INNOVATION ECOSYSTEMS OF SECOND-GENERATION ETHANOL (SELECTED AB3E PAPER)

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Overview

Concerns regarding the environmental consequences of greenhouse gas (GHG) emissions have led several countries to redefine their economies to achieve more sustainable goals. In order to meet transportation energy demands, biofuels emerge as one of the main solutions. Ethanol has been the most widely used biofuel in the world (BP, 2017), but its sustainable expansion in decarbonization scenarios requires its production through advanced technologies (IEA, 2017), as the second-generation (2GE), obtained from non-food raw materials such as sugarcane bagasse and straw.

2GE industry is characterized as innovative with important structuring challenges. The concept of Innovation Ecosystems (IE) can contribute to the understanding of this process. An IE is a set of collaborative and competitive arrangements through which companies from different knowledge domains combine their individual offerings into a coherent customer-focused solution (Moore, 1993).

Considering the increasingly urgent sustainability goals, it is important to question the structuring processes of these new industries. What are their main challenges? How are they being faced? Therefore, the objective of this research is to understand how the 2G ethanol industry structuring process has been developing to identify its main challenges and forms of competition and cooperation. These results are intended to assist decision makers and entrepreneurs in the development of a low carbon economy.

Innovation Ecosystems

Moore (1993) was the first to present the concept of business ecosystem where it was highlighted that a company must be viewed not as a member of a single industry but as part of a business ecosystem that crosses a variety of industries. In this ecosystem, a group of actors works cooperatively and competitively to support new products, satisfy customer needs and, eventually, incorporate a new round of innovations. This process occurs mainly through co-evolution: a complex interaction between competitive and cooperative business strategies (Teece, 2007, Moore, 2006).

Iansiti & Levien (2004) showed that in an ecosystem, agents can adopt three strategic roles: keystone, dominator and niche. The keystone is that player that will improve the ecosystem performance by providing common assets for the ecosystem (Gawer & Cusumano, 2014). Its success guarantees its own survival and prosperity of the ecosystem as a hole. The domination strategy aims to integrate, vertically or horizontally, a large part of the ecosystem networks; in doing so the dominator holds a greater portion of the created value, but also its risks and challenges. The niche strategy is followed by most companies, especially if the ecosystem has a relevant keystone. Niche participants aim to develop skills that differentiate them from other companies. These players are often overshadowed by the keystone, however, they are responsible for much of the ecosystem's value creation.

The structure of an ecosystem can be analyzed in two ways: first, considering the focal ecosystem (Adner & Kapoor, 2010), which is the ecosystem around a focal company, usually a keystone; or second, considering the general ecosystem, which means the set of all companies involved in the innovation (set of different focal ecosystems) (Overholm, 2014; Weil et al., 2014).

Adner & Kapoor (2010) structure the focal ecosystem into three main parts: the focal company, the components (mainly suppliers) and the complementors (companies that develop innovations complementary to those of the focal company). The authors associated the location of cooperative and competitive challenges within this structure with the increase of competitive advantage in the ecosystem.

Adner (2012) introduced a mapping tool called value blueprint (VB). The idea of the value blueprint is to make explicit the ecosystem dependencies. The value blueprint has a strong relationship with the business models value proposition (Chesbrough, 2003; Teece, 2010), but also identifies and measures the ecosystem dependencies. From the VB, 3 types of ecosystem configuration can be identified: Minimum Viable Ecosystem (MVE): smaller configuration of elements that still manage to create a unique commercial value; Sequential Expansion: configuration that allows elements to be added to the EMV so that each new contribution increases the proposed value and facilitates the entry of a new element; and, Carryover ecosystem: ecosystem configured to leverage the current elements in order to promote the construction of a new ecosystem.

