IOSR Journal of Business and Management (IOSR-JBM)
e-ISSN:2278-487X, p-ISSN: 2319-7668. Volume 25, Issue 6. Ser. 5 (June. 2023), PP 61-66
www.iosrjournals.org

The Worldwide Patent Landscape Of Biorefinery-Related Technologies Between 2000 And 2022

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Abstract:

Background*: This study aims to analyze ongoing research efforts focused on developing novel technologies for application in biorefinery platforms. The transition from petroleum-based energy sources to a bioeconomy is crucial for reducing greenhouse gas emissions and mitigating the adverse impacts of climate change, as outlined in the Paris Agreement. By examining the current state of research in this field, this study seeks to identify emerging technologies that can contribute to achieving these environmental objectives.*

Materials and Methods*:We utilized the Derwent Innovations Index platform, which is a comprehensive platform that provides access to a wide range of global patent documents and related information. We search for patent applications classified under the International Patent Classification (IPC) code C12P-007/00. This technological class is associated with the preparation of oxygen-containing organic compounds through microbial or enzymatic processes. We limited our search to patent applications filed between 2000 and 2022.*

Results*: The study identified a total of 1,036 patent families. Among these intellectual property documents, a significant number were attributed to enzymatic solutions for second-generation ethanol production. Our results revealed that Dupont holds the most relevant patents in this area. The American multinational company has a significant number of patent applications between the years 2000 and 2013; however, there was a subsequent decline in its patent fillings. In contrast to Dupont's declining trend, the study observed an expansion in research and development efforts undertaken by European companies in recent years.*

Conclusion:*The article suggests that the incentives undertaken by the European Union to foster the development of innovative bioproducts, and renewable energy sources are generating the intended outcomes. The increased activity and investment by European organizations in various technological fields related to biorefinery indicate a positive response to these incentives.*

Key Word*:Bioeconomy; Climate Change, Second-generation Ethanol*

Date of Submission: 08-06-2023 Date of Acceptance: 18-06-2023

I. Introduction

The reduction of carbon dioxide and other greenhouse gases is a key priority within the framework of the Paris Agreement, established in 2015 with the explicit objective of limiting global warming. Consequently, the pursuit of effective solutions to address the challenges associated with climate change, the development of new renewable energy sources, and the enhancement of global health conditions have garnered increased attention in global community. Despite the complexity of these challenges and the uncertainties surrounding their mitigation strategies, there is a prevailing consensus that transitioning from a fossil fuel-based energy matrix to the utilization of bioeconomy is a precondition for addressing the main environmental issues and successfully achieving the goals outlined in the Paris Agreement (1,2,3).

The bioeconomy encompasses severalindustrial sectors where biological resources are converted into value-added products such as biofuels, biochemicals, and biomaterials. By integrating different conversion technologies to efficiently utilize biomass and minimize waste, biorefinery platforms play a crucial role in the transition from petroleum-based energy sources to bioeconomy. Hence, biorefineries serve as integrated industrial platforms that enable the integration of biofuel refining activities with several other key functions: i) the production of novel products and inputs derived from biological resources; ii) co-generation of energy through the utilization of biomass; iii) the treatment of industrial and forest waste, as well as the management of water resources used in manufacturing processes; iv) the trading of carbon emission (4,5,6).

The economic and environmental potential of these activities has drawn the attention of policymakers worldwide. For instance, the Horizon Europe project of the European Union has allocated €10 billion in funding

for the energy, natural resources, and bioeconomy sectors during the 2020s (7). Despite the significant enthusiasm surrounding the bioeconomy, there is a research gap in this field, as no previous study has examined the state of research and development efforts specifically linked to biorefinery platforms. This study aims to address this gap by utilizing the Derwent Innovations platform to conduct a search of global patent applications for biofuels and other cellulose-derived bioproducts/raw materials. Consequently, the primary objective of the authors is to contribute to the understanding of the patent landscape within the bioeconomy-related sectors between the years 2000 and 2022.

This article is structured as follows: Section 2 provides a comprehensive explanation of the methodological procedures utilized to construct the patent database and gather the information employed in this study. In Section 3, an analysis is conducted on the technologies claimed by these patents and the primary patent holders involved in their development. Lastly, Section 5 presents the conclusions derived from the findings of this study.

II. Methods

The patent searches conducted for this study spanned the period from 2000 to 2022 and focused on US patents claiming technologies specifically related to biorefineries. The Capes Portal (https://www-periodicos-capes-gov-br.ezl.periodicos.capes.gov.br/index.php?) was utilized to access the Derwent Innovations Index database, which enabled a comprehensive search for patents that: i) display the 'US' prefix in their numbering, indicating that the document has been granted or validated by the United States Patent and Trademark Office (USPTO); ii) were classified under the technological class C12P-007/00 ("preparation of oxygen-containing organic compounds") by the World Intellectual Property Organization (WIPO). Table 1 describes all the technologies encompassed within the C12P-007/00 class.

Table no 1: Technological subclasses within the C12P-007/00 class ("preparation of oxygen-containing organic compounds"), considering three levels of stratification.

First Level	Second Level	Third Level
C12P 7/02 containing a hydroxy group		
	C12P 7/04 acyclic	
		C12P 7/06 Ethanol, i.e. non-beverage
		C12P 7/16 Butanols
		C12P 7/18 polyhydric
C12P 7/24 containing a carbonyl group		
	C12P 7/24 Ketones	
		C12P 7/28 Acetone-containing products
		C12P 7/46 Cyclopentanone- or cyclopentadione- containing products
C12P 7/40 containing a carboxyl group		
	C12P 7/42 Hydroxy carboxylic acids	
	C12P 7/44 Polycarboxylic acids	
		C12P 7/48 Dicarboxylic acids having four or less carbon atoms, e.g. fumaric acid, maleic acid
		C12P 7/50 having keto groups, e.g. 2-ketoglutaric acid
	C12P 7/52 Propionic acid; Butyric acids [2006.01]	
	C12P 7/54 Acetic acid	
	C12P 7/56 Lactic acid	
	C12P 7/58 Aldonic, ketoaldonic or saccharic acids	
		2-Ketogulonic acid
C12P 7/60 Carboxylic acid esters		
	C12P 7/62 Polyesters of hydroxy carboxylic acids	
C12P 7/64 Fats; Fatty oils; Ester-type waxes; Higher fatty acids, i.e. having at least seven carbon atoms in an unbroken chain bound to a carboxyl group; Oxidised oils or		

fats		
	C12P 7/6409 Fatty acids	
		C12P 7/6418 by hydrolysis of fatty acid esters
		C12P 7/6427 Polyunsaturated fatty acids [PUFA], i.e. having two or more double bonds in their backbone
	C12P 7/6436 Fatty acid esters	
		C12P 7/6445 Glyceride
		C12P 7/649 Biodiesel, i.e. fatty acid alkyl esters

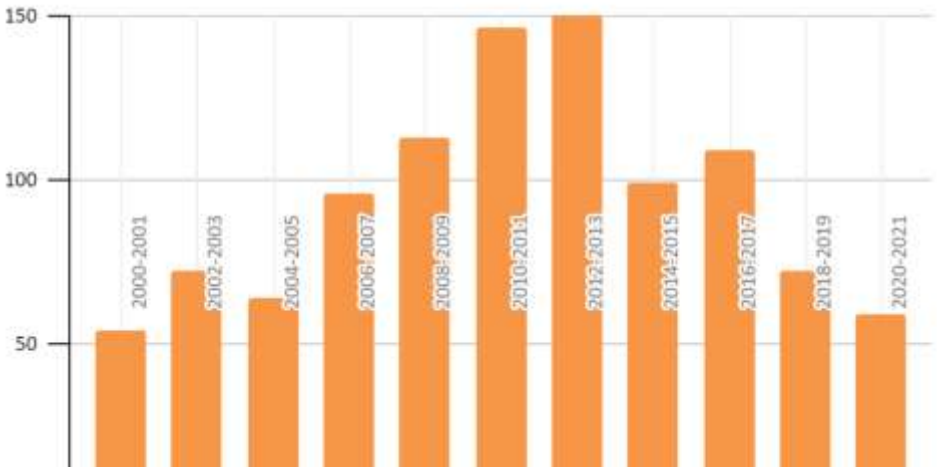
Source: World Intellectual Property. Available in: https://www.wipo.int/classifications/ipc/en/

The patents identified in this study were categorized into technological subclasses using the available features within the Derwent platform. Furthermore, the additional data mining resources provided by Derwent played a crucial role in collecting information regarding the temporal evolution of patent filings and the distribution of patent holders.

III. Results

Our investigation identified a total of 1,036 patent families. Figure 1 illustrates that the biennial distribution of patent filings in the field of biorefineries exhibits an "inverted U" shape. Initially, a growth phase is observed, characterized by a notable increase in patent filings, reaching its peak during the 2012-2013 biennium. Subsequently, a decline in the number of patent families becomes evident, ultimately regressing to levels observed in the early 2000s. Thus, Figure 1 describes the existence of two distinct phases that have marked the development of technologies applicable to biorefinery platforms, demonstrating alternating periods of growth and decline in patent filings.

Figure no 1: Patent applications per biennium encompassing biorefinery-related technologies (database of 1,036 Patent Families)



Source: Derwent Innovations Index

Table 2 illustrates the leading patent holders, with DuPont securing the top position. The table underscores the broad range of companies actively involved in the development of biorefinery technologies, encompassing the following categories: i) multinational corporations that hold strong market share in the global chemical products market (e.g., DuPont, BASF, Shell); ii) American universities; iii) a state-owned company, namely the French Petroleum Institute; and iv) technology-driven firms, headed by the Danish firm Novozymes.

Table no 2: Top 15 Patent Holders in Biorefinery Technologies

Patent Holders	General Ranking	Patents
DUPONT	1	44
NOVOZYMES AS	2	32
BASF	3	29
UNIV CALIFORNIA	4	23
XYLECO INC	5	20

LANZATECH NEW ZEALAND LDT	6	18
DSM IP ASSETS BV	7	17
COSKATA INC	8	15
EVONIK DEGUSSA GMBH	9	14
UNIV MICHIGAN STATE	10	12
CARGILL LTD	11	11
GENOMATICA INC	12	10
SHELL OIL CO	13	10
CALIFORNIA INST OF TECHNOLOGY	14	9
INST FRANCAIS DU PETROLE	15	9

Source: Derwent Innovations Index

Table 3 offers insights regarding the specific time periods during which the Top 15 patent holders directed their research and development (R&D) efforts. Analyzing the data from this perspective unveils that the period preceding 2013, marked by a noteworthy surge in patent applications (Figure 1), witnessed a robust presence of American companies in the biennial rankings of patent holders. In addition to DuPont, which consistently maintained its position among the Top 10 patent holders for nearly fifteen consecutive years, two other significant contributors within the United States' national innovation system focused their patent filings between 2000 and 2015. These entities include academic institutions, specifically the universities of California and Michigan, and biotech firms specializing in second-generation ethanol technical solutions, with special recognition given to Xyleco.

Table no 3: Organization position in the biennial Top-10 rankings of patents holders.

Patent Holder	2000-2001	2002-2003	2004-2005	2006-2007	2008-2009	2010-2011	2012-2013	2014-2015	2016-2017	2018-2019	2020-2021	Total Patents
DUPONT	4	1	1	1	9	1		4				44
NOVOZYNES AS			4		2	2	2	1				32
BASF	1	2	3	9	1	7			4		10	29
UNIV CALIFORNIA				2		8	6					23
XYLECO INC						3	4					20
LANZATECH NEW ZEALAND LTD				10	10		5			1	1	18
DSM IP ASSETS BV				6	5					3		17
COSKATA INC							1		6			15
EVONIK DEGUSSA GMBH					4				8	5		14
UNIV MICHIGAN STATE	2											12
CARGILL LTD		7						3		4		11
GENOMATICA INC						5						10
SHELL OIL CO							7	2				10
CALIFORNIA INST OF TECHNOLOGY				3								10
INST FRANCAIS DU PETROLE									2	8	4	9
COUNCIL SCI & IND RES INDIA		6	10									8

Source: Derwent Innovations Index

During the 2000s, Dupont's prominent role in biofuel research and ownership of intellectual property exerted a significant influence on the technological profile and temporal distribution of patent applications. This influence is clearly demonstrated in Table 4, which showcases the two primary technological classes, namely C12P-001/00 and C12P 5/00, that registered the highest number of patent filings following C12P 7/00. Moreover, Table 3 provides detailed information on the most relevant subclasses within the C12P 7/00 category, including C12P 7/06, C12P 7/40, C12P 7/64, and C12P 7/62.

Dupont and Novozymes, identified as the top patent holders in Table 2, are also the global leaders within the enzyme market. Analysis of Table 4 reveals a notable surge in patent applications within the domain of class C12P-001/00, focusing on enzymatic solutions for biomass utilization, during the period spanning from 2000 to 2015. Bueno CS et al. (6) highlight the huge technological challenges of deconstructing crystalline polysaccharides, particularly cellulose, in the production of second-generation ethanol derived from biomass. In response to these challenges, class C12P-001/00 contains patents that propose pioneering technologies enabling

the enzymatic conversion of such polysaccharides into mono and disaccharides, thus facilitating their subsequent fermentation.

Table 4 also unveils a diminishing importance of research areas covered by the C12P-001/00 technological class starting from 2015. This decline can primarily be attributed to a decrease in patent applications from Dupont, the global frontrunner in enzyme solutions (see Table 3). Furthermore, this reduction in patent filings was observed among other US institutions, offering insights into the inflection point observed in Figure 1 after 2013.

Table no 4: Biennialpatent filings by technological class

4A: Patent Application Count by Technological Class											
Technological Classes	**2000-2001**	**2002-2003**	**2004-2005**	**2006-2007**	**2008-2009**	**2010-2011**	**2012-2013**	**2014-2015**	**2016-2017**	**2018-2019**	**2020-2022**
C12P 001/00	9	22	15	21	39	37	15	8	7	6	5
C12P 5/00	15	4	3	8	17	24	26	16	11	10	6
C12P 7/00											
7/06	1	5	13	14	27	33	30	13	22	10	6
7/40	11	13	12	18	20	25	20	15	9	9	11
7/64	6	5	13	16	17	18	13	10	7	10	3
7/62	9	14	10	21	13	16	13	5	5	8	3
Table 4B: Patent Filings by Technological Class as a Percentage of Total Patent Applications											
Technological Classes	**2000-2001**	**2002-2003**	**2004-2005**	**2006-2007**	**2008-2009**	**2010-2011**	**2012 2013**	**2014-2015**	**2016-2017**	**2018-2019**	**2020-2021**
C12P 001/00	16,70%	30,60%	23,40%	21,90%	34,50%	25,30%	10,00%	8,10%	6,40%	8,30%	8,50%
C12P5/00	27,80%	5,60%	4,70%	8,30%	15,00%	16,40%	17,30%	16,20%	10,10%	13,90%	10%
C12P 7/00											
7/06	1,90%	6,90%	20,30%	14,60%	23,90%	22,60%	20%	13,10%	20%	13,90%	10%
7/40	20,80%	18,10%	18,80%	18,80%	17,70%	17,10%	13%	15,20%	8,30%	12,50%	18,60%
7/64	11,10%	6,90%	20,30%	16,70%	15,00%	12,30%	8,70%	10%	6,40%	13,90%	5,10%
7/62	16,70%	19,40%	15,60%	21,90%	11,50%	11%	8,70%	5,10%	4,60%	11,10%	5,10%

Source: Derwent Innovations Index

Devaney and Iles (8) postulate the hypothesis that the declining interest of the US business sector in biorefineries can be predominantly attributed to the escalating investments in expanding fossil fuel production and the provision of alternative petrochemical derivatives throughout the 2010s. This transition in emphasis arises from the competitive advantages derived from shale gas exploration in the USA, which prompted the American chemical industry to disclose an investment portfolio of approximately US$ 71.7 billion in 2013 (9). On the other hand, the data presented in Table 3 for the period of 2016-2021 suggests that the decline in patent applications for biorefinery-related technologies by US companies was partially offset by the increased R&D efforts undertaken by certain European companies in these technological field.

The European business plan for the bioeconomy was formally established in 2012 to foster innovation and address the technological, energy, and ecological challenges associated with the sustainable utilization of natural resources. As part of this program, the European Union allocated a substantial amount of €3.85 billion in financial resources to support R&D investments focused on renewable energy sources, as well as other sustainable and circular technological solutions (10). Apparently, these incentives have played a significant role in maintaining the interest of European multinational companies in the development of technologies applicable to biorefinery platforms and attracting new organizations in this technological field. According to Table 3, BASF, Europe's largest chemical company, has consistently remained among the Top 10 patent holders in the biennia of 2016-2017 and 2020-2021. Similarly, the German company Evonik and the Anglo-Dutch Shell have also maintained their positions in the Top 10. Moreover, the French Petroleum Institute entered the ranking of the Top 10 patent holders for the first time in 2016-2017 and continued to hold this position in subsequent biennia.

Furthermore, Tables 4A and 4B reveal that the decrease in patent applications for technologies associated with biodiesel production (C12P7/64) after 2013, a fuel for which Germany holds the title of the world's largest producer, was relatively less significant when compared to the decline in patent filings related to ethanol.

IV. Discussions and Conclusions

This paper discussed the patent landscape within bioeconomy-related sectors. The findings reveal two distinct phases in the development of biorefinery-related technologies. The initial phase, encompassing the period leading up to the biennium of 2012-2013, experienced an increase in the number of patent families. Over a span of 13 years starting from 2000, patent filings in this technological field nearly tripled, culminating in a peak in 2013. Us companies emerged as the top patent holders of this period, particularly DuPont, a leading global player in the enzyme market. Consequently, a significant portion of the patent applications submitted between 2000 and 2013 focused on enzymatic solutions to produce second-generation ethanol. However, after reaching its peak in 2013, a decline in patent filings occurred, returning the numbers to levels comparable to the beginning of the 2000s.

Our analysis yields valuable insights suggesting that the decrease in patent filings related to biorefinery technologies can be partially attributed to the heightened competitiveness of the US petrochemical complex, propelled by the successful exploitation of shale gas resources. Consequently, the intensified investments by the North American business sector in expanding fossil fuel production and supplying other petrochemical derivatives could have hindered new research efforts in the field of biofuels. This trend is exemplified by the decrease in patent filings for enzymatic solutions, which coincides with a simultaneous increase in the number of patent documents focusing on technologies associated with hydrocarbon preparation.

In 2021, the United States rejoined the Paris Agreement. The discussions presented in this article suggest that, given the objective of attaining carbon neutrality by 2050, it is imperative to reinvigorate the interest of the US business sector in biorefineries. This aim will demand the implementation of new industrial policies to complement the existing federal and state subsidies that currently support corn-derived ethanol production.

On the other hand, this study also reveals that while patent filings for technologies applicable to biorefinery platforms by North American companies experienced a decline, this setback was partially counterbalanced by the increased R&D efforts undertaken by European organizations in this technological field. These findings indicate that the incentives undertaken by the European Union to foster the development of innovative bioproducts, and renewable energy sources may indeed be generating the intended outcomes.

In sum, this article filed a research gap by examining the state of R&D efforts linked to biorefinery platforms. The findings shed light on the patent landscape within the bioeconomy-related sectors, highlighting the alternating phases of growth and decline in patent fillings and the diverse range of patent holders actively engaged in this field. The data also indicate the evolving dynamics within the biorefinery field, influenced by factors such as shifting priorities in different countries and the emphasis on sustainable technological solutions. These insights contribute to a better understanding of the bioeconomy and its potential in addressing environmental challenges while fostering economic growth.

V. Acknowledgment:

We express our gratitude to the Pontifical Catholic University of Campinas (PUC-Campinas) for their support of this research. We also extend our thanks to the Brazilian National Council for Scientific and Technological Development (CNPq) for awarding Letícia Andrade Motta de Moraeswith a PIBIC fellowship.

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