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Identifying bioethanol technology generations from the patent data

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ABSTRACT

Reliable search results are necessary in the empirical analyses utilizing patent data. In this study, we evaluate the tagging schemes for patent documents related to low carbon technologies and provide a patent analysis of bioethanol with PCT patent publications between 2010 and 2016. The classification-based queries were optimized to find grain bioethanol (1G), cellulosic bioethanol (2G) and patents belonging to grain and cellulosic bioethanol (1G AND 2G) trajectories. The results reveal that based on original search strategy, only second-generation cellulosic bioethanol patents could be identified with a good match. Through use of co-classification and content analysis of patents we expand understanding of bioethanol inventions and potential future technology generations in the field.

1. Introduction

Countries around the world have sustainable development goals and cleaner transportation is one of them. Biofuels have played and will play an important role in curbing oil consumption and greenhouse gas emissions. Because of effects on food chain and carbon emissions reduction potential it matters if the biofuels are first or second generation. Hence, identifying the biofuel technology generations is of great importance.

Growing awareness of environmental issues together with the need to measure and analyze green inventions have created considerable interest in research for eco-innovations [1,2]. Policy makers are interested in measuring environmental innovations for various reasons [2,3], and patent data have a number of attractive properties when analyzing environmental technologies. Patent data allow very specific 'environmental' technologies to be identified [2]. In the context of environmentally-friendly technologies, the IPC Green Inventory (GI) database [4] was developed by the WIPO IPC committee of experts in order to facilitate searches for 'green' inventions. However, the natural classification of patents by their IPC codes does not translate easily into some industry classification and previous research has shown major difficulties in linking patents to specific economic activities [5,6]. The rigid categorization is one of the main challenges especially when analyzing emerging fields of technologies and cross-cutting technological fields, like biofuels [7]. Complexity of the biofuels sector is a challenge for patent analyses as inventions are usually suitable for a variety of purposes [8]. Problems related to GI database have been recognized and Contantini et al. [7] propose the keyword-based methodology for identifying cross-cutting technologies in their case study of biofuels sector, where evolution of technological generations represents a crucial aspect.

Most recently, the European Patent Office has developed a dedicated classification scheme for environmentally-friendly technologies as part of the Cooperative Patent Classification (CPC) available for public use within EPO's Espacenet and PATSTAT services. The Y section is general tagging of new technological developments and cross-sectional technologies spanning over several sections of the IPC. The Y02 classification for climate change mitigation technologies (CCMT) scheme provides important technical information to support policy making for CCMT innovation, technology transfer and strategic decisions in the climate change field used by many institutions worldwide [9]. According to Rudyk et al. [10], the categories provide the most reliable method available today for identifying CCMT patent filings, and the scheme is becoming the 'de facto' international standard for clean innovation studies. In combination with patent statistics tools, the tagging makes it possible to map sustainable technologies, identify trends and produce facts and evidence for policy and business decisions [10]. As the new classification scheme is still developing and it provides opportunities to distinguish technology generations in the biofuels sector, it is now right time to evaluate and validate the database. We take one specific sector, liquid bioethanol as a case example.

The governments have played an active role in steering the development and market introduction of biofuels. For example in Brazil, there were a series of activities already in the early 70's to encourage ethanol, and in the United States, there are subsidies for the production

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0172-2190/

of ethanol. In Finland, biofuels have been considered as a cost-effective way to achieve climate change targets [11]. Ethanol is currently the most commonly used renewable automobile fuel and has been widely used as a 10% blend to gasoline in the USA or as a neat fuel for vehicles in Brazil in the last two decades. More recently, the use of E85, an 85%/15% ethanol/gasoline blend has been implemented especially for clean city applications.

Currently ethanol and other fermentation products are mainly produced from various foodstuffs such as sugarcane or corn, and such ethanol is called first-generation bioethanol. However, because of economics as well as concerns of human food resource and sustainability issues the first-generation biofuels have been increasingly questioned [12], especially if the biofuel systems are not sustainably managed [13]. The development of economically viable processes for the production of second-generation biofuels is currently a growing topic in the field [14,15]. These fuels are produced mainly from non-food lignocellulosic biomass and give rise to fewer problems regarding the competition with the use of agricultural land for food [16]. In light of growing concerns associated with climate change, there may be a significant role for sustainable biofuel technologies, because they can be generated from locally available sustainable biomass feedstocks.

