerous cases (EISENHARDT; GRAEBNER, 2007). The differentiation we made in regards to strategic focuses contributes also for an embedded design (YIN, 2009), since permits analyses between the pairs and across the six firms.

3.3 Literature review

The business model concept has received increased attention within the strategy literature, but there is still a lack of clarity regarding its meaning (ZOTT et al., 2011). Despite the divergences about its definition, we agree that a business model can be understood through three main dimensions, as argued by Teece (2010): value proposition, value chain structuring and value capture. Our initial hypothesis is that the three startups strategic focuses devised entail different ranges of products that can be offered, which in turn may affect the firm ability to experiment in business model design. For a startup with limited resources, having a restricted set of opportunities to choose from can result on commitments to opportunities that are not economically feasible in the current stage of the industry or that are challenging to manage, consequently, leading to the startup failure. Conversely, a broader number of opportunities may allow early adaptations in business models, i.e. leading to some experimentation flexibility. Considering that new business models are rarely successful as firstly designed (SOSNA et al., 2010) and the dynamism of the biobased industry, assessing the flexibility of startups to adapt and experiment in business model design is of paramount importance for practice. In this sense, we aim at assessing the degree of flexibility associated with those three strategic focuses and its relationships with business model experimentation, besides exploring if and how other aspects impact business model design.

Teece's (2007) framework on dynamic capabilities is used to support our analyses with valuable insights. Derived from the Resource Based View (RBV) approach, which sees resources and competencies as crucial for sustainable competitive advantage (BARNEY, 1991), the dynamic capabilities acknowledge that in fast-changing business environments, where the geographical and organizational sources of innovation and production are dispersed, maintaining competitive advantage demands more than the possession of difficult-to-replicate resources and competencies (TEECE, 2007). The author highlights the necessity of unique and difficult-to-replicate dynamic capabilities, defined by Helfat et al. (2007, p. 4) as "*the capacity of an organization to purposefully create, extend, and modify its resource base"*, where the *"resource base"* includes the *"tangible, intangible, and human assets (or resources) as well as capabilities which the organization owns, controls, or has access to on a preferential basis"* (HELFAT et al., 2007, p. 4). Teece's (2007) framework distinguishes three basic dynamic capabilities: sensing and shaping opportunities and treats (environmental comprehension and goals definition), seizing opportunities (structuring) and managing treats and reconfiguring (the process of learning and readapting). Sensing new opportunities is very much a scanning, creation, learning, and interpretive activity, normally supported by investment in research and related activities. Seizing occurs after a technological or market opportunity is sensed, being addressed by investing in new products, processes, or services, and encompassing the design of a suitable business model. Finally, reconfiguring dynamic capabilities address the augmented enterprise-level resources and assets, resulting from enterprise growth after an opportunity was successfully seized. In face of markets and technologies changes, this augmentation is likely to lead to unfavorable path dependencies, incompatible with sustained competitive advantage (TEECE, 2007).

Although our empirical research design does not allow the description of these firm-level processes (i.e. these dynamic capabilities), we are able to highlight startups' strategic decisions that are indicative of sensing, seizing or reconfiguring, which is useful for evaluating how flexible the companies present themselves along their business trajectories. We hope that such approach further contributes to the still underdeveloped theory concerning dynamic capabilities (HELFAT; PETERAF, 2009), by focusing on the interplay between the process of business model design, and sensing, seizing and reconfiguring.

The following section presents our main findings.

3.4 Empirical findings and discussions

3.4.1 Companies overview

3.4.1.1 Genomatica

Genomatica is a biotechnology startup founded in 1998 and headquartered in San Diego, California. Since its early days, the firm has a strong commitment to using biological modeling and simulation technologies to transform the manner through which organisms are engineered and drugs are discovered. As of 2003, Genomatica was seen as a leader in biological pathways simulation, providing modeling solutions for both academic and commercial users. Its proprietary SimPheny™ modeling platform was designed to rapidly generate broad information regarding genes, proteins, and biological pathways, as well as information on the expression, regulation, and potential products that affect these biological systems. Genomatica's was seizing this opportunity much around licensing its software and providing related services, such as training and scientific support (PR NEWSWIRE, 2003). The development of such modeling platform can be pointed as the first strategic decision related to sensing opportunities, but not particularly related to changes in the chemical and petrochemical industries (as is the focus of the present study).

Following many projects in advanced biofuels around the globe and highs in oil price, Genomatica decided to reincorporate and review its business model around 2007. Since then, the company has been building a vast intellectual property portfolio in basic and intermediate chemicals (identical to their petroleum-based counterparts but obtained from different renewable feedstocks), and decided to license the related technologies by forging strategic alliances with industry partners (XCONOMY, 2012). Although the opportunity sensed was somewhat different from the previous one, the firm intended to seize it similarly, as a licensor. Even so, Genomatica needed to engage in helping building the initial plants (pilot, demonstration or commercial), which was not foreseen by the company (XCONOMY, 2012). The seizing process was conducted by maintaining Genomatica as a privately held company, receiving investments from the venture capital and other partners (GENOMATICA, 2015b).

From 2007 on, Genomatica focused its development efforts primary on BDO (1,4-butanediol, a raw material for synthetic fibers production), butadiene (mostly used in synthetic rubbers) and, recently, on nylon intermediate chemicals such as hexamethylene diamine (HMD), caprolactam and adipic acid. For the first two, the firm has already established partnerships with intermediate chemicals producers such as BASF, Novamont, Braskem and Versalis. In some instances, production of derivatives such as PBT (polybutylene terephthalate) have been conducted using BDO obtained through Genomatica's process, but with no direct participation of the firm(BIOFUELS DIGEST, 2015c). In 2015, Genomatica partnered with the agricultural giant Cargill, in an agreement through which the companies will co-market Cargill's feedstock and production services to current and prospective Genomatica licensees. Genomatica will focus on the process technology, while Cargill can provide the required feedstocks, but can also build and operate biobased chemical plants for chemical producers or consumers. Cargill offers its experience in fermentation-based processes, which may be a source of difficulty for industrial players that never operated this type of units (ICIS CHEMICAL BUSINESS, 2015).

3.4.1.2 Solazyme

Solazyme is a biotechnology startup founded in 2003, headquartered in San Francisco, California. The first opportunity sensed by the company was in producing biofuels from microalgae, employing either open ponds or photobioreactors. By 2004, however, scale-up and cost issues related to these technologies led to a review in their approach and Solazyme decided to invest in heterotrophic microalgae. The core of the new technology consists in bypassing the difficulties related to converting sunlight to sugars - by simply feeding plant-based sugars - and focusing on the microalgae ability to produce oils. One of the main advantages of Solazyme's technology is the possibility to employ industrial fermentation vats already used to make antibiotics and industrial chemicals, for example, which would additionally reduce capital expenditures, since existing facilities could be leased (XCONOMY, 2010).

In the following years, Solazyme has continued its efforts in biofuels, being awarded by the U.S. National Institute of Standards and Technology in 2007 (SOLAZYME, 2007) and by the U.S. Department of Energy (DOE) in 2009 grants to advance the microalgae biofuel technology (SOLAZYME, 2015). The biofuel opportunity was continued through a R&D partnership with Chevron from 2009 to 2012, supplying of marine diesel to the U.S. Navy for testing and certification from 2010 to 2011, supplying of algal oil to Dynamic Fuels, LLC in 2012, among others (SOLAZYME, 2015). In the field of biofuels, Solazyme had leveraged partners expertise in oils processing, as in the agreement with Honeywell UOP to produce jet fuel (HONEYWELL, 2010).

However, starting as early as 2005, the company sensed opportunities in cosmetics and nutritional supplements, markets with less volume, but higher profits than biofuels. The company's claimed strategy was to pave the way to biofuels by first scaling up production in these types of markets (XCONOMY, 2013). Solazyme seized these opportunities as planned, through a variety of manufacturing partners, but also owning some production facilities. Relevant manufacturing capacity was reached through the joint venture with Bunge and the beginning of production at the Moema facility, in Brazil, with a nameplate capacity of 100,000 ton/year of oil (SOLAZYME, 2015).

Solazyme claims a superior capability to produce tailor-made triglyceride oils through manipulation of microalgae strains. In the last years, the company has tapped into a vast number of applications in industrial, food and personal care markets, establishing partnerships with an equally vast myriad of partners. These include chemical (e.g. BASF, Mitsui), agribusiness (e.g. Bunge, ADM) and personal care companies (e.g. Unilever, Natura), besides personal care products distributors (e.g. Sephora, QVC) (SOLAZYME, 2015). Solazyme holds a proprietary line of anti-aging skin care products, under the name of Algenist®. However, following the recent massive supplies of cheap petroleum and uncertainties in U.S. government subsidies for biobased chemicals, Solazyme decided in 2016 to abandon biofuels and industrial oils, focusing on nutrition and health products. The new company was named TerraVia and the other business are to be divested (FORTUNE, 2016).

3.4.1.3 Amyris

Amyris is a biotechnology startup established in 2003 and headquartered in San Francisco, California. First research activities started in 2005 and were directed to the development of an alternative source of artemisinic acid for the treatment of malaria, through a grant from the Bill & Melinda Gates Foundation. The fundamental knowledge in artemisinic acid synthesis was related to engineering isoprenoids biosynthetic pathways in *Escherichia coli* and Amyris sensed an opportunity in providing difficult to obtain isoprenoids to the pharmaceutical industry (IPIRA, 2015). In 2006, Amyris launched research efforts for the production of farnesene (also called Biofene®), a platform chemical, aiming at fragrance and essences markets.

However, during the company capitalization process, Vinod Khosla from Khosla Ventures probed the possibility of making biofuels and Amyris started efforts for producing diesel and jet fuel from farnesene. By this time, there were third parties interested in licensing from Amyris the chemicals portion of their business (those not related to biofuels), but Khosla counseled the firm to maintain this option, which turn out to be a great part of their business (LASSITER et al., 2011). In the biofuels field, Amyris commenced collaboration with the energy company Total to explore diesel and jet fuel from farnesene, culminating in the establishment of a joint venture in December 2013. One of the most remarkable steps towards commercialization of diesel was an arrangement with the city of São Paulo, Brazil, to supply renewable diesel for the city’s bus fleet, realized from 2011 to 2014.

Although Amyris had pursued the biofuels path, the company also explored the platform characteristic of farnesene. Others markets currently targeted by Amyris are the cosmetics (with its own line of skin-care products called Neossance™), flavors, solvents, polymers and lubricants. Many particular applications of farnesene, chemically transformed or not, are the result of inputs from collaborators, as disclosed by the company (AMYRIS, 2015a). Partnerships include fuels and energy (e.g. Cosan, Total), agribusiness (e.g. Tonon Bioenergia) and fragrances companies (e.g. Firmenich, Givaudan). It is worth noting that Amyris also engineer microbes to produce target molecules not derived from farnesene, such as isoprene used in synthetic rubber production (advanced in a partnership with Michelin and Braskem) (MICHELIN, 2014) and patchouli oil used in fragrances (AMYRIS, 2014). Besides, the firm still have some efforts in the medicine field (AMYRIS, 2015b).

Amyris’ basic technology for isoprenoids production through fermentation was improved along the years (including the substitution of *E. coli* by yeast), but relatively unchanged.

The company adopted a producer profile, initially relying on contract manufacturing (AMYRIS, 2011) and, later, constructing its own facilities. Amyris choose Brazil to locate its plants due to the availability of low cost feedstock (sugarcane) and, in 2012, commenced operation in the Brotas facility, located in the state of São Paulo. The company still uses contract manufacturing for some operations, mainly those related to farnesene transformation (AMYRIS, 2015a).

3.4.1.4 BioAmber

BioAmber is a startup mainly known by its involvement with bio-succinic acid, one of the biobased platform chemicals listed by Bozell and Petersen (2010) and that is nowadays explored by a number of companies. The core bio-succinic acid technology used by BioAmber was developed in the 1990s by entities funded by the DOE and licensed to DNP Inc. In 2008 and 2009, an asset spin-off transaction from DNP led to the establishment of BioAmber. A key advantage of biobased succinic acid is that fermentative low cost processes are being developed and effectively displacing its petroleum-based counterpart, used only in niche applications due to its increased cost. This characteristic allows such replacement, but also the exploration of its potential as a platform chemical and as a substitute of similar chemicals, such as adipic acid, maleic anhydride and phthalic anhydride (WEASTRA, 2012).

BioAmber has been assessing and developing technologies for succinic acid derivatives, including PBS (polybutylene succinate, a biodegradable plastic), BDO and its derivatives, such as THF (tetrahydrofuran, an intermediate in the production of elastic fibers) and GBL (gamma butyrolactone, used as solvent, for example). For a number of these opportunities, the company decided to leverage specific technologic know-how of some partners in order to build the succinic acid value chain, for example, by becoming a licensee of DuPont catalysts for the conversion of succinic acid to BDO and THF, and partnering with Evonik to scale-up such catalysts. Additionally, BioAmber partnered with Mitsubishi Chemicals, a holder of important PBS patents, to become a supplier of succinic acid used in PBS production. Even though BioAmber did not establish itself as a PBS producer, the company plans to seize this opportunity by buying PBS and making modified PBS/PLA composites initially used in food applications, in a joint venture with NatureWorks. PLA stands for polylactic acid and is a also a biodegradable plastic (BIOAMBER, 2015).

BioAmber also sensed an opportunity as a producer of another dicarboxylic acid, adipic acid. The basic technology was licensed in 2010 from Celexion and also encompasses adipic acid's derivatives such as HMD, caprolactam (both applied in nylon production) and hexanediol (used in polyesters and polyurethanes production). One of the motivations claimed by BioAmber in pursuing the adipic acid opportunity is the chemical similarity with succinic acid, which would allow the company to apply its know-how in product purification and transformation in derivatives (BIOAMBER, 2015).

Even before BioAmber foundation, DNP conducted scale-up of the DOE's *E. coli* technology for succinic acid, in a contract manufacturing facility located in France, from 2005 to 2010. Given some limitations related to using *E. coli*, in 2010 BioAmber entered in an agreement with Cargill to become an exclusive licensee of its yeast platform. From 2010 to 2014, BioAmber conducted both commercial production using the DOE technology and the scale-up and validation of the yeast technology, which was implemented in the Sarnia plant, in Canada (BIOAMBER, 2015). The Sarnia facility was constructed as part of a joint venture with the chemical company Mitsui that build and operates the plant, besides assisting BioAmber in product trading and shipping procedures.

3.4.1.5 Avantium

Avantium was founded in 2000 as a spin-off from Shell and is headquartered in the Netherlands. During its first years, the objective of the company was to apply the high-throughput R&D initially developed by Shell for catalysis research across a number of industries. Avantium invested significant resources to advance the technology acquired from Shell in the spin-off and structured its business around providing catalysis services to firms in the chemical and energy industries, and crystallization research for the pharmaceutical industry. This approach was expanded in 2005, when the company also started offering R&D systems (AVANTIUM, 2007), but it remained an opportunity relatively apart from the biobased industry.

In 2006, Avantium decided to initiate proprietary development programs, including their biofuels program based on furanics. By 2007, the company declared its intention to explore the opportunity of furanics not only in biofuels, but as well as in biobased polymer monomers, specialty and fine chemicals, that would later translate in Avantium's YXY process®. Avantium intended to seize this opportunity as a licensor (AVANTIUM, 2007).

The YXY process® was developed in the following years, culminating in the startup of a pilot plant for production of methyl levulinate, 2,5-furandicarboxylic acid (FDCA) and polyethylene furanoate (PEF) polymer, in December 2011. Avantium sensed a very important opportunity in converting FDCA to PEF polymer, which is a potential substitute of PET (polyethylene terephthalate), resulting on a partnership with Coca-Cola towards biobased plastic bottles (AVANTIUM, 2011). Avantium later established other partnerships to develop PEF bottles, with Danone in 2012 and ALPLA, a company with know-how in PET conversion, bottle design and bottle manufacturing, in 2013 (BIOFUELS DIGEST, 2014). In order to further extend the PEF opportunity, in 2013 Avantium entered a partnership with Wifag-Polytype, a manufacturer of thermoforming and printing equipment, aiming at developing thermoforming of cups, containers and trays for food packing (AVANTIUM, 2013). Since this opportunity had demonstrated greater commercialization potential, Avantium declared its intention to step off the exploration of biofuels (AVANTIUM, 2015).

In 2016, Avantium announced negotiations with the chemical giant BASF to form a joint venture to further develop Avantium's technology and to build a reference 50,000 ton/year plant for FDCA production, in BASF's site in Belgium. The aim is to build up world-leading positions in FDCA and PEF, and later license the technology (BASF, 2016c). It is worth mentioning that Avantium already intended to license its YXY process® for methyl levulinate and FDCA and that FDCA polymerization to PEF can be potentially conducted in existing PET reactors, reducing the need of an entirely new polymerization process (PLASTICS TECHNOLOGY, 2014).

3.4.1.6 Metabolix

Metabolix is a spin-off from MIT founded in 1992 aiming at developing polyhydroxyalkanoates (PHAs), a type of naturally occurring biodegradable polyester, by genetically modifying bacteria. The basic concept behind PHA production is engineering these microorganisms to yield building blocks of interest in a fermentation process (feeding sugar and other raw materials), which are later polymerized by these bacteria to polymers with desired properties. An additional research program initiated in 1998 was dedicated to produce PHAs directly in plants, such as switchgrass, in a way that after the polymer recovery, the plant residue would be used to power or biofuels generation (MCCARTHY, 2003). Since its beginning, sensing related strategic decisions were strongly directed to these opportunities, given the great plastics pollution concerns during the 1990s and PHA's biodegradability value proposition.

Metabolix market approach was to sell PHAs as premium-priced, specialty materials, that meet both functional needs (as plastics obtained from petrochemicals) and biodegradability needs, in applications such as injection molding, casting film and sheet, thermoforming and paper coating (METABOLIX, 2007). In order to supply test quantities of polymers and build a customer base, the company initially engaged in pilot and contract manufacturing, but intended to establish more definitive production partnerships to access financial resources and production capabilities. In 2004, Metabolix entered in a strategic alliance with the agribusiness company ADM to build a manufacturing facility, which came into operation in 2008 and was located at Clinton, Iowa. By 2006, Metabolix declared business development activities along with ADM using pre-commercial amounts of PHAs polymers with about 40 prospective customers in approximately 60 different applications (METABOLIX, 2006). However, less than two years after the startup of the plant, ADM decided to terminate the joint venture with Metabolix, so the later had to downsize its operations and refocused its marketing efforts to more high-valued applications (METABOLIX, 2015). This change forced a reconfiguration of Metabolix's tangible and intangible assets, and sensing/shaping dynamic capabilities were once again necessary to adjust the company's business model.

Another opportunity assessed by Metabolix around 2007 was the selective thermolysis of PHA to yield hydrocarbons of interest, with three or four carbons (C3/C4). In 2012, the company conducted industrial-scale demonstration of GBL production, followed by its conversion to BDO (using a conversion process available), and laboratory-scale production of acrylic acid (METABOLIX, 2013).

Currently, Metabolix continues dedicated to finding new applications for PHA biopolymers, mostly as performance additives and for uses requiring functional biodegradation. Since the ending of the joint venture with ADM, market development is being conducted using the product inventory from the Iowa facility or produced in contract manufacturing. In connection with a more focused business strategy, Metabolix also plans to spin-out its crop science program and suspend work in the C3/C4 chemicals field (METABOLIX, 2015).

3.4.2 Factors impacting flexibility in business model experimentation

From the multiple case studies, we were able to identify two main factors impacting the flexibility in business models experimentation: the technological possibilities of the firm and the product nature. These factors are depicted below.

3.4.2.1 Technological possibilities

The basic motivation for entrepreneurs to found startups could be roughly described as the recognition of distinct capabilities that would allow them to deploy innovative products or services, i.e., upon which a successful business could grow. Therefore, one of the first things a startup needs to identify when designing a business model is their market segments (CHESBROUGH, 2010). This inquiry is straightly aligned with the technological possibilities of the firm, which in turn, can be initially analyzed from the strategic focuses we devised in the beginning of this study.

Allocated with a strategic focus of technology manipulation, Solazyme continuously expanded its target markets relying on its capacity to engineer microalgae and to obtain tailor-made oils. The firm's strategic decisions related to expanding the number of partnerships were largely enabled by its technological capabilities. In other words, being capable to adapt its technology favored sensing opportunities by addressing different markets, and allowed different business models to be tested (from high-volume, commodity biofuels, to low-volume, specialty skin-care products). The other company we have selected with a strong focus on technology was Genomatica. Despite its clear capabilities on technology manipulation, the case study revealed that the company business model is basically unchanged since it decided to engage in the biobased industry (being a developer and licensor of technologies for molecules already produced by the petrochemical industry, and partnering with established companies of this industry). In this manner, one of the main differences between Solazyme and Genomatica is their strategy in respect to the variety of markets targeted. While Solazyme experimented in business model design by adapting to different markets, Genomatica strategic decision to focus on existing intermediate chemicals currently restricts its business model. Even so, it is clear that Genomatica's technological capabilities position the company well in the still infant biobased industry, by drawing the interest of multiple established companies.

Amyris and BioAmber, involved respectively with the platform chemicals farnesene and succinic acid, have demonstrated great flexibility in business model design. Since platform chemicals are by definition chemical building blocks underexplored, there is a variety of possible market segments targeted. For instance, Amyris portfolio of products derived from farnesene includes biofuels, cosmetics, resins and even farnesene directly sold to third parties. Similarly, BioAmber is a supplier of succinic acid, but also aim to produce GBL (used as solvent), THF (intermediate in the production of elastic fibers) and modified PBS/PLA composites polymers used in food applications, for example. Some possible drivers for choosing market segments in the case of platform chemicals are the know-how possessed by the startup, difficulties associated with accessing complementary assets, the firm business strategy, etc.

Finally, allocated with a strategic focus on final products, Metabolix demonstrated difficulties to flexibly experiment in business model design. The versatility of a final product could be mainly attributed to its properties, allowing its employment in a certain array of applications. Although Metabolix PHA polymers may present interesting properties, suiting then to the necessities of users has shown to be difficult and major uses were not identified in our study. It is important to highlight that Avantium's initial technological possibility has shown to be actually a platform chemical (FDCA), but the final product PEF is a major component of the firm's strategic decisions. When focusing on this product, the flexibility of Avantium in business model design has shown to be limited, largely depending on a reduced number of prominent partnerships, such as Coca-Cola, Danone and BASF.

The three general strategic focuses proposed by Alves et al. (2014) and that we initially adopted in the present study does outlines important differences in regard to sensing dynamic capabilities. Exploring the manipulation of technologies to yield different products and/or platform chemicals facilitate sensing opportunities, since opens the possibility of targeting different markets, conferring an advantageous degree of flexibility to startups. On the other hand, focusing efforts on products that have, to some extent, experimentation restrictions (such as final products), may hinder firm's business model testing.

After evaluating technological possibilities and which offerings can be advantageous in an opportunity sensing perspective, firms can envision how they will position in the value chains and the types of development efforts they will need to engage in. Our analysis stresses that these processes are related to the product nature, discussed in the next Section.

3.4.2.2 Product nature

This factor refers to the drop-in or non drop-in characteristic of the target products, but with certain distinctions from the established definitions. Drop-in products were defined as biofuels or other bioproducts that can be used in replacement of fossil-based products requiring no adaptation in distribution infrastructure, transformation or use equipment, i.e., drop-in products are able to integrally use the complementary assets in-place (BOMTEMPO, 2013). This concept is being extensively employed in the biofuels and bioplastics fields, where complying with existing technical specifications is a major component to avoid significant investments in specific assets (OROSKI et al., 2014).

However, we identified that the term drop-in is also being used for products that are not technically identical to the existing offerings, usually surpassing the later in performance. This is the case of Solazyme's algal oils, for example (SOLAZYME, 2015). The interesting finding here is that these products may in fact directly replace the existing offerings and demand only minor investments in complementary assets, but also imposes some degree of interaction with users to develop their technical specifications. Although this adaptability in the offering can be an advantageous feature, companies are not able to fully deliver the product for themselves and are often required to enter in agreements with development partners. We, hence, conceptualize drop-in as: *products obtained from renewable sources whose specifications are identical to either their fossil-based counterparts or other naturally occurring molecules with low availability*[12]*, replacing these without adaptation in distribution infrastructure, transformation or use equipment.*

Summarizing, a drop-in solution deals basically with an internal effort, much directed to process engineering and optimization. As a positive feature, the startup does not need to concern with market development and its product is easily integrated downstream, if competitive in cost. However, on the down side, market exploration movements are usually very limited and the company can only insert in the different links of the established value chains, as long as proposing unconventional process technologies. This is the case of Solazyme's and Amyris' biofuels, and Genomatica's and BioAmber's drop-in intermediates, for example. These limitations are not present when a drop-in product is also a platform chemical, as is the case of succinic acid. Even though produced in reduced scale from petrochemical route, succinic acid specifications are well defined in its traditional markets. Succinic acid would only assume non drop-in characteristics if its future uses demand different specifications.

By the other hand, since non drop-in solutions are not available in the market, they demand increased market development efforts and greater participation of the company in articulating the value chains, which can be very time and resources consuming. Yet, the firm faces more flexibility to position in the embryonic value chains and is able to capture a greater share of the opportunity value by participating in the development of derivatives downstream. Such behavior is observed in the cases of Solazyme's algae oils, Amyris' wide range of farnesene derivatives and BioAmber's modified PBS/PLA composites polymers, for instance.

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[12] Our research showed a movement of the startups to produce molecules that could be obtained from renewable sources, but are difficult to extract. Examples include Amyris' patchouli oil and squalane.

While these two factors impact startups flexibility in business model experimentation, the firm profile (producing or licensing) is a business model decision that must be weighted by the opportunities and treats currently present in the industry. It is approached in the next Section.

3.4.3 Firm profile: producing or licensing?

From the multiple case studies, two basic forms of startups engagement in the industry (profiles) stood out: producing biobased chemicals or licensing the related technologies. The product nature discussed above is a factor that shapes the possibility of licensing. Non drop-in products are not likely to be eligible for licensing at the current stage of the industry, since licensees would have to intensively participate in market development. Therefore, to become licensors, startups need to conduct this effort, as is the case of Avantium and its partnerships with end-users to assure that a main derivative of its technology (PEF, polymerized from FDCA) has a concrete demand. In the case of Genomatica, which deals with drop-in products, more straight-forward licensing arrangements can be undertaken, without the need (and even the possibility) of market development activities.

An interesting parallel can be drawn from the study of Arora (1997) regarding the chemical industry licensing patterns during the 20th century. After World War II, licensing became a more common practice, due to the emergence of specialized engineering-construction firms (many of which engaged in technology development) and, also, a shift in the strategy of chemical producers, that started to license some of their process innovations. The author's analyses related to the period of 1980-1990 shows that licensing was most present in sectors with large scale production facilities, relatively homogeneous products and with a large number of new plants, whereas was less common in sectors where product differentiation, products tailoring and small production scales are present. The author also highlighted that an innovator has greater motivation to license its technology in markets with more established producers, since it would have a lower market share if tried to produce (ARORA, 1997). In the context of biobased industry, producer profile startups are achieving revenues mostly in low demand market segments and we have noticed no licensing movements regarding the associated technologies. These are the cases of Solazyme's and Amyris's health products, and Metabolix's PHA polymers, for example. However, technologies for drop-in products that comply with Arora's (1997) description (large scale production and homogeneous products) are in fact suitable for licensing, as is the case of Genomatica portfolio of drop-in intermediate chemicals. A mixed approach (producing some products and licensing technologies) could be possible, but was not identified in our multiple case studies.

Naturally, factors other than those cited above may induce a firm to license, including: limited financial and managerial resources, lack of familiarity with international markets and anti-trust considerations (ARORA, 1997). Most startups willing to become producers tackle these constraints by creating partnerships with established companies that already possess the capabilities aforementioned, including, for instance, BioAmber joint venture with Mitsui (that build and operates its succinic acid plant) and Solazyme joint venture with Bunge. For producers, licensing may also arise as an emergent rather than a deliberate strategy (MINTZBERG, 1978), following favorable business environment and/or organizational conditions.

3.4.4 Business model possibilities

3.4.4.1 Towards a comprehensive decision flow chart

This section articulate the arguments presented previously in a decision flow chart that can give firms a concise view of how to sequentially evaluate the potential of their technological possibilities and how they may be constrained by some characteristics of the industry. As such, the decision flow chart provides a prospective view well-aligned with sensing related strategic decisions and that can guide seizing strategic decisions. Furthermore, the flow chart is useful to organize the broad product lines that a company is involved with and point out distinctions that may lead to the establishment of different business models within the firm. Figure 1 presents this decision flow chart, including the position(s) of each company analyzed in the multiple case studies.

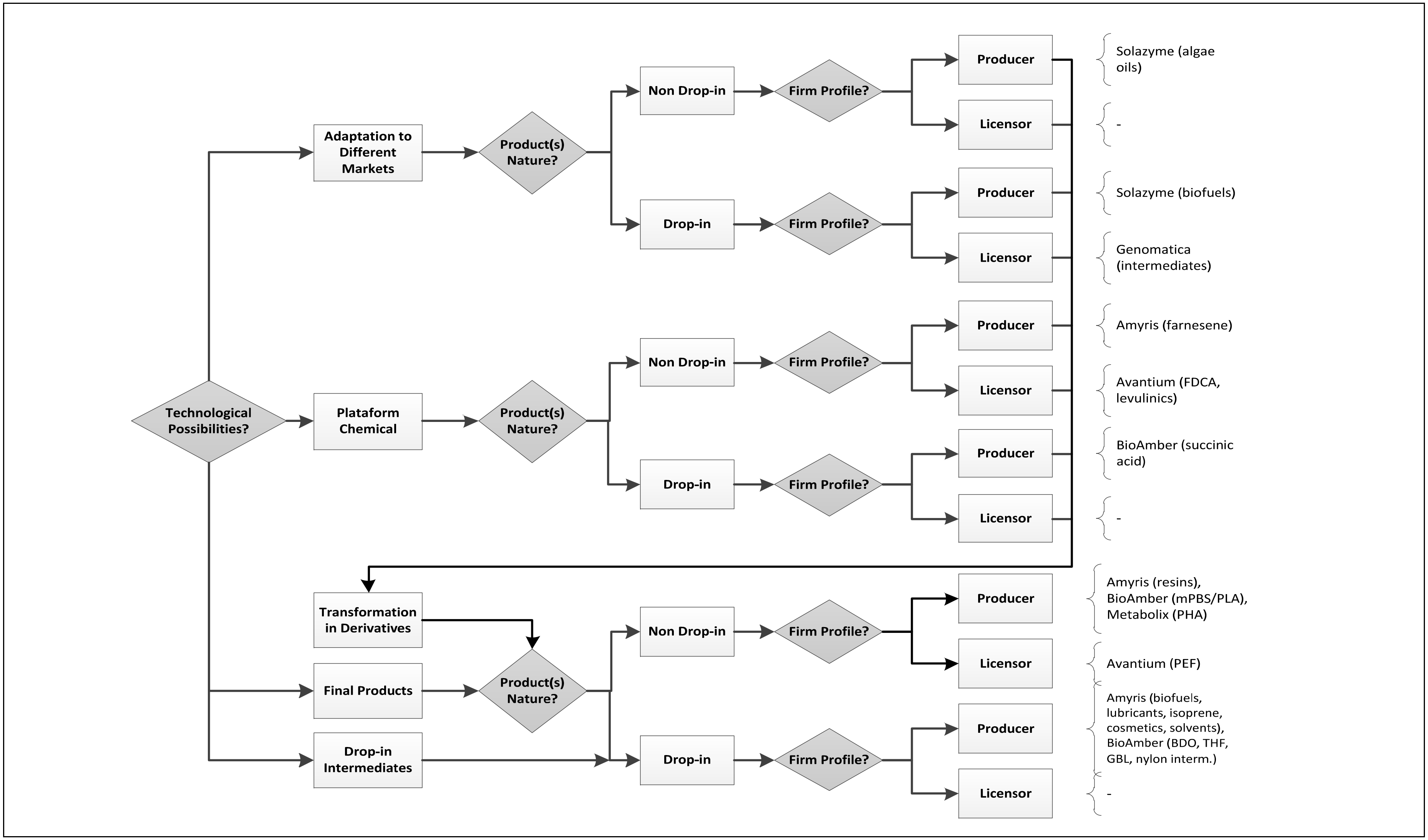

Figure 1 – Startups business model choices in the biobased industry

The initial consideration regards the technological possibilities of the firm, dividing the flow chart in three main branches. The branch "*Adaptation to Different Markets*" refers to technologies that enable startups to generate different products for distinct markets (or specific customers), as is the case of Solazyme. Sensing activities are not restricted to the possibilities of an initial product, so startups are motivated to connect with possible partners to spur innovation and find the most attractive business opportunities. Interestingly, the case of Genomatica showed that a startup may follow a focused strategy even holding important technological capabilities. The firm superior biological simulation expertise position Genomatica well in the industry, drawing interest of multiple partners and does not required significant business model experimentations. The second branch encompasses platform chemicals, biobased intermediates capable of yielding a large set of derivatives, a path followed by Amyris, Avantium and BioAmber. As already discussed, both of these technological possibilities translate into enhanced business model experimentation flexibility. Their main difference is the type of product, since companies that are able to adapt to different markets may focus on final products, whereas the opportunity of platform chemicals may be more attractive when the firm participate in derivatives manufacturing (i.e. products with greater value). On the other hand, the path of exploring final products imposes difficulties for the startup to experiment, since it depends on products having reasonably broad properties to target different prospective markets, the case of Metabolix. A possibility that was not identified in the multiple case studies but may occur in the industry is startups holding technologies for drop-in chemical intermediates. Assuming that the firm has limited technological capabilities to adapt to different markets, offering these intermediates would result in limited flexibility, due to its drop-in nature. Hence, the impossibility of targeting multiple markets entails lower flexibility, similarly to final products. Their main differences appear when assessing product nature and subsequently the firm profile.

Product nature is a factor associated with the adequacy of the offering in relation to the environment, which will determine the types of efforts the startup need to conduct, besides pointing how demanding the innovation is in respect to new complementary assets. This decision step applies even for platform chemicals, albeit these are in most cases intermediates not widely produced (non drop-in). As already explained, succinic acid is an example of a drop-in platform chemical, which already have defined specifications in its traditional markets.

Finally, after considerations regarding product nature, a firm may assess how they will seize the opportunities (producing and/or licensing). From this point, a set of new opportunities emerges for companies either in the branch of "*Adaptation to Different Markets*" or the platform chemicals branch - the transformation of their chemicals in derivatives through further chemical conversions[13]. In the flow chart, this process is connected to the third branch (drop-in intermediate chemicals or final products), since our analyses showed a very high degree of specificity in the applications of the resulting products, which in turn allows business model experimentation flexibility similar to products in such branch. Even when producing other intermediate chemicals that may be employed by many markets (such as BDO and THF from succinic acid), business model experimentation suffers from restrictions. After chemical transformation, products are again evaluated in terms of product nature, since they may relate to the existing industrial structures in different ways.

In terms of seizing the opportunities, startups may select the most suitable way of positioning in the value chain, especially when dealing with non drop-in products or under explored drop-in products. In all instances, choosing firms' boundaries should be evaluated on a case-to-case basis and prescriptive frameworks are available in the literature to guide decision-making (JACOBIDES et al., 2006; TEECE, 1986).

It is important to highlight that we do not consider the biobased industry sufficiently mature so as reconfiguring (the third basic dynamic capabilities distinguished by Teece (2007)) could take place, since this capability is required to depart from deleterious path dependencies when previous firm success occurred and there are both augmented enterprise-level resources and assets. In the multiple case studies, startups are most likely still experimenting in business model, such as Metabolix that by the time the partnership with ADM was ended was prospecting customers and applications for PHA. Similarly, Solazyme recent decision to abandon biofuels and industrial algal oils followed a period of experimentation with different target markets, which highlights the importance of flexibility.

3.4.4.2 Degree of irreversibility in business model design

Although our decision flow chart is more suitable for identifying opportunities and treats before a business model is actually implemented, a question that arises is how these strategic decisions may be considered irreversible in the context of startups in an emerging industry? These startups have a relatively reduced timeframe to establish themselves and attract sufficient attention of partners to support their growth, hence, some of their medium-term business model characteristics may be to a certain extent hard to manipulate.

One irreversibility that we identified is associated with the assumed firm profile, i.e., if the startup intends to become a producer or a technology licensor. The set of

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[13] As a very important characteristic of a platform chemical, it is possible that these transformations also expand the opportunities for firms in the "*Adaptation to Different Markets*" branch, although these types of movements were not specifically identified in our analyses.

capabilities accumulated by a licensor tend to restrict its possibility of becoming a producer, due to the limited know-how in plant operation, products shipping, logistics and marketing, etc. For example, Genomatica has a clear strategy to remain a technology licensor and did not even foresee the necessity to build initial plants (pilot, demonstration or commercial). Similarly, Avantium intends to remain a licensor and partnered with an industrial player (BASF) to bring its technology to market. These companies tend to accumulate superior technology development capabilities, but their business models are basically unchanged during the startup initial years. On the other hand, a producer may experiment more ease to become a licensor, as did chemical and oil companies in the past (ARORA, 1997).

In terms of technological possibilities, it is important for a startup to acknowledge that final products or drop-in intermediates lead to reduced flexibility to experiment in business model design. Therefore, from a strategic point of view, keeping development programs associated with platform chemicals or continuously investing in technological capabilities may be interest.

3.4.5 Sensing and seizing on business model design

On Teece's (2007) framework, the business model is considered as one of the microfoundations of seizing, implying that sufficient market research (i.e. sensing opportunities) has been conduct to support conscious business model design. From our point of view, in the context of startups within an emerging industry, such perspective constrains the understanding of business model's dynamics. We noticed that sensing/shaping opportunities is a process still present when seizing an initially perceived opportunity, which can lead to reviews in components of the business model. The need of startups to capitalize and grow their businesses imposes the adoption of a "first-trial business model", since small-scale business model experimentations that established companies could conduct (CHESBROUGH, 2010) are not feasible.

We perceived that products for which market conditions are not well known (either underexplored drop-in products or non drop-in products) demand prior opportunity seizing to support sensing activities. Startups need to define business models and commit resources to make sufficient quantities of their products available for testing, which can mean significant amounts considering the large demands that the biobased industry may need to supply. In this sense, startups design business models that can generate revenues to sustain operations (even if at small scale), but the firms are still realizing the actual potential of their offerings. This situation in clearly perceived with Metabolix, which was by 2003 (prior to their partnership with ADM) a 30-person company (MCCARTHY, 2003) using contract manufacturing to conduct market development activities[14]. The case of Amyris is another example, since the company initial venture capital investments and strategy were mainly related to converting farnesene to biofuels. The option to maintain the knowledge related to other chemicals (LASSITER et al., 2011) proved to be right and in the following years the number of markets targeted largely expanded, taking advantage of the platform characteristic of farnesene. Therefore, we see the business model design of startups intimately related with sensing activities, which in turn means that sensing and seizing can be seen as interacting with each other, in an iterative process to define the most suitable business model.

Sosna *et al.* (2010) highlight that new business models are rarely successful as firstly designed, due to struggles at both exploratory and implementation stages. At the exploratory stage, when conceptualizing the business model, decision-makers face the uncertainties of fast-changing markets and also their own cognitive limitations to comprehend the environment. At the implementation stage, new business models also demand organizational realignment, requiring managers to mobilize limited resources, develop unique competencies and adjust organizational structures to promote learning, change and adaptation (SOSNA et al., 2010). The current fluid pattern (ABERNATHY; UTTERBACK, 1978) of the biobased industry implies that these difficulties are even more pronounced, supporting that sensing is very much present after seizing an initial opportunity. From our multiple case studies, we identified startups that largely expanded their target markets in their first years, but relying basically on the same innovative technologies. Examples include companies that began their participation in the biobased industry with advanced biofuels, such as Amyris and Solazyme.

The present paper provides extended empirical evidence to support these insights, which was also suggested by Alves et al. (2014). An interesting point to be highlighted is that in a recent theoretical work, Amit and Zott (2014) propose a dynamic capability perspective to business model design, which is segmented in five broad stages: observing, synthesizing, generating, refining, and implementing. *Observing* consists in a close examination of business model stake-holders interaction in meeting customers' needs, i.e., the development of a deep understanding of business model design drivers. *Synthesizing* involves the comprehension of the market gaps addressed and the forces that will shape the process of bringing solutions to customers, in a way to make sense of all that has been learned during the observation stage. *Generating* is the creation of potential business models, though not yet their implementation. *Refining*, in turn, consists in the consolidation, evaluation (according to criteria such as feasibility and desirability),

[14] The use of contract manufacturing or retrofit of existing units proved to be a valuable strategy for startups to minimize complementary assets expenditures, scale-up technologies and/or spur sensing activities

small-scale experimentation of the business models generated and, eventually, narrowing the number of possible business models. Finally, *implementing* involves selecting one specific design, and making the necessary organizational and strategic adaptations. The separation between the *refining* and *implementing* stages may not be clear (AMIT; ZOTT, 2014). The authors highlight that in both *refining* and *implementing* stages, where seizing dynamic capabilities are more prominent, the use of sensing is also required to adjust the business models. This is the pattern we have identified in our multiple case studies, mostly in the examples cited above.

3.5 Conclusions

With this study, we aimed to contribute to the comprehension of companies' strategies in the biobased industry, analyzing specifically technology-based startups. Through an empirical exploration of factors impacting flexibility in startups' business model design, we have identified two main factors that may impact this flexibility: (1) the technological possibilities that the startup possesses, related to the variety of markets that can be targeted and (2) the product nature, which balances products' market exploration potential with the ease to incorporate them in existing industrial structures. The assumed firm profile, producing and/or licensing, emerges as a significant business model decision that must consider the current opportunities and treats of the industry. These aspects were summarized in a decision flow chart that provides decision-makers with a practical way of assessing the paths a startup may want to pursue and their associated advantages and difficulties, besides highlighting specific characteristics that may lead to the establishment of different business models within a firm.

Contributing to the emerging literature on dynamic capabilities (HELFAT; PETERAF, 2009), we also perceived that a disaggregated view of sensing and seizing dynamic capabilities in relation to business model design can limit the comprehension of its dynamics, since the process of evolving a business model can be dependent on sensing dynamic capabilities, not only those related to seizing. We found that such overlapping of sensing and seizing occurs in the biobased industry and we expect to be also present in other situations, in which products market potential is not fully understood when establishing an initial business model. These empirical findings are also consonant to Amit's and Zott's (2014) dynamic view of business model design. The authors argue that sensing and seizing dynamic capabilities are closely interwoven in the process of crafting and evolving a business model. Therefore, we were able to support their suggestions, by looking the case of the biobased industry.

Another important discussion stressed in the present paper is the degree of irreversibility in business model design, especially in the medium-term. Startups in emerging industries should keep in mind factors that may contribute to low flexibility in business model experimentation and acknowledge that some offerings may be intrinsically restrictive, despite potentially large markets. The key point here is that flexibility can be decisive to perceive more readily deliverable offerings, which may guarantee the company's economic growth. Furthermore, the firm assumed profile (producing and/or licensing) affects the set of capabilities a startup accumulates and medium-term irreversibility could occur if the startup pursue a technology licensor profile.

Although we were able to collect and analyze a great number of data, all findings are inferred from publicly available information and misinterpretations could occur. To minimize that issue, we have employed a multiple case study design, cross-checked crucial information and tried to properly picture companies' history of strategic decisions by searching data from the time specific movements occurred, i.e., eliminating possible biases associated with companies' current strategies.

Our future expectations are to further validate our findings by analyzing the history of other startups. We are also interested in exploring the seizing dimension on startups' strategic decisions, more specifically, the impacts of different modes of partnerships in the construction of business models. Finally, we envision the possibility of applying our decision flow chart rationale to established companies entering the biobased industry, but factors such as competition with current businesses and availability of complementary assets are likely to alter the importance of the factors we found.

Chapter 4 - Conclusions and final comments

4.1 Conclusions

The general objective of this dissertation was to contribute with the understanding of the insertion strategies of two types of companies in the biobased industry and some general conclusions may be extracted from the two papers presented in the previous chapters.

Considering first the Paper 1 referring to the established chemical firms, it can be noticed that their current innovation strategies are balanced by their respective historical propensions to technological changes. These firms insertion in the industry seem to involve processes of change more or less pronounced, starging from the cases of transformation, in which firms may be more propense to incorporate new technologies and being more active when shaping opportunities (the cases of DSM and DuPont), and reaching in the cases of adaptation, in which a more deep involvement of the firm seems to depend yet on the decrease of market and technological uncertainties (as noticed in the cases of BASF and most of all Braskem). In opposition to what was argued by Hamilton (1985), differences in the strategies to manage these new technologies was perceived depending of this rate of change. Whereas adaptation processes in technological base tend to favor partnerships with startups until reduction of uncertainties, as pointed out by the author, firms in transformation seem to prefer the internalization of key knowledge through specific acquisitions.

Besides that, even for established firms with relevant local or global presence in the chemical industry, the commercialization of products obtained from renewable resources is showing to be challenging. The raw materials transition has a significant weight in this matter, since it may lead to geographical changes in the production of chemicals (for example, towards countries like Brazil, more privileged in terms of agriculture), and also allows that new entrants insert themselves in specific bonds of the value chain, like agribusiness and food companies. The study of Hamilton (1985) does not present this issue so markably due to not involve an industrial environment as complex as the biobased industry, where new established entrants from many sectors are able to participate and bring important resources along them. Considering yet the difficulties in advancing production technologies, establishing partnerships for assessing key resources becomes almost mandatory, as most cases explored show.

When observing the challenges related to the commercialization of bio-based products, some strategies may be highlighted. Firms that develop their strategies in a way to minimize impacts on current products portfolio, generally assume a production profile, adjusting the new products within existing operations. Drop-in products stand out as an important solution in such cases, taking advantage of well-established applications and distributions channels. Conversely, companies with a focus towards assuming leadership positions in the industry (mostly through mastering biotechnology techniques) do not need necessarily to invest in products aligned with their current portfolio, being able to become licensors of technologies that can be of interest for many players. Since they involve large scale production and homogeneous products (ARORA, 1997), licensing technologies for drop-in products show to be more suitable for licensing nowadays. Finally, mixed strategies were identified, involving both adequacy to existing portfolio and diversification towards new products (including non drop-in).

From Paper 2, which analyses startups, the importance of flexibility to experiment in business models stands out. The innovations proposed must be adequate to both the moment of the industry and the availability of interested investors. For example, specific startups were relevantly involved with biofuels around the year 2005, including Amyris, Avantium and Solazyme. After struggling to producing them in a economically feasible manner, Avantium and Solazyme reorganized and left the biofuels opportunity aside, while Amyris still invests in this area in partnership with Total but also expanded significantly to other markets, which are currently its main revenue sources. The three startups demonstrate some level of success for being able to find more feasible opportunities in the short term.

Two factors impacting the flexibility of startups to experiment in business model design were identified: the firms' technological possibilities and the product nature. Such possibilities relate to the variety of products and applications with which the firm can be involved, being wider if the startup is able to adapt to different markets or is exploring platform chemicals, and more restricted if the firm is focused in some specific final products or drop-in intermediates. The product nature (drop-in or non drop-in), in turn, involve issues such as the availability of complementary assets, efforts to develop the market and flexibility to structure the opportunity. Drop-in products are more easily inserted in existing markets, but do not allow a large flexibility to experiment in business models. The inverse occurs with non drop-in products, since they tend to demand new assets and efforts to develop markets, allowing certain flexibility to shape the new opportunities.

The choice to produce and/or license has been identified as a relevant business model decision to startups. That decision shall be weighted by the industry characteristics, as non drop-in molecules do not yet have established markets and companies would hardly become licensees of their respective technologies. In addition, since involves a separation of production and marketing activities, the decision to license can be somewhat irreversibly, at least in the medium term. It is expected that companies with a licensing profile and focus on the development of technological capabilities have more difficulties to become producers, while manufacturing companies apparently would not have so many impediments to license their technologies. This decision would not be properly associated with flexibility in the manner discussed in the article, as it relates to the accumulation of capabilities over time. In other words, the two factors depicted impact the flexibility in a more immediate way, expanding or reducing business opportunities, while the "irreversibility" arising from a licensing profile is felt after the startup is consolidated as a licensor.

These points are summarized in a decision flow chart, which provides a useful way to evaluate the potential of technological possibilities of startups and how they may be impacted by the industry characteristics. In line with the understanding of the environment and defining goals, this flow chart has the potential to assist decision makers and is suitable for organizing different lines of the firm's products, emphasizing characteristics that may indicate the existence of different business models.

Finally, analyze the cases from the dynamic capabilities of Teece (2007) perspective brought empirical evidence of sensing role on business models design, which appears only as a microfoundation of seizing dynamic capabilities. Particularly in situations involving products with uncertain applications, startups establish business models that generate enough income to sustain their operations (even on a small scale and focusing on specific markets at first) and start prospecting for more applications, adapting to meet the new opportunities and challenges. In other words, in the business model implementation process, in which dynamic capabilities of seizing are prominent, dynamic capabilities related to sensing are still needed and present.

4.2 Final comments

The two papers have an interesting complementarity, since deal with newly formed companies and a group of firms already established. The challenges inherent to these two groups are quite distinct from one another. While startups are new entrants whose primary focus is to innovate and thrive based on these innovations, established chemical companies must somehow balance innovation and those businesses that currently constitute their main income sources. This is one of the reasons why different base literatures were used for each paper, despite involving the same context.

Startups' business model experimentation seems to be reasonably well supported by Teece's (2007) framework of dynamic capabilities, especially for involving dynamic capabilities related to opportunities perception (sensing) and to pursuing them (seizing). The nature of such companies provides the identification of strategies related to sensing and seizing that are not affected by decisions and resources previously established. In other words, startups decisions are not affected by previous successful paths.

On the other hand, one of the most interesting points in using this literature for established companies would be through the analysis of reconfiguring dynamic capabilities. These firms have well-established resources and routines, and the role of dynamic capabilities of reconfiguration is to facilitate resource mobility for the organization to take advantage of new opportunities and face threats. However, identifying these capabilities would require deeper studies on the firms, through interviews with different employees, for example. For our purposes, to dialogue with Hamilton's (1985) work was more beneficial, for promoting discussion of chemical companies partnerships in the biobased industry (bringing different evidence from those presented by the author) and for allowing the identification of the insertion strategies for these companies.

The direct use of the decision flow chart developed in Paper 2 to the established chemical companies does not seem reasonable, since other factors can guide their decisions. The case of DSM in the succinic acid initiative shows that not necessarily the characteristic flexibility of the platform chemical is the main motivation for the effort. Through the Reverdia joint venture, the company seems to prefer to maintain itself as a licensor and a technologies developer, rather than exploring the production of derivatives. Regarding the nature of the product, it may be advantageous for chemical companies both drop-in products that require few adjustments in complementary assets and can be readily marketed as innovative products, and non drop-in products that can position the company well in emerging markets (the case BASF with the bio-BDO and PEF polymer, respectively). In other words, established firms' strategies to reconcile efforts in the biobased and chemical industries, as well as the overall company strategy, can decrease the importance of inserting themselves in the industry flexibly.

The own development of technological capabilities tends to allow for adaptability to different markets (first branch of the decision flow chart), arising as a source of business models experimentation flexibility. As an example, even though it proved to be the most conservative company among those analyzed, Braskem invests in technological capabilities and industry monitoring. The company has built a laboratory dedicated to bioprocess research and developed a detailed roadmap for monitoring new technologies (see Coutinho and Bontempo (2011)). Again, the big question is whether the flexibility resulting from these capabilities will lead to experimentation in business models, that is, if the firm's strategy allows it to depart from the dominant logic.

In general terms, it is worth to highlight the important roles of both established firms and startups in the biobased industry context. One of the main aspects underlining the discussions of Paper 1 is the variety and wide distribution of complementary assets among industry participants. While complementary assets are undoubtly relevant, the startups approached in Paper 2 usually have capabilities that favor innovation and less rigidity to experiment with business models. These two dimensions (complementary assets management and experimentation with innovative business models) are key aspects of an emerging industry, especially in a complex environment as the biobased industry. In this manner, established firms willing to assume significant roles in manufacturing products from renewable resources need to actively engage in finding value chain architectures to make these new opportunities feasible, but also leveraging the innovative strength of startups, firms that need many assets to scale-up their technologies to commercialization.

4.3 Study limitations

Despite possible limitations related to information interpretation, at least in a first moment the use of publicly available information show to be a satisfactory way to approach the theoretical issues proposed hereby and, simultaneously, provide some practical findings.

4.4 Future research

As described by the end of Paper 1, we hope with future works to deepen the comprehension of which characteristics of complementary assets and technological capabilities favor partnerships between established firms. Analyze windows strategies (HAMILTON, 1985) and patents evolution of established firms would also be interesting steps to support the discussion of technological base transformation. The next steps of Paper 2 could involve testing the decision flow chart and probably enhancing it from the analysis of other startups. Exploring the strategic decisions of these firms in regards to partnerships would also help the comprehension of their insertion in the industry and possible business models impacts. For instance, partnerships between startups and established companies could theoretically affect the former experimentation flexibility, through the alignment of their efforts mainly with established firms' interests.

In general terms and following the rationale of the two papers developed hereby, a suggestion for future works would be to analyze the insertion of established firms from food ingredients, pulp and paper, agribusiness and oil and gas sectors in the biobased industry, focusing on their insertion strategies. Such studies would maybe provide more insights to the comprehension of the industry boundaries and the contributions of each type of firm to the commercialization of biobased products.

As Forbes e Kirsch (2011) argue, the literature related to entrepreneurship and to the emergence of new industries is many times focused on the production firms, but the understanding of new industries creation process also demands the analysis of the "infrastructure" that favors it, i.e. the roles of universities, investors, public institutions and their politics, standards organisms, as well as end-users. Hence, there are many other potential research areas in the study of the biobased industry. One example, would be to advance the comprehension of the mechanisms of bioproducts promotion, in other words, how producers are coordinating themselves with end-users to expand their adoption and how the “renewable” value proposition impacts such coordination. The initiatives of Coca-Cola and Danone in PEF polymer promotion and the approximation of a car producer with Braskem to advance green PE are some examples that demonstrate the importance of external actors.

Bibliographical references

ABELSHAUER, W. BASF Since Its Refunding in 1952. **German Industry and Global Enterprise - BASF: The History of a Company**. 1º ed. Cambridge, United Kingdom: Cambridge University Press. 2004.

ABERNATHY, W. J.; UTTERBACK, J. M. Pattern of Industrial Innovation. **Technology Review**, v. 80, n. 7, 1978.

ALBRECHT, J.; CARREZ, D.; CUNNINGHAM, P.; et al. **The Knowledge Based Bio-Economy (KBBE) in Europe: Achievements and Challenges - Full report**. Brussels, Belgium: European Commission, 2010.

ALVES, F.; BOMTEMPO, J. V.; OROSKI, F. Business Model Innovation and Dynamics in Emerging Industries. Montreal, Canada, 2014.

AMIT, R.; ZOTT, C. **Business Model Design: A Dynamic Capability Perspective**. Working Paper, 2014.

AMYRIS. Form 10-K (Annual Report). 2011. Disponível em <http://investors.amyris.com/sec.cfm>. Acesso em 28 de outubro de 2015.

AMYRIS. Amyris Biorefinery Successfully Restarts Industrial Production in Brazil - Amyris. **Amyris**. (2014). Disponível em <https://amyris.com/amyris-biorefinery-successfully-restarts-industrial-production-in-brazil/>. Acesso em 28 de outubro de 2015.

AMYRIS. Form 10-K (Annual Report). 2015a. Disponível em <http://investors.amyris.com/sec.cfm>. Acesso em 28 de outubro de 2015.

AMYRIS. µPharm. **Amyris**. Disponível em <https://amyris.com/collaborations/%ce%bcpharm/>. Acesso em 27 de outrobro de 2015b.

DE ARAÚJO, M. R. **Desenvolvimento de Novas Plataformas Químicas: O caso do bio-ácido succínico**. Rio de Janeiro: UFRJ, 2015.

ARORA, A. Patents, licensing, and market structure in the chemical industry. **Research Policy**, v. 26, n. 4–5, p. 391–403, 1997.

ARORA, A.; GAMBARDELLA, A. Complementarity and External Linkages: The Strategies of the Large Firms in Biotechnology. **The Journal of Industrial Economics**, v. 38, n. 4, p. 361–379., 1990.

AVANTIUM. Avantium Holding N.V. Public Offering. 2007. Disponível em <http://www.afm.nl/registers/emissies_documents/630.pdf>. Acesso em 29 de outubro de 2015.

AVANTIUM. Avantium - Avantium and The Coca-Cola Company sign partnership agreement to develop next generation 100% plant based plastic: PEF. **Avantium.** (2011). Disponível em <http://avantium.com/news/2011-2/Avantium-and-The-Coca-Cola-Company-sign-partnership-agreement-to-develop-next-generation-100-plant-based-plastic-PEF.html>. Acesso em 15 de outubro de 2015.

AVANTIUM. Avantium - Wifag-Polytype and Avantium announce agreement on 100% biobased PEF for thermoforming. **Avantium.** (2013). Disponível em <http://avantium.com/media/news/2013-2/Wifag-Polytype-and-Avantium-announce-agreement-on-100-biobased-PEF-for-thermoforming.html>. Acesso em 16 de outubro de 2015.

AVANTIUM. Avantium - biofuels. **Avantium**. (2015). Disponível em <http://www.avantium.com/biofuels>. Acesso em 16 de outubro de 2015.

BARNEY, J. Cooperative Strategies: Strategic Alliances. **Gaining and Sustaining Competitive Advantage : Theory and Practice**. 3º ed. Upper Saddle River, NJ: Prentice Hall, 2007.

BARNEY, J. B. Firm Resources and Sustained Competitive Advantage. **Journal of Management**, 1991.

BASF. Corporate Report 2004. 2004. Disponível em < https://www.basf.com/documents/corp/en/about-us/publications/reports/2005/BASF_Corporate_Report_2004.pdf>. Acesso em 15 de maio de 2016.

BASF. BASF starts operations at expanded Ecoflex plant - Production capacity for biodegradable plastics increases by 60,000 metric tons per year. **Plastics Portal**. (2011). Disponível em <http://www.plasticsportal.net/wa/plastics/portal/show/common/plasticsportal_news/2011/11_139>. Acesso em 11 de maio de 2016.

BASF. BASF and Renmatix agree on a joint development for the production of industrial sugars from biomass. **BASF**. (2013). Disponível em <https://www.basf.com/en/company/news-and-media/news-releases/2013/12/p-13-470.html>. Acesso em 11 de maio de 2016.

BASF. Renewable all-rounder. **BASF**. (2014). Disponível em <http://www.intermediates.basf.com/chemicals/topstory/basfia-succiniciproducens>. Acesso em 11 de maio de 2016.

BASF. History. **BASF**. (2016a). Disponível em <https://www.basf.com/en/company/about-us/history.html>. Acesso em 10 de maio de 2016.

BASF. Lupranol BALANCE: polyols on the basis of renewable raw materials. **BASF**. (2016b) Disponível em <http://www.plasticsportal.net/wa/plasticsEU~en_GB/portal/show/common/plasticsportal_news/2007/07_281>. Acesso em 2 de junho de 2016.

BASF. BASF and Avantium intend to establish joint venture. **BASF**. (2016c) Disponível em <https://www.basf.com/en/company/news-and-media/news-releases/2016/03/p-16-153.html>. Acesso em 11 de maio de 2016.

BENNETT, S. J.; PEARSON, P. J. G. From petrochemical complexes to biorefineries? The past and prospective co-evolution of liquid fuels and chemicals production in the UK. **Chemical Engineering Research and Design**, Special Issue on Biorefinery IntegrationBiorefinery Integration SI., v. 87, n. 9, p. 1120–1139. 2009.

BERESFORD, M. Braskem freezes green plastics plans, focuses elsewhere. **BNamericas**. (2013). Disponível em <http://www.bnamericas.com/en/news/petrochemicals/braskem-freezes-green-plastics-plans-focuses-elsewhere>. Acesso em 5 de maio de 2016.

BIOAMBER. Form 10-K (Annual Report). 2015. Disponível em <http://investor.bio-amber.com/sec-filings>. Acesso em 23 de outubro de 2015.

BIO-BASED WORLD NEWS. Ask the Industry: Markus Hummelsberger, Marketing & Sales Director, Succinity. Bio-Based World News. (2015). Disponível em <http://www.biobasedworldnews.com/markus-hummelberger-succinity-interview-0>. Acesso em 11 de maio de 2016.

BIOFUELS DIGEST. DSM enzymes qualify for Inbicon cellulosic ethanol process. **Biofuels Digest**. (2012). Disponível em <http://www.biofuelsdigest.com/bdigest/2012/06/05/dsm-enzymes-qualify-for-inbicon-cellulosic-ethnaol-process/>. Acesso em 26 de abril de 2016.

BIOFUELS DIGEST. Avantium: Biofuels Digest’s 2014 5-Minute Guide : Biofuels Digest. **Biofuels Digest**. (2014). Disponível em <http://www.biofuelsdigest.com/bdigest/2014/02/25/avantium-biofuels-digests-2014-5-minute-guide/>. Acesso em 15 de outubro de 2015.

BIOFUELS DIGEST. DuPont opens world’s largest cellulosic ethanol plant, in Iowa: the full story in pictures : Biofuels Digest. **Biofuels Digest**. (2015a). Disponível em <http://www.biofuelsdigest.com/bdigest/2015/11/01/dupont-opens-worlds-largest-celulosic-ethanol-plant-in-iowa-the-full-story-in-pictures/>. Acesso em 2 de maio de 2016.

BIOFUELS DIGEST. Renewable Isobutanol: It’s Time for a Truce. **Biofuels Digest**. (2015b). Disponível em <http://www.biofuelsdigest.com/bdigest/2015/05/18/renewable-isobutanol-its-time-for-a-truce/>. Acesso em 2 de maio de 2016.

BIOFUELS DIGEST. Genomatica: Biofuels Digest’s 2015 5-Minute Guide : Biofuels Digest. **Biofuels Digest**. (2015c). Disponível em <http://www.biofuelsdigest.com/bdigest/2015/03/31/genomatica-biofuels-digests-2015-5-minute-guide/>. Acesso em 14 de outubro de 2015.

BIOFUELS DIGEST. The 50 Hottest Companies in the Advanced Bioeconomy 2016. **Biofuels Digest**. (2016). Disponível em

<http://www.biofuelsdigest.com/bdigest/2016/02/17/the-50-hottest-companies-in-the-advanced-bioeconomy-2016/52/>. Acesso em 24 de maio de 2016.

BIOFUELS JOURNAL. Kluyver Centre and TU Delft (Netherlands) License Modified Yeast to DSM For Cellulosic Ethanol Production | BioFuels Journal. **Biofuels Journal**. (2011). Disponível em <http://www.biofuelsjournal.com/articles/kluyver_centre_and_tu_delft__netherlands__license_modified_yeast_to_dsm_for_cellulosic_ethanol_production-105747.html>. Acesso em 26 de abrilmaio de 2016.

BOMTEMPO, J. V. **Agendas Tecnológicas Setorias (ATS) - Química de Renováveis**, 2013.

BOMTEMPO, J. V.; ALVES, F. C. Innovation dynamics in the biobased industry. **Chemical and Biological Technologies in Agriculture**, v. 1, n. 1, p. 19, 2014.

BOMTEMPO, J. V.; ALVES, F.; OROSKI, F. DE A. Innovation strategies diversity in the biobased economy: a comparative approach. University of Paris Ouest, Nanterre, La Défense, 2014.

BOZELL, J. J.; PETERSEN, G. R. Technology development for the production of biobased products from biorefinery carbohydrates—the US Department of Energy's "Top 10" revisited. **Green Chemistry**, v. 12, n. 4, p. 539, 2010.

BRASKEM. Braskem 2003 Management Report. 2003. Disponível em <http://www.braskem-ri.com.br/annual-reports>. Acesso em 23 de abril de 2016.

BRASKEM. Braskem amplia parcerias e pesquisa na área de biotecnologia. **Braskem**. (2010). Disponível em <https://www.braskem.com.br/detalhe-noticia/Braskem-amplia-parcerias-e-pesquisa-na-area-de-biotecnologia>. Acesso em 5 de maio de 2016.

BRASKEM. Braskem - History and Profile. **Braskem**. (2016a). Disponível em <http://www.braskem-ri.com.br/history-and-profile>. Acesso em 3 de maio de 2016.

BRASKEM. Time Line - Braskem. **Braskem**. (2016b). Disponível em <http://www.braskem.com/site.aspx/Time-Line>. Acesso em 5 de maio de 2016.

CHANDLER, A. D. **Shaping the Industrial Century: The Remarkable Story of the Evolution of the Modern Chemical and Pharmaceutical Industries**. Cambridge, Mass.: Harvard University Press, 2005.

CHEMICALS TECHNOLOGY. DuPont Tate & Lyle's Biochemical Plant, Tennessee. **Chemicals Technology**. (2016). Disponível em <http://www.chemicals-technology.com/projects/dupont-tate-lyle-biochemical-loudon-tennessee/>. Acesso em 5 de maio de 2016.

CHESBROUGH, H. Business Model Innovation: Opportunities and Barriers. **Long Range Planning**, v. 43, p. 354–363, 2010.

CORBION. About Corbion. **Corbion**. (2016). Disponível em <http://www.corbion.com/about-corbion>. Acesso em 15 de junho de 2016.

COUTINHO, P.; BOMTEMPO, J. V. A technology roadmap in renewable raw materials: a basis for public policy and strategies in Brazil. **Química Nova**, v. 34, n. 5, p. 910–916, 2011.

CURTIS, B. **US Ethanol Industry: The Next Inflection Point**. BCurtis Energies & Resource Group, 2008.

DANISCO. Sustainability Report 2006. 2006. Disponível em <http://www.danisco.com/uploads/tx_tcdaniscofiles/Sustainability_Report_2006.pdf>. Acesso em 16 de junho de 2016.

DOE. Largest Cellulosic Ethanol Plant in the World Opens October 30. **Energy.gov**. (2015). Disponível em <http://energy.gov/eere/bioenergy/articles/largest-cellulosic-ethanol-plant-world-opens-october-30>. Acesso em 2 de maio de 2016.

DSM. DSM finalizes portfolio transformation and enters era of focused growth. (2010). Disponível em <http://www.dsm.com/corporate/media/informationcenter-news/2010/09/42-10-dsm-finalizes-portfolio-transformation-and-enters-era-of-focused-growth.html>. Acesso em 18 de abril de 2016.

DSM. DSM strengthens yeast technology leadership for 2G biofuels. **DSM**. (2011). Disponível em <http://www.dsm.com/corporate/media/informationcenter-news/2011/06/45-11-dsm-strengthens-yeast-technology-leadership-for-2g-biofuels.html>. Acesso em 26 de abril de 2016.

DSM. Achieving higher bio-based content in DSM Arnitel® copolyesters - Results from testing 1,4-butanediol (BDO) made with Genomatica’s process technology. **DSM**. (2013). Disponível em <https://www.dsm.com/content/dam/dsm/arnitel/en_US/documents/DSM-Paper-Bio-BDO.pdf>. Acesso em 1 de junho de 2016.

DSM. Royal DSM Integrated Annual Report. 2015. Disponível em <http://www.dsm.com/content/dam/dsm/cworld/en_US/documents/dsm-integrated-annual-report-2015.pdf>. Acesso em 25 de abril de 2016.

DSM. An evolution of successful transformations. (2016a). Disponível em <http://www.dsm.com/corporate/about/our-company/dsm-history.html>. Acesso em 16 de abril de 2016.

DSM. EcoPaXX®. **DSM**. (2016b). Disponível em <http://www.dsm.com/products/ecopaxx/en_US/home.html>. Acesso em 1 de junho de 2016.

DUPONT. Form 10-K (Annual Report). 2010. Disponível em <http://investors.dupont.com/investor-relations/filings-and-reports/quarterly-and-annual-reports/default.aspx>. Acesso em 16 de junho de 2016.

DUPONT. DuPont Industrial Biosciences to Acquire Biotechnology Assets from Dyadic. **DuPont**. (2015a). Disponível em <http://www.dupont.com/products-and-services/industrial-biotechnology/press-releases/DuPont-Industrial-Biosciences-to-Acquire-Biotechnology-Assets-from-Dyadic.html>. Acesso em 8 de julho de 2016.

DUPONT. Form 10-K (Annual Report). 2015b. Disponível em <http://investors.dupont.com/investor-relations/filings-and-reports/quarterly-and-annual-reports/default.aspx>. Acesso em 16 de junho de 2016.

DUPONT. 2015 DuPont Data Book. 2015c. Disponível em <http://investors.dupont.com/investor-relations/filings-and-reports/quarterly-and-annual-reports/default.aspx>. Acesso em 5 de fevereiro de 2016.

DUPONT. Cerenol™ Polyols. **DuPont**. (2016). Disponível em <http://www2.dupont.com/Renewably_Sourced_Materials/en_US/cerenol.html>. Acesso em 2 de junho de 2016.

DUPONT TATE AND LYLE BIO PRODUCTS. Applications. **DuPont Tate and Lyle Bio Products**. (2016). Disponível em <http://www.duponttateandlyle.com/>. Acesso em 2 de maio de 2016.

EISENHARDT, K. M.; GRAEBNER, M. E. Theory building from cases: Opportunities and challenges. **Academy of Management Journal**, v. 50, n. 1, p. 25–32. 2007.

FDC. Visão 2020: O conceito de sustentabilidade torna-se proeminente. **FDC**. (2010). Disponível em <https://www.fdc.org.br/hotsites/mail/livro_sustentabilidade_poder/oasis/braskem-da-quimica-verde-ao-desafio-da-quimica-sustentavel/visao-2020-o-conceito-de-sustentabilidade-torna-se-proeminente.html>. Acesso em 3 de maio de 2016.

FORBES, D. P.; KIRSCH, D. A. The study of emerging industries: Recognizing and responding to some central problems. **Journal of Business Venturing**, v. 26, n. 5, p. 589–602. 2011.

FORTUNE. Solazyme Ditches Biofuels, Changes Name to TerraVia - Fortune. **Fortune**. (2016). Disponível em <http://fortune.com/2016/03/16/solazyme-terravia-ditches-biofuels/>. Acesso em 24 de maio de 2016.

FREEMAN, C. **The Economics of Industrial Innovation** (L. Soete, Org.). 3º ed. London: Routledge, 1997.

GENOMATICA. Braskem signs joint development agreement for bio-based butadiene. **Genomatica**. (2013). Disponível em <http://www.genomatica.com/news/press-releases/braskem-signs-joint-development-agreement-for-bio-based-butadiene/>. Acesso em 5 de maio de 2016.

GENOMATICA. Genomatica and Braskem confirm direct, single-step biological production of butadiene. **Genomatica**. (2015a). Disponível em <http://www.genomatica.com/news/press-releases/genomatica-and-braskem-confirm-direct-biological-production-of-butadiene/>. Acesso em 5 de maio de 2016.

GENOMATICA. Genomatica – Transforming the chemical industry | Genomatica. **Genomatica**. (2015b). Disponível em <http://www.genomatica.com/about/>. Acesso em 14 de outubro de 2015.

GOLEMBIEWSKI, B.; SICK, N.; BRÖRING, S. The emerging research landscape on bioeconomy: What has been done so far and what is essential from a technology and innovation management perspective? **Innovative Food Science & Emerging Technologies**, APPLICATIONS OF PEF FOR FOOD PROCESSING., v. 29, p. 308–317. doi: 10.1016/j.ifset.2015.03.006, 2015.

GRANBIO. GraalBio announces the first cellulosic ethanol plant in the Southern Hemisphere. **GranBio**. (2012). Disponível em <http://www.granbio.com.br/en/wp-content/uploads/sites/2/2015/04/First_cellulosic-ethanol_plant.pdf>. Acesso em 26 de abril de 2016.

GREEN CAR CONGRESS. DuPont and Genencor Form Cellulosic Ethanol Joint Venture. **Green Car Congress**. (2008). Disponível em <http://www.greencarcongress.com/2008/05/dupont-and-gene.html>. Acesso em 2 de maio de 2016.

GUZMAN, D. DE. Braskem to build Bio-PP plant. **ICIS Green Chemicals**. (2010). Disponível em <http://www.icis.com/blogs/green-chemicals/2010/11/braskem-to-build-bio-pp-plant/>. Acesso em 5 de maio de 2016.

GUZMAN, D. DE. BASF expands bioplastic investments. **Green Chemicals Blog**. (2013). Disponível em <http://greenchemicalsblog.com/2013/06/25/basf-expands-bioplastic-investments/> Acesso em 11 de maio de 2016.

HAMILTON, W. F. Special Issue Techonology in the Modern Corporation A Strategic PerspectiveCorporate strategies for managing emerging technologies. **Technology in Society**, v. 7, n. 2, p. 197–212. doi: 10.1016/0160-791X(85)90025-9, 1985.

HAMILTON, W. F. The dynamics of technology and strategy. **European Journal of Operational Research**, v. 47, n. 2, p. 141–152. doi: 10.1016/0377-2217(90)90273-E, 1990.

HAMPRECHT, J.; BÜRGER, L.; PHILIPP, S. Resource Use and Waste Management: Bio above All? **Kunststoffe International**, v. 8, p. 26–30, 2011.

HELFAT, C. E.; FINKELSTEIN, S.; MITCHELL, W.; et al. **Dynamic Capabilities: Understanding Strategic Change in Organizations**. Malden, MA: Blackwell, 2007.

HELFAT, C. E.; PETERAF, M. A. Understanding dynamic capabilities: progress along a developmental path. **Strategic Organization**, v. 7, n. 1, p. 91–102. doi: 10.1177/1476127008100133, 2009.

HOLLIDAY, C. Sustainable Growth, the DuPont Way. **Harvard Business Review**, setembro, 2001. Disponível em <https://hbr.org/2001/09/sustainable-growth-the-dupont-way>. Acesso em 1 de maio de 2016.

HONEYWELL. Honeywell’s UOP Renewable Jet Fuel Technology to be Used for U.S. Military Testing and Certification - Case Studies. **Honeywell**. (2010). Disponível em <http://www51.honeywell.com/honeywell/news-events/case-studies-n3n4/jet_fuel_technology.html?c=>. Acesso em 27 de outrobro de 2015.

HOUNSHELL, D. A.; SMITH, J. K. **Science and Corporate Strategy: Du Pont R and D, 1902-1980**. 1 edition ed. Cambridge Cambridgeshire; New York: Cambridge University Press, 1988.

ICIS CHEMICAL BUSINESS. DuPont Unveils Final Exit Strategy From Energy. **ICIS Chemical Business**. (1998). Disponível em <http://www.icis.com/resources/news/1998/10/05/89031/dupont-unveils-final-exit-strategy-from-energy/>. Acesso em 1 de maio de 2016.

ICIS CHEMICAL BUSINESS. DuPont Sells Invista to Koch Industries for $4.4 Billion in Cash. **ICIS Chemical Business**. (2003). Disponível em <http://www.icis.com/resources/news/2003/11/21/536569/dupont-sells-invista-to-koch-industries-for-4-4-billion-in-cash/>. Acesso em 1 de maio de 2016.

ICIS CHEMICAL BUSINESS. DSM going after health and nutrition with Vision 2010. **ICIS**. (2005). Disponível em <http://www.icis.com/resources/news/2005/11/07/2010980/dsm-going-after-health-and-nutrition-with-vision-2010/>. Acesso em 18 de abril de 2016.

ICIS CHEMICAL BUSINESS. DSM adds adipic acid to bio-based chemicals portfolio. **ICIS Chemical Business**. (2011). Disponível em <http://www.icis.com/resources/news/2011/10/10/9498186/green-chemicals-dsm-adds-adipic-acid-to-bio-based-chemicals-portfolio/>. Acesso em 26 de abril de 2016.

ICIS CHEMICAL BUSINESS. Genomatica/Cargill biochem model can be game-changer. **ICIS Chemical Business**. (2015). Disponível em <http://www.icis.com/resources/news/2015/10/28/9937624/genomatica-cargill-biochem-model-can-be-game-changer/>. Acesso em 10 de agosto de 2016.

IEA. Biofuel-driven Biorefineries. IEA Bioenergy – Task42 Biorefinery, 2013.

ILES, A.; MARTIN, A. N. Expanding bioplastics production: sustainable business innovation in the chemical industry. **Journal of Cleaner Production**, Sustainable Innovation and Business Models., v. 45, p. 38–49. doi: 10.1016/j.jclepro.2012.05.008, 2013.

INVESTE SÃO PAULO. Braskem inaugura o novo laboratório de produtos químicos renováveis - InvesteSP. **Investe São Paulo**. (2014). Disponível em <http://www.investe.sp.gov.br/noticia/braskem-inaugura-o-novo-laboratorio-de-produtos-quimicos-renovaveis/>. Acesso em 5 de maio de 2016.

IPIRA. Amyris Biotechnologies | IPIRA-Intellectual Property and Industry Research Alliances (Technology Transfer). **IPIRA - Office of Intellectual Property & Industrial Research Alliances**. (2015). Disponível em

<http://ipira.berkeley.edu/amyris-biotechnologies>. Acesso em 27 de outubro de 2015.

ISTOÉ. O futuro da química é verde. **ISTOÉ**. (2015). Disponível em <http://www.istoedinheiro.com.br/noticias/negocios/20151030/futuro-quimica-verde/313446>. Acesso em 5 de maio de 2016.

JACOBIDES, M. G.; KNUDSEN, T.; AUGIER, M. Benefiting from Innovation: Value Creation, Value Appropriation and the Role of Industry Architectures. doi: 10.2139/ssrn.1309509, 2006.

JEANNET, J.-P.; SCHREUDER, H. **From Coal to Biotech: The Transformation of DSM with Business School Support**. 1º ed. Berlin Heidelberg: Springer -Verlag, 2015.

KURIAN, J. V. DuPont Sorona® Polymer: A New Bio Based Material for the 21st Century. South Korea. (2005). Disponível em <http://www2.dupont.com/Hyundai_Kia/en_US/assets/downloads/presentations/Sorona_Korea_Kurian.pdf>. Acesso em 1 de maio de 2016.

LASSITER, J. B.; SAHLMAN, W. A.; WAGONFELD, A. B.; RICHARDSON, E. Khosla Ventures: Biofuels Gain Liquidity. **Harvard Business Review**, 2011.

LUBBEN, M. Successfully Scaling Up Industrial Fermentation of Biosuccinium™. San Diego, California, 2016.

MARKETSANDMARKETS. 1,3-Propanediol Market worth $621.2 Million by 2021. **MarketsandMarkets**. (2016). Disponível em <http://www.marketsandmarkets.com/PressReleases/1-3-propanediol-pdo.asp>. Acesso em 2 de maio de 2016.

MCCARTHY, A. Metabolix, Inc. and Tepha, Inc.: Bioplastics for Industry and Medical Devices. **Chemistry & Biology**, p. 893–894, 2003.

MELÉNDEZ, J.; LEBEL, L.; STUART, P. A Literature Review of Biomass Feedstocks for a Biorefinery. **Integrated Biorefineries**, Green Chemistry and Chemical Engineering. p.433–460. CRC Press. (2012). Disponível em <http://www.crcnetbase.com/doi/abs/10.1201/b13048-20>. Acesso em 5 de maio de 2016.

METABOLIX. Form 10-K (Annual Report). 2006. Disponível em <http://ir.metabolix.com/sec.cfm>. Acesso em 26 de outubro de 2015.

METABOLIX. Form 10-K (Annual Report). 2007. Disponível em <http://ir.metabolix.com/sec.cfm>. Acesso em 26 de outubro de 2015.

METABOLIX. Form 10-K (Annual Report). 2013. Disponível em <http://ir.metabolix.com/sec.cfm>. Acesso em 26 de outubro de 2015.

METABOLIX. Form 10-K (Annual Report). 2015. Disponível em <http://ir.metabolix.com/sec.cfm>. Acesso em 26 de outubro de 2015.

MICHELIN. Braskem joins Amyris and Michelin to Accelerate the Industrialization and Commercialization of Renewable Isoprene | Michelin. **Michelin**. (2014). Disponível em <http://www.michelin.com/eng/media-room/press-and-news/press-releases/Group/Braskem-joins-Amyris-and-Michelin-to-Accelerate-the-Industrialization-and-Commercialization-of-Renewable-Isoprene>. Acesso em 5 de maio de 2016.

MINTZBERG, H. Patterns in Strategy Formation. **Management Science**, v. 24, n. 9, p. 934–948, 1978.

NAIR, S.; PAULOSE, H. Emergence of green business models: The case of algae biofuel for aviation. **Energy Policy**, v. 65, p. 175–184. doi: 10.1016/j.enpol.2013.10.034, 2014.

NOEL, A. BASF Agrees to Buy Verenium as It Attacks DuPont, Novozymes. **Bloomberg.com**. (2013). Disponível em <http://www.bloomberg.com/news/articles/2013-09-20/basf-agrees-to-buy-verenium-as-it-attacks-dupont-novozymes>. Acesso em 29 de agosto de 2016.

NOVOZYMES. Conference Call - Q1 2014. 2014. Disponível em <http://www.novozymes.com/en/investor/events-presentations/Documents/2014_Q1_Conference%20Call_FINAL.pdf>. Acesso em 29 de maio de 2016.

ODEBRECHT. Caminho de crescimento. **Odebrecht Informa Online**. (2007). Disponível em <http://www.odebrechtonline.com.br/materias/01201-01300/1240/>. Acesso em 3 de maio de 2016.

OECD. The Bioeconomy to 2030 - Designing a Policy Agenda. 2009. Disponível em <https://www.oecd.org/futures/long-termtechnologicalsocietalchallenges/42837897.pdf>. Acesso em 23 de maio de 2016.

OROSKI, F. DE A. **Modelos de Negócio e Transição de Sistemas Tecnológicos: o caso dos bioplásticos**. Tese de Doutorado, Rio de Janeiro, Brasil: Universidade Federal do Rio de Janeiro, 2013.

OROSKI, F. DE A.; ALVES, F. C.; BOMTEMPO, J. V. Bioplastics Tipping Point: drop-in or non-drop-in? **Journal of Business Chemistry**, p. 43–50, 2014, fevereiro.

PETTIT, H. Developing a Corn Stover Supply Chain with DuPont. Pacific Ag. (2015). Disponível em <http://www.pacificag.com/default-blog/developing-a-corn-stover-supply-chain-with-dupont>. Acesso em 7 de junho de 2016.

PLASTICS TECHNOLOGY. DuPont Plans for Large-Scale Conversion to Biobased Polymers. **Plastics Technology**. (2013). Disponível em

<http://www.ptonline.com/articles/dupont-plans-for-large-scale-conversion-to-biobased-polymers>. Acesso em 2 de junho de 2016.

PLASTICS TECHNOLOGY. 100% biobased polyester charts course to commercialization : Plastics Technology. **Plastics Technology**. (2014). Disponível em <http://www.ptonline.com/blog/post/100-biobased-polyester-charts-course-to-commercialization#/cdn/cms/Avantium%20Bottles.jpg>. Acesso em 16 de outubro de 2015.

POET. Cellulosic Ethanol - POET. (2016). Disponível em <http://poet.com/cellulosic>. Acesso em 25 de abril de 2016.

PORTER, M. E. **Competitive Strategy: Techniques for Analyzing Industries and Competitors**. New York: The Free Press, 1980.

PR NEWSWIRE. Christophe Schilling, Ph.D., Named One of the World's Top Young Innovators by Technology Review, MIT's Magazine of Innovation. **PR Newswire**. (2003). Disponível em <http://www.prnewswire.com/news-releases/christophe-schilling-phd-named-one-of-the-worlds-top-young-innovators-by-technology-review-mits-magazine-of-innovation-71121437.html>. Acesso em 14 de outubro de 2015.

PROVINE, W. D. DuPont's Journey to Build a Global Cellulosic BioFuel Business Enterprise. Washington, DC, 2014.

QUINTANA-GARCÍA, C.; BENAVIDES-VELASCO, C. A. Innovative competence, exploration and exploitation: The influence of technological diversification. **Research Policy**, v. 37, n. 3, p. 492–507. doi: 10.1016/j.respol.2007.12.002, 2008.

REVERDIA. Company Overview. **Reverdia**. (2016). Disponível em <http://www.reverdia.com/about/company-overview/>. Acesso em 26 de abril de 2016.

VAN ROOIJ, A. **The Company that Changed Itself: R&D and the Transformations of DSM**. 1º ed. Amsterdam: Amsterdam University Press. 2007.

ROQUETTE. BioHub programme has come to a successful closure. **Roquette**. (2015). Disponível em <http://www.roquette.com/2015/biohub-programme-has-come-to-a-successful-conclusion/>. Acesso em 26 de abril de 2016.

ROTHAERMEL, F. T. Incumbent's advantage through exploiting complementary assets via interfirm cooperation. **Strategic Management Journal**, v. 22, n. 6–7, p. 687–699. doi: 10.1002/smj.180, 2001.

SCHREUDER, H. DSM Transformation: The Learning Cycle of Innovation. Vlerick Business School. (2012). Disponível em <http://www.ceeman.org/docs/default-source/exed-presentations/hein-schreuder---the-learning-cycle-of-innovation.pdf?sfvrsn=0>. Acesso em 18 de abril de 2016.

SCOTT, A. BASF and Avantium join for biopolyester. **Chemical & Engineering News**. (2016). Disponível em <http://cen.acs.org/articles/94/i12/BASF-Avantium-combine-bio-polyester.html>. Acesso em 2 de maio de 2016.

SHERMAN, L. M. Engineering Thermoplastics Are Going “Green” : Plastics Technology. **Plastics Technology**. (2015). Disponível em <http://www.ptonline.com/articles/engineering-thermoplastics-are-going-green>. Acesso em 2 de junho de 2016.

SIJBESMA, F. Embracing the Future. (2008). Disponível em < https://www.dsm.com/content/dam/dsm/cworld/en_US/documents/fsi-vaalsbroek-250908.pdf>. Acesso em 2 de junho de 2016.

SIMS, R.; TAYLOR, M.; SADDLER, J.; MABEE, W. **From 1st to 2nd-Generation Biofuel Technologies - An Overview of Current Industry and RD&D Activities**. p.124. Paris, France: IEA Bioenergy, 2008.

SOLAZYME. Solazyme, Inc. Selected for National Institute of Standards and Technology $2 million Award. **Solazyme**. (2007). Disponível em <http://investors.solazyme.com/releasedetail.cfm?ReleaseID=588785>. Acesso em 27 de outubro de 2015.

SOLAZYME. Form 10-K (Annual Report). 2015. Disponível em <http://investors.solazyme.com/sec.cfm?view=all>. Acesso em 26 de outubro de 2015.

SOSNA, M.; TREVINYO-RODRÍGUEZ, R. N.; VELAMURI, S. R. Business Model Innovation through Trial-and-Error Learning: The Naturhouse Case. **Long Range Planning**, Business Models., v. 43, n. 2–3, p. 383–407. doi: 10.1016/j.lrp.2010.02.003, 2010.

SPITZ, P. H. **Petrochemicals: The Rise Of An Industry**. New York: John Wiley & Sons, 1988.

TATE & LYLE. Tate & Lyle and Dupont - Annouces joint development agreement. **Tate & Lyle**. (2000). Disponível em <http://mediacentre.tateandlyle.com/r/204/tate___lyle_and_dupont_-_annouces_joint_developme>. Acesso em 2 de maio de 2016.

TEECE, D. J. Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. **Research Policy**, v. 15, n. 6, p. 285–305. doi: 10.1016/0048-7333(86)90027-2, 1986.

TEECE, D. J. Explicating dynamic capabilities: the nature and microfoundations of (sustainable) enterprise performance. **Strategic Management Journal**, v. 28, n. 13, p. 1319–1350, 2007.

TEECE, D. J. Business Models, Business Strategy and Innovation. **Long Range Planning**, Business Models., v. 43, n. 2–3, p. 172–194. doi: 10.1016/j.lrp.2009.07.003, 2010.

TEIXEIRA, L.V.; ALVES, F.C.; BOMTEMPO, J. V.; OROSKI, F.A.. **Exploring business model dynamics in emerging industries: the case of the biobased industry.** Working Paper, 2016.

THE DAILY TIMES. DuPont closing Vonore biorefinery. **The Daily Times**. (2015). Disponível em < http://www.thedailytimes.com/business/dupont-closing-vonore-biorefinery/article_ad36d945-8227-57c9-8a0b-a6cf1fc5afab.html>. Acesso em 2 de maio de 2016.

TULLO, A. H. Global Top 50 Chemical Companies. **Chemical & Engineering News**. (2015). Disponível em <http://cen.acs.org/articles/93/i30/Global-Top-50.html>. Acesso em 10 de maio de 2016.

VAN LANCKER, J.; WAUTERS, E.; VAN HUYLENBROECK, G. Managing innovation in the bioeconomy: An open innovation perspective. **Biomass and Bioenergy**, v. 90, p. 60–69. doi: 10.1016/j.biombioe.2016.03.017, 2016.

VERDEZYNE. Verdezyne’s Xylose Isomerase Technology Acquired by DuPont Industrial Biosciences. **Verdezyne**. (2012). Disponível em <http://verdezyne.com/2012/12/12/verdezynes-xylose-isomerase-technology-acquired-by-dupont-industrial-biosciences/>. Acesso em 8 de julho de 2016.

VOESTE, D. Sustainability takes center stage in BASF’s organizational culture. . (2011). Disponível em <http://www.petrotechsociety.org/Presentations/Sustainability%2014%20Reading%20Material/5.%20Sustainability%20takes%20center%20stage%20in%20BASF.pdf, 2011>. Acesso em 8 de julho de 2016.

WARD, L. POET-DSM Project LIBERTY. DOE Biomass Platform Peer Review (BPR), 2015. Disponível em <http://energy.gov/sites/prod/files/2015/04/f22/demonstration_market_transformation_ward_3433.pdf>. Acesso em 26 de abril de 2016.

WEASTRA. **WP 8.1. Determination of market potential for selected platform chemicals**, 2012.

WHITE HOUSE. National Bioeconomy Blueprint. 2012. Disponível em <https://www.whitehouse.gov/sites/default/files/microsites/ostp/national_bioeconomy_blueprint_april_2012.pdf>. Acesso em 23 de maio de 2016.

XCONOMY. Solazyme, Founded on “Delusional” Idea of Algae Biofuel, Stakes Claim as Industry’s First Mover | Xconomy. **Xconomy**. (2010). Disponível em <http://www.xconomy.com/san-francisco/2010/07/27/solazyme-founded-on-delusional-idea-of-algae-biofuel-stakes-claim-as-industrys-first-mover/3/>. Acesso em 27 de outubro de 2015.

XCONOMY. The Road Not Taken and Genomatica’s Renewable Chemicals Strategy. **Xconomy**. (2012). Disponível em <http://www.xconomy.com/san-diego/2012/11/21/the-road-not-taken-and-genomaticas-renewable-chemicals-strategy/>. Acesso em 14 de outubro de 2015.

XCONOMY. Solazyme Bets on Cosmetics Now, But Still Sees Biofuel Future. **Xconomy**. (2013). Disponível em <http://www.xconomy.com/san-francisco/2013/08/15/solazyme-bets-on-cosmetics-now-but-still-sees-biofuel-future/>. Acesso em 14 de outubro de 2015.

YIN, R. K. **Case Study Research: Design and Methods**. 4º ed. London: SAGE, 2009.

ZOTT, C.; AMIT, R.; MASSA, L. The Business Model: Recent Developments and Future Research. **Journal of Management**, v. 37, n. 4, p. 1019–1042. doi: 10.1177/0149206311406265, 2011.