Methods

To achieve the proposed objectives, a case study methodology was conducted. Primary sources of consultation were 570 articles from 56 biofuel related sites. The six companies in the sector that had commercial plant were analyzed. Then two rounds of semi-structured interviews were conducted with industry experts, one to triangulate the information obtained from other sources (set of materials, events and articles) and another to validate the built ecosystems with experts. A total of 10 interviews were conducted from May 2017 to December 2018.

To identify the key dimensions of the EI approach, a literature review was carried out, resulting in the reading and analysis of the 10 most cited articles, the six most influential articles in the Innovation Ecosystem construct (identified by Gomes *et al*. 2016) and the three most cited review articles. The two most cited books on the EI approach were also consulted - Adner (2012) and Iansiti & Levien (2004). A summary of the methodological process is described in Figure 1.

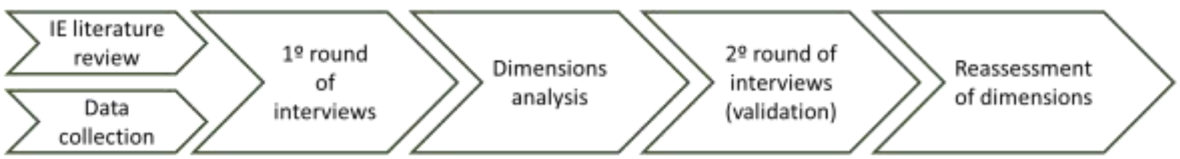

Figure 1: Schematic illustration of the methodological process

Results

Second Generation Ethanol Focal Ecosystems

The innovative content of the 2GE production process can be divided into 4 main parts: collection and processing of cellulosic raw material, pre-treatment, hydrolysis and fermentation. In the last decade, several companies have sought to develop the second-generation ethanol production process by a biotechnological route, however only six projects have reached commercial scale. Of these six projects, 3 were sold/deactivated between 2016 and 2017. The characteristics of the six projects are described in Table 1.

Table 1: 2G Etanol Commercial Projects

Granbio	**Raízen**	**Poet-DSM**	**Beta Renewables**	**Abengoa**	**Dupont**
S. João dos Milagres, Brazil	Piracicaba, Brazil	Emmetsburg, USA	Crescentino, Italy	Hugoton, USA	Nevada, USA
Capacity (millions of liters/ano)					
82	40	94	75	95	113
CAPEX (millions of dolars)					
265	100	275	210	500	225
Raw Material					
Sugarcane straw	Sugarcane bagasse	Corn straw	Wheat straw	Corn straw	Corn straw
Conversion Technologies					
Pre-Treatment					
Steam explosion	Diluted acid	Diluted acid	Steam explosion	Diluted acid	Alkali
Hydrolysis					
Enzymatic (SSFC)	Enzymatic (SSFC)	Enzymatic (SSF)	Enzymatic (SSFC)	Enzymatic (SSF)	Enzymatic (SSF)
Yeast					
DSM	Iogen	DSM	Leaf Technologies	Abengoa	Dupont
Status					
Active	Active	Active	Deactivated	Deactivated	Deactivated

Granbio

Granbio structured partnerships to develop the entire production chain. For biomass, Granbio initially used sugarcane straw, which led to the challenge of collecting, bundling and storing this material, as it was usually burned or left in the field (Nyko *et al*., 2010). To overcome this challenge, the company supported mechanized straw harvesting by purchasing specific equipment for producers (Interviews 6 and 8). However, the company's focus was to use energy cane (*cana enegia*) - a higher fiber content variety of sugarcane - as its main raw material (Interview 8, Granbio, 2018). To produce the energy cane, some key partnerships were needed. The identification of each partnership can be seen in Figure 2.

Developing all the key stages of the second-generation process was not Granbio's first choice (Interview 6, 7, 8). The objective was to search for available technology and invest efforts in bringing these different actors together (Interview 8). However, the company faced several technological challenges after the inauguration of its industrial plant, which resulted in the replacement of two of its main partners - Beta Renewables and API. This challenges also profoundily chaged Granbio's value blueprint. Granbio's goal was to become a reference in the combination of modular technologies for biomass processing, but it had to restructure itself by assuming an increasing role as a technology developer (Interview 8).

Raízen

While Granbio was based on a standalone model - characterized by a plant dedicated exclusively to the production of second-generation ethanol - Raízen opted for a integrated plant with a first generation ethanol production. This option has some advantages such as the utilities optimization (e.g. water and steam) from an existing plant. Another advantage is the possibility of combining the cellulose hydrolysate fermentation together with the sucrose in the cane juice and making the pentose fermentation separately (Canilha *et al*., 2012; Interview 9). This difference allowed Raízen to focus on the problems separately. Therefore, in the first year (2016) Raízen focused on solutions for the pre-treatment - which, as in all cases, was a limiting step in the process - and on enzymatic hydrolysis of cellulose. In the second year (2017) Raízen was able to focus on the problem of pentose fermentation (Interview 9).

Raízen's decisions reflected its skills and resources. The bagasse availability and the lack of skills in collecting straw, were the reasons for the exclusive use of bagasse. The absence of genetically modified yeasts technology for pentose fermentation was the reason for the separation step after pre-treatment.

Raízen's choice to make an integrated unit also connect with its strategy and positioning in the current ethanol industry. As it has a large production that includes the entire value chain - plantation, harvesting and processing - Raízen sees cellulosic ethanol as an alternative to not only increase its production without increasing its planted area - which could be done with sugarcane genetic improvement and better cultivation techniques – but also without the need to change its feedstock, optimizing the use of the biomass that companies already own.

Raízen also followed a keystone strategy, but less branched than Granbio since most of the process was controlled by the company. The mastery over much of the biofuel value creation allowed Raízen to make long-term partnerships which, despite the risk of dependence, promoted a higher level of cooperation and commitment with the partner company, ensuring its permanence in the ecosystem and, consequently, part of the burden of the innovation (Adner, 2012).

Raízen's VB is in some ways similar to that of Granbio, mainly in its proposal to build other units that are supposed to be more efficient and with less arduous construction steps (Novacana, 2014).

Poet-DSM

Poet-DSM was already integrated into the ethanol sector, so the part of structuring the ecosystem regarding production, harvesting, and transportation of the raw material was already established with Poet's expertise. The biomass processing part was provided by DSM, which included enzymes for hydrolysis and yeasts for fermentation. Poet-DSM also had a partnership with the company Andritz, responsible for the pre-treatment technology and part of the engineering and with specialized companies for straw logistics (Lux Research, 2016).

The combination of the joint venture between Poet and DSM has considerably reduced the need for other partners for the ecosystem, which explains the domination strategy, where the company controls most of the process, reducing the risk of co-innovation. However, despite the reduced risk, Poet-DSM also experienced obstacles related to partner dependency. Like Granbio and Raízen, the company faced difficulties in reaching the scale projected mainly by the pre-treatment of biomass (Interview 3, Novacana, 2017). Poet even sued Andritz for breach of contract and professional negligence after investing $ 25 million in the company's pre-treatment system (Biofuels Digest, 2017a).

In the same way that Granbio needed to restructure in the face of partner poor performance, Poet-DSM also had to adapt to the new situation. The alternative was to combine Poet's internal knowledge with South Dakota’s State University. In November 2017, Poet-DSM announced that its new pre-treatment would be working at 80% capacity (Poet-DSM, 2017).

Although Poet is a company of the ethanol sector - and could seek to maintain the competitive advantage of 2GE - Poet-DSM's VB was built with a focus on licensing the integrated technological package (Poet-DSM, 2018).

Beta Renewables

The objective of Beta Renewable was to validate the PROESA ™ technology through licensing the technological package and EPC services (Beta Renewables, 2014, Interview 4). Between 2013 and 2014 four projects were planned using Beta Renewables technology, however only one was completed for Granbio in Brazil.

Beta Renewables was structured in a similar way to Granbio. As a start-up, it sought partners who completed the skills needed for innovation. The Crescentino project was also experiencing the same difficulties as the previously mentioned companies. However, the heart of the problem was related to the economic crisis faced by the Mossi Ghisolfi group (Biofuels Digest, 2017b).

Abengoa Bioenergy

The structuring of the Abengoa ecosystem was highly vertical since the company already operated in the ethanol sector and developed the technology for most of the process. The plant operated for approximately one year, but its activities were halted in December 2015 (Biofuels Digest, 2015; Research Lux, 2016). A sequence of indebtedness caused a crisis in the company, which in 2015 owed more than 8.9 billion euros (Novacana, 2016). An asset sale plan was initiated and, in July 2016, the cellulosic ethanol production unit in Hugoton was sold (Novacana, 2016).

Dupont

Dupont is a multinational company with operations in multiple segments. Due to its diversified expertise, most of the process technology was developed by the company itself. As in all commercial plants, Dupont was also experiencing difficulties in achieving the desired production (Novacana, 2017; Interview 5). In addition to the process difficulties, Dupont had problems with fires in the straw warehouses, also suffered by Granbio. The companies came in contact to investigate the causes and possible solutions to mitigate this risk (Interviews 6 and 8). But before reaching the desired production, Dupont announced the plant sale as a result of the merger process with the chemical company Dow Chemicals. DowDupont announced that its participation in the second-generation ethanol industry would be redirected towards the supply of key elements for the process, such as enzymes and yeasts (Interview 5). After the merger process, there is a reconfiguration of Dupont's VB, focusing on a niche strategy.

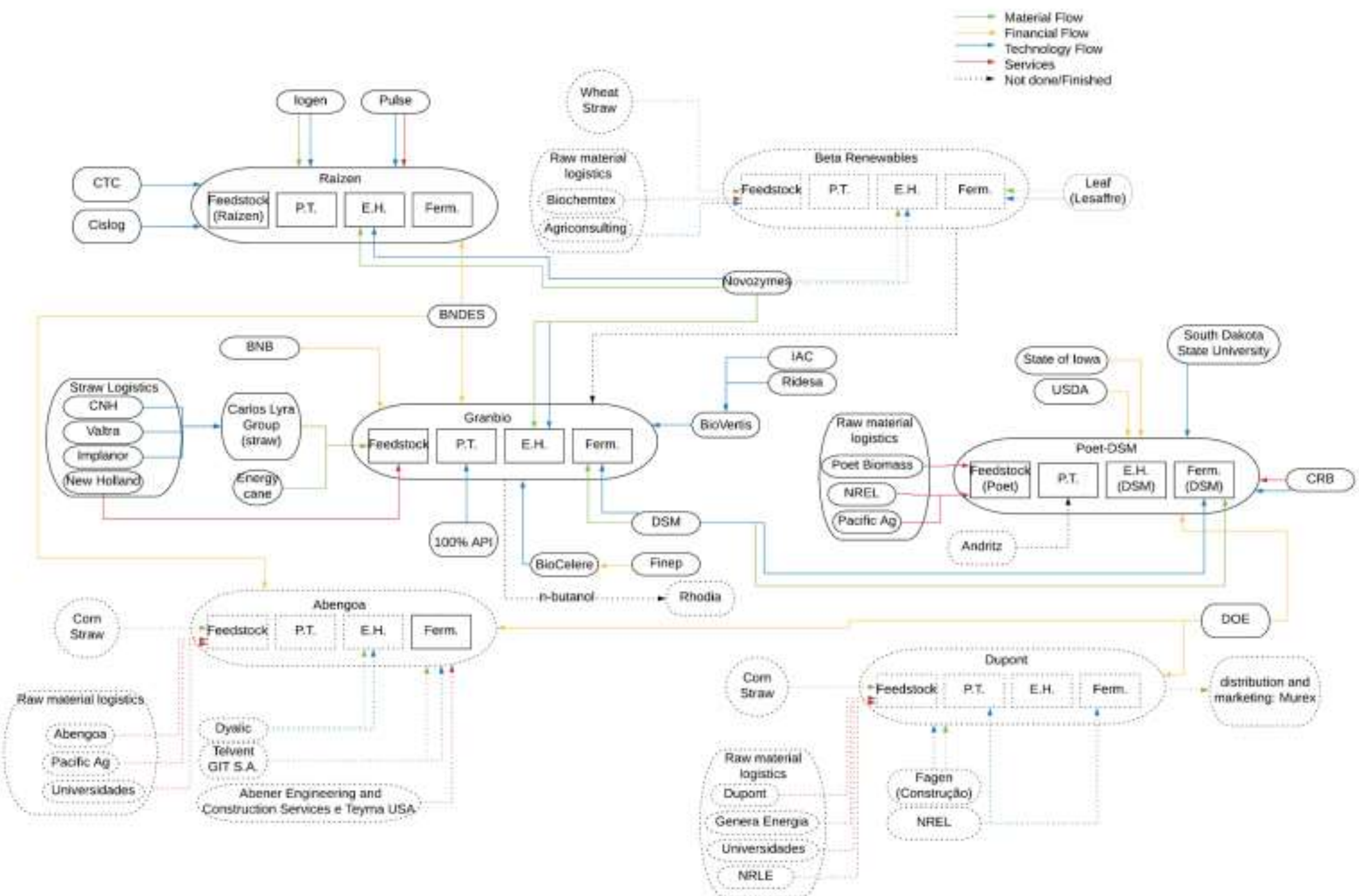

Figura 2: 2GE focal ecosystems Structure

History of the 2GE Innovation Ecosystem

The graph in Figure 3 shows the history of the 2GE innovation ecosystem based on the data survey and is a way to understand the structuring process of the 2GE ecosystem. The figure shows that initially, from 2012 to 2014, most of the material discussed the business opportunity and the initial structuring movements, such as the search for partners to co-innovate. From 2014 to mid-2015, the challenge curve begins to rise, reflecting the first difficulties of the recently inaugurated plants. Between 2015 and 2017 the curve of closed projects appears, representing the abandonment of 3 out of the 6 main players. In 2016, there is a peak in the “evolution and co-evolution” curve translated from the challenge curve. This profile reflects the actions of companies in seeking to face their challenges through processes of restructuring their ecosystems, mainly through the replacement and addition of new actors and knowledge.

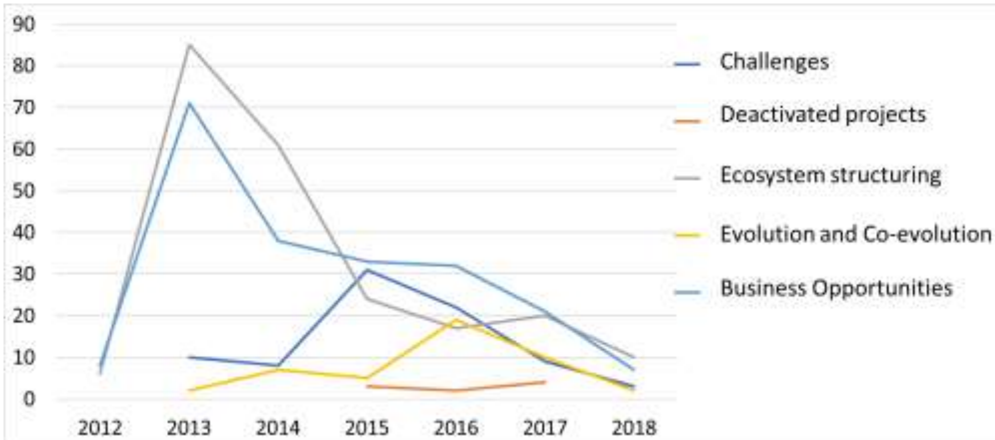

Figure 3: History of the 2GE innovation ecosystem

Currently, the industry sees itself in a “turning point” to validate the technology. The actions to restructure their ecosystems and redesign their VBs have already been carried out by the surviving players and there are some indications of the structuring process evolution in terms of technology, such as the acquisition of API patents by Granbio, the restructuring of Poet-DSM technology with the announcement of the enzyme production unit and the entry of Clariant, a new player, also as an enzyme producing unit. There is still no announcement of a second plant, a fact that would define the advancement of the evolutionary stage of the ecosystem.

Challenges and Evolutionary Stage of Innovation Ecosystems

Other dimensions that help to clarify the 2GE structuring process are: definition of the evolutionary stage and identification of challenges. Moore (1993) defines 4 evolutionary stages: birth, expansion, leadership and renewal / death. This work identified that the new 2GE sector is at the birth stage. This finding is not as trivial as it might seem at first. Despite the use of a new technology and raw material, a good part of the ecosystem already exists due to the production of first-generation ethanol - logistics for the acquisition of raw material (for integrated plants), distribution and sales channels for ethanol, process stages subsequent to fermentation, norms and quality standards, among others.

Another point that brings complexity to the analysis is the period when there were 6 commercial plants opened by different companies, of which 2 had already announced plans for expansion through the construction of new plants. These two reasons could raise the hypothesis that the 2GE ecosystem would be in the expansion stage. This hypothesis, however, is confronted by the competitive and cooperative challenges faced by the sector, which are in line with what was described by Moore (1993) about the birth stage. The results on the main competitive and cooperative challenges faced by the sector are described in Tables 2 and 3.

Analyzing the challenges, it is possible to observe the typical characteristics of ecosystems in the birth stage. From a competitive point of view, there is the protection and search for improvement of process critical stages and the race for the loyalty of key suppliers and customers. On the cooperative side, there is a search for key partners to access all the skills required by second generation technology. However, a point that disagrees with what was presented by Moore (1993) was the presence of several cooperation actions between focal ecosystems, that is, competing companies. Some examples of these actions were: workshops to find a solution to the problems of pre-treatment, meetings to investigate the causes and solutions to the fires in the raw material warehouses, cooperation for the sale and distribution of biofuel, and, in the Brazilian case, Granbio, Raízen and CTC sought political action to remove obstacles to the technology development regarding genetically modified micro-organisms. (Interviews 1, 3,4,6 and 8).

Regarding the types of challenges faced by the general ecosystem, it was observed that the main obstacles were related to the components, that is, the key stages of the process (obtaining the raw material, pre-treatment, hydrolysis and fermentation) which causes production restriction. The challenges with complementors were low, causing little risk to consumption. According to the framework of Adner and Kapoor (2010), overcoming this type of challenge is favorable to the creation of competitive advantage for the survivors, creating a distance between the new entrants greater than if there were no challenges. This is mainly due to the level of new and tacit knowledge that is generated in the exercise of overcoming such barriers.

Table 2: Competitive challenges of 2GE ecosystems.

Competitive challenge	Firm
Protect ideas and technologies, especially in the most critical steps of the 2G process, such as pre-treatment, yeast and enzymes.	All
Compete for exclusive suppliers (mainly enzymes and yeasts)	All. Dupont to a lesser extent.
Competition between production models - independent plants or integrated production.	Granbio, Beta Renewables and Dupont x Raízen, Poet-DSM and Abengoa
Competition between processing models	Raízen x Granbio and Poet-DSM
Oil price competition	All

Table 3: Cooperative challenges of 2GE ecosystems.

Cooperative challenge	Firm
Attract people, companies and institutions to integrate the steps of the 2G process.	All. Dupont to a lesser extent.
Feedstock challenges: Create networks with local producers to advance the techniques for collecting sugarcane and corn straw.	All expect Raízen
Pre-treatment and engineering challenges	All
Enzymatic hydrolysis challenges	Granbio, Raízen and Poet-DSM
Fermentation challenges	Mainly Raízen
Find new partnerships to replace those that did not deliver the necessary value for the ecosystem.	Mainly Poet-DSM and Granbio
Tropicalization of technologies	Granbio and Raízen
Creation of networks with new consumers that reward 2GE	Granbio, Raízen and Poet-DSM
Contest bureaucratic challenges of handling genetically modified microorganisms (especially in the Brazilian case)	Granbio and Raízen
Combat raw material storage challenges (fires)	Granbio and Dupont

Structures and Strategies

The case studies have shown that the structure of ecosystems is influenced by the type / size of the focal companies. When companies are established and have a reasonable part of the technological process, the need for partnerships is less than the case of start-ups. Another factor that influences the structuring of the ecosystem is the origin of the company, whether it is in the energy or chemical industry. Depending on this origin, the role of the 2G technology is different. For some, the goal is to increase the production of biofuels while taking advantage of their own waste, for others the goal is to develop the process responsible for releasing sugars that can be fermented. Figures 4a and 4b illustrate how these factors influenced structures and strategies.

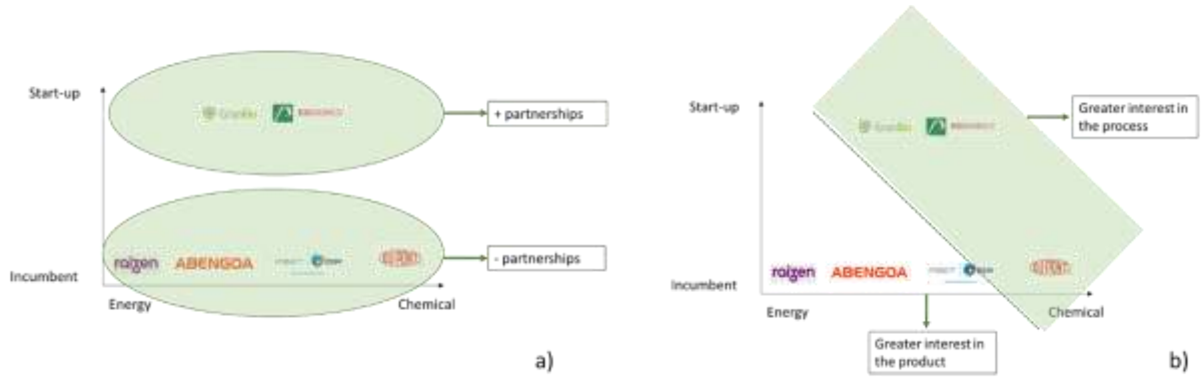

Figura 4: Factors that influenced IE strategies and structures. a) number of partnerships e b) strategy for the 2GE.

Figure 4b shows that Poet-DSM is between the two regions because the joint venture was created to meet the specific demands of both companies. While Poet wants to increase its production, DSM wants to validate and sell its enzymes and yeasts.

The IE strategies showed the positions of the focal companies towards their partners. Granbio and Beta Renewables were keystones of their focal ecosystems, with a more branched structure and, consequently, with greater risks of co-innovation. Raízen and Abengoa also followed the keystone strategy, however, with less dependence on partners because of their skills in the energy sector. The Poet-DSM joint venture was able to solve most of the demands of its process by the competencies of the partner companies, which allowed its process to be more vertical and less dependent on other actors. This dominant characteristic of Poet-DSM did not completely shield it from the risks of co-innovation (lawsuit against partner Andritz). Dupont was the most dominant because it contained the fewest partners involved in the key stages of the process. Figure 5 shows the strategies of the main 2GE players in the graph proposed by Iansiti & Levien (2004).

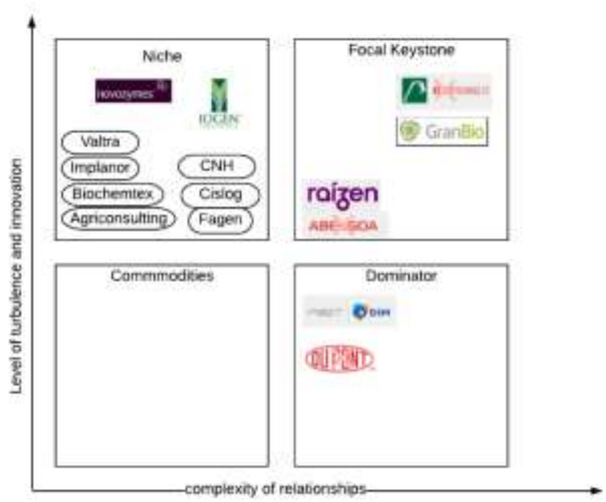

Figure 5: Strategies followed by focus companies.

Value Blueprint

The ability to restructure and adapt to problems has been a key competence for companies in the 2G ethanol ecosystem. If the company has few partners, it needs to have a good R&D to face the challenges of process innovation. If there are too many, it needs to protect itself against the risks of co-innovation. Identifying these risks is part of a good innovation management.

The need for restructuring influenced the VB for several projects. The innovation potential generated a fierce dispute between several different players at the beginning of the process. The high expectations associated with this potential were clearly reflected in the players' VBs mainly through business plans announcements that involved projects of new plants in short periods of time and through the strategies of technological licensing. In summary, these VBs reflected the ambition of various players to pursue an ecosystem carryover. However, when faced with the various challenges presented, companies found themselves reducing their ecosystems to stages of minimum viable ecosystems (Adner, 2012). For Granbio and Dupont, there were important changes in VBs. Granbio changed the focus of the company that previously sought to be a technology integrator and became a knowledge company as a consequence of the patents acquired with Beta Renewables and API. After merging with Dow, Dupont changed its position within the general ecosystem from being a producer / licensor to being a supplier of specific inputs.

Conclusions

This research showed that the structuring of the 2GE ecosystem has been taking place with a heterogeneity of players and strategies. This reflects the potential of the innovation to transform not only the biofuels industry, but potentially that of renewable chemicals. In addition to the objective of increasing productivity, companies such as Granbio, Beta Renewables and Dupont demonstrated the possibility of fermenting second generation sugars in other products. However, technological and non-technological challenges have proved to be quite relevant.

The challenges faced by the players were not only restricted to the new process stages, but also to the need to integrate a new value chain. Challenges like access to raw materials, storage, access and use of genetically modified micro-organisms and access of products to specific markets were solved through cooperation between rival companies - a factor that is not considered common in the birth stage. Due to its intersectoral characteristic, this specific characteristic for the 2GE ecosystem can be extrapolated to other ecosystems that target the transition from the use of fossil raw materials to renewables. Unplanned difficulties can be expected in relation to the production, access and handling of new raw materials. It is worth emphasizing that ethanol is a widely used biofuel, which reduces several barriers to production and commercialization, and yet 2GE reached the commercial stage of production with difficulties that led players to completely restructure their businesses and resort to initial levels of research.

One of the main effects of 2GE's challenges was the need for companies that aimed to be technology implementers to become technology developers. The cases of Granbio and Poet-DSM demonstrated this characteristic when they started to develop their own technology after the failures with their initial partners. This is a second message that could be extrapolated to other ecosystems of the so-called Bioeconomy: the risks of co-innovation must be the core of strategies to promote the change of raw material. Obviously, companies that have the complete technological content of the innovation can overcome such risks, however, the experience with ET2G showed that even companies such as Dupont and DSM found themselves dependent on some new knowledge that needed to be accessed through partnership.

This research was limited to a set of pre-selected dimensions and only discussed the 2G ethanol, however, the results presented here serve as a first reference for researchers and entrepreneurs in the search for mitigating innovation risks in ecossystems based on renewable resources.

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