Our initial search strategy and queries were optimized to find (sugar/starch) grain bioethanol (1G), cellulosic bioethanol (2G) and grain AND cellulosic bioethanol (1G2G) technology generations. The evaluation is based on a classification-based search strategy of patents and content analysis of the patents. Our contributions are two-fold. The research first explores the use of Green Inventory (GI) and CCMT databases and creates a search strategy in order to identify bioethanol technology generations from the patent data. The results show that CCMT classification increases the accuracy in finding relevant cellulosic bioethanol patents. However, the results also reveal that based on the original search strategy we could not identify all bioethanol technology generations correctly. Secondly, we propose IPC co-classification method as a potential tool for increasing the precision of the search results. This paper combines patent bibliometric approaches with content analysis of patent documents to generate meaningful information about current technological trajectories in the bioethanol sector. Section 2 sheds light and background on the bioethanol technology generations. Section 3 introduces the data and empirical analysis based on sampling of bioethanol technology generation patents. This is followed by empirical results of co-classification analysis and content analysis based on the feedstock used. Conclusions are presented in section 5.

2. Bioethanol generations

There is no strict definition of bioethanol generation. The main criteria of identifying the generations are related to feedstock used and the conversion technology. European Commission [17] defines *conventional biofuels* including risk in feedstock regardless of the conversion technology, *advanced biofuels* as low-risk feedstock regardless of the conversion technology, and *non-conventional* biofuels as low-risk feedstock and advanced technology. The definitions highlight the importance of biomass origin and the type of feedstock, which can be classified in three main groups: (1) readily fermentable sugar materials, (2) starchy materials, and (3) lignocellulosic materials.

First-generation bioethanol is generally related to a biomass that is edible. In practice, only a few different feedstocks, mostly grain-based feedstocks (e.g. corn) or from sugar (e.g. sugarcane, sugar beets), have been used for the production of first-generation bioethanol. Other more marginal feedstocks that are used or considered to produce first-generation bioethanol include wheat, barley and potato wastes [18]. Sugarcane is the main feedstock for bioethanol production in Brazil. The process that allows the production of ethanol out of sugarcane is rather simple. The sugarcane is crushed in water to remove sucrose, which is then purified either to produce raw sugar or ethanol. Corn is the major feedstock for the production of ethanol in the United States, although unlike sugarcane, corn requires a preliminary hydrolysis of starch to liberate the sugars that can then be fermented to ethanol. The fermentable sugar material contains simple sugars that can readily be fermented by yeast (e.g. Brazilian ethanol production). In contrast to starchy and lignocellulosic feedstocks, there is no need for prior hydrolysis of polysaccharides such as starch and/or cellulose/hemicellulose (e.g. US ethanol production). Sugarcane ethanol and corn ethanol are first-generation bioethanols. In recent years, the food or fuel debate has probably been an obstacle to more widely spread adoption of bioethanol.

Second-generation biofuels are defined as fuels produced from a wide array of different biomass feedstocks, especially of non-edible lignocellulosic biomass. The price of this biomass is usually significantly less than the price of the feedstocks for first-generation bioethanol. On the other hand, such lignocellulosic feedstock is generally a considerable technological challenge and the more complex the biomass gets the more complicated and expensive the conversion processes become. The conversion processes for second-generation bioethanol are heavily dependent on new technologies, and the development of economically viable processes for the production of second-generation biofuels is currently a hot topic in the field.

Most agricultural products will have to be reserved for feeding the nine billion people as well as for feeding animals for the food chain. The biomass available for industrial purposes in the future will largely be biowaste, crop residues and other woody biomass. Such materials are primarily composed of plant lignocelluloses with a highly recalcitrant structure, which needs a host of enzymes or acid for decomposition [19]. Second-generation biofuels are produced from cellulose, hemicellulose or lignin with two main conversion routes: the biochemical route and the thermochemical route. The biochemical route is somewhat comparable with a pulping process. Once purified, enzymatic or acid hydrolysis is used to break the lignocellulosic material into fermentable sugars. In the second step of the process, these sugars are fermented into alcohol which is then distilled into ethanol. After more than a century of process development, there are still significant challenges in the production. In the thermochemical route, the first step in the process is the gasification of the feedstock under high temperature into synthesis gas. This gas can then be transformed into different types of liquid or gaseous fuels, so-called “synthetic fuels” [2,21,22].

Based on the feedstock used and conversion processes (Fig. 1), the bioethanol generations can be classified as follows [20,22]:

- First-generation bioethanol processes (1G ET): ethanol made of sugar or starch containing food – typically grains, sugarbeet, sugarcane – via fermentation process of biomass that is generally edible. More advanced (1.5G ET) ethanol sometimes refers to ethanol made of sugar or starch containing waste food. In principle also waste-food-based ethanol should be in 1G ET.
- Biochemical or “sugar route” second-generation bioethanol (2G ET): ethanol made of non-food biomass. Typically raw material is lignocellulosic biomass (wood, grasses, straw). Lignocellulosic biomass is hydrolyzed either with acids or enzymes into various sugars, which are fermented into ethanol (direct fermentation processes).
- Thermochemical or Indirect second-generation bioethanol processes (2G ET), in which whatever biomass is gasified into synthetic gas and then fermented or converted into alcohols catalytically or biologically by micro-organisms.

First-generation bioethanol processes are mature technologies and the fuel ethanol can be economically produced. The drawbacks include the use of foodstuff to fuel cars and typically relatively high life-cycle greenhouse gas emissions. However, sugarcane ethanol is an exception with very low greenhouse gas emissions. For second-generation bioethanol, the production processes have been known for over a hundred years, but they are not yet commercially and industrially proven. Second-generation bioethanol does not compete with food chain and the life-cycle greenhouse emissions are typically very low.

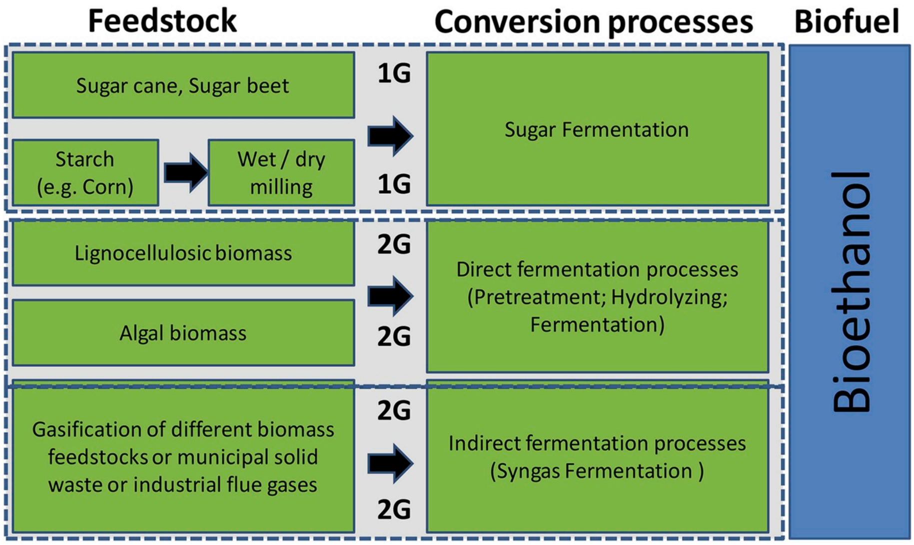

Fig. 1. Bioethanol generations, feedstocks and conversion processes [Adapted 22].

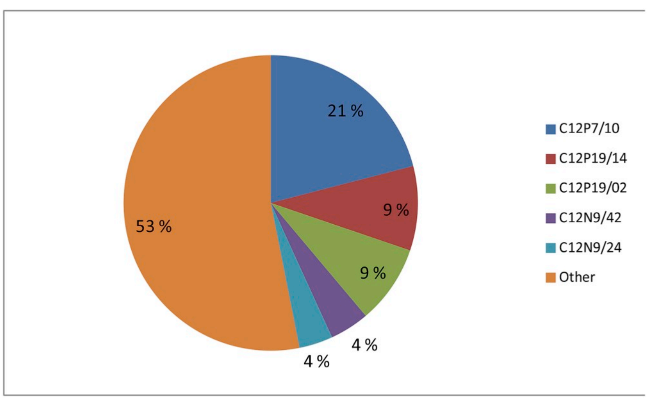

Fig. 2. IPC co-classification of 2G lignocellulosic patents (sample: 150 patent publications).

3. Methods and data

3.1. Search strategy

In different stages of invention and patent life cycle, different kind of search projects are carried out [23,24]. Trippe & Ruthven [24] categorize patent searches to four major categories: 1) state-of-the-art (SOA); 2) freedom-to-operate (FTO); 3) patentability; 4) validity. There are major differences between patent search (e.g. patentability) and patent analyses audience, purpose, risks, customizations and more [25]. The state-of-the-art searches (SOA) identify patents for the purposes of a general review, product development or patent landscaping purposes. In the SOA searches, the general risk of the search results is not as critical compared to the other types of searches. The precision of SOA searches does not have to be exact, but on the other hand we do not want to miss relevant documents (recall > precision) [24]. When applying a patent search, two possible types of error may arise: irrelevant patents may be included or relevant ones are left out.

Currently there are three main ways of identifying relevant patents [2]: 1) patent classification is the most common approach, because it is based on detailed knowledge of patent examiners; 2) keyword searches in cases when it is difficult to identify relevant patent classifications, and 3) manual selection. Montecchi et al. [26] and Hascic & Migotto [2] highlight some of the drawbacks of keyword-based search, such as different official languages, inaccurate terminology, inconsistent detail level in the patent description, less suitable for international comparisons and cross-country analyses. Manual selection, on the other hand, requires too much time and is unsuitable for large-scale analyses. More recently also artificial-intelligent-based search service providers are becoming to the markets, like Teqmine Analytics from Finland and Octimine Technologies from Germany.

The literature shows that in the biofuels and bioethanol sector there is significant subjectivity in selecting classifications and keywords when utilizing patents[1] [3,7,27,28]. Once the search starts, the initial main focus must typically be continuously revised and adapted in an iterative process [9]. Our search strategy was optimized to find grain bioethanol (1G), cellulosic bioethanol (2G) and grain AND cellulosic bioethanol (1G2G) based on International Patent Classification (IPC) WIPO Green Inventory (GI) and Y02 classification scheme.[2] This was followed by empirical results of co-classification analysis and content analysis based on the feedstock used. One of the authors has the technical expertise to analyze the contents of the patent documents, especially background descriptions and the claims. For the patents three main routes can be used, i.e. national, regional and international.

The count of patent applications filed under the international Patent Cooperation Treaty (PCT) is a frequently used patent indicator. International patent applications under PCT, which have effect on 152 jurisdictions, are commonly used as an indirect method of estimating global patent trends. Regarding patent searches, three most significant patent related dates are the priority date, the filing and the publication dates [29]. The PCT route extends the priority period to 31 months instead of usual 12 months, giving the applicant more time for assessing the potential value of the invention. The analyses based on PCT publications are less subject to home bias and the timeliness of this indicator is good, as the applications are published by the WIPO 18 months after the priority date [30]. Generally, it has to remembered that PCT applications do not represent an enforceable right in any jurisdiction as it must enter the national phase to proceed towards grant. Our search focused on Patent Cooperation Treaty (PCT) publications, which have become an increasingly frequently used filing route for patent applications [31] and they are suitable for our purposes in identifying technology generations and recent developments in bioethanol sector.

The main patent classification systems, such as the International Patent Classification (IPC) and the Cooperative Patent Classification (CPC), provide a hierarchical system of **language-independent symbols** for the classification of patents according to the different areas of

[1] See Appendix A.
[2] See Appendix B.

technology. The IPC classification scheme was reviewed and relevant sub-groups identified for the selected technologies. The relevant IPCs were obtained from the WIPO GI in an attempt to capture patents likely to have relevance to biofuels.

The new Y02 classification scheme collects a wide spectrum of technical fields associated with climate change mitigation technologies in one location. The new tagging scheme is made by the qualified EPO examiners who have both technical expertise and expertise in patent classification and search. The inclusion of technologies is done according to their potential for reducing green house gas emissions. The developers are well aware of that this can be contested for some sectors, like biofuels or nuclear energy. Once the automated statements were refined, these algorithms have been used to find and update all documents relating to CCMTs, and experts are responsible for keeping the algorithms up-to-date when changes in classification occur [9]. The important aspect of this new tagging scheme is that it allows identifying technologies with a very detailed level even by a non-specialist. However, the users should be aware of the limitations of the new tagging scheme, its role being rather complementary for the IPC or CPC classification symbols [32] and its dependence on the quality of IPC and CPC classification by patent offices [9].

In our search, bioethanol patents were sorted into first, second and first/second generation based on whether the technology made use of conventional food crops or lignocellulosic raw materials. In the content analysis of individual patents, technologies making use of non-food or non-conventional resources were sorted into second-generation technologies.

3.2. Search tools and data collection

There are various free-of-charge and commercial search, analysis and visualization tools in the field of patent analytics. Empirical results for this study have been carried out for PCT applications using the Espacenet and WIPO Patentscope. The patent literature is an extensive source of information, together with European Patent Office's Espacenet offering access to over 106 million bibliographic data and over 80 million full-text patent documents from over 90 countries [33]. The Y02 tagging scheme is available and searchable through Espacenet or PATSTAT. The full scheme can be searched using the Classification Search option, in combination with other filters available in the Advanced Search Option and can be used in conjunction with the functionalities of the European Patent Register [9].

For our purposes Espacenet online database was a good solution as it offers opportunities to make searches with the Y02 tagging scheme and it is an easy-to-use and versatile search tool. The search was carried out in summer 2017. Data were manually downloaded and cleaned for further analysis in standard excel database. For the manual content analysis, top ten organizations patents were analyzed including in total 420 PCT patent publications. For these patents, additional patent information were retrieved from Patentscope, European Patent Register and common citation document tool for citation data (see Table 1).

4. Empirical results

4.1. Results of the initial queries

The three different queries provided a total sample of 1227 PCT patent publications in years 2010–2016 (Table 2). The cellulosic bioethanol (search 1) query provided 476 patents of which 34.5% were made by ‘top ten’ applicants.

Manual content analysis of the top ten companies' patent publications shows that the classification accuracy varies considerably across categories (Table 3). Content analysis of the feedstock used revealed that 150 patents of the 164 patents (91.5% accuracy) contained cellulosic or lignocellulosic material as feedstock for bioethanol production. Many of the patents highlighted the advantages of the ready availability of large amounts of feedstock, the desirability of avoiding burning or land filling the materials, and the cleanliness of the fuel. Mostly wood, agricultural residues, herbaceous crops and municipal solid wastes have been considered as feedstocks for bioethanol production. In general, the search accuracy of cellulosic bioethanol query is very good and can be validated for patent landscaping and other purposes.

Feedstock analysis of grain bioethanol patents (search 2) revealed that only 45 patents of the 145 patents were from sugar or starch-containing material (31.0% accuracy). From these 45 correctly classified patents in 44 cases the feedstock was starch-containing material and only in one case readily fermentable sugar material. Most typical starch-containing material in patents was corn. Starch-containing material was derived also from wheat, barley, rye, sago, cassava, manioc, tapioca, sorghum, rice and potatoes. However, in 61 seven cases the feedstock was carbon monoxide, carbon dioxide and/or hydrogen, and in 16 cases the feedstock was cyanobacterium or pyruvate.

The third structured query was optimized to find starch-containing (grain) AND cellulosic bioethanol patents (1G2G). The feedstock analysis of the 111 patents revealed, however, that only 26 patents were those sugar/starch AND cellulose containing patents (23.4% accuracy). In the feedstock analysis, over 70% (78/111) of patented inventions were pure lignocellulosic patents (2G).

The results showed that the search 2 could not identify grain-based bioethanol technologies at satisfactory level. Many seemingly second-generation bioethanol patents have been classified as first-generation bioethanol patents. For example, a number of synthesis gas fermentation patents by LanzaTech, Ineos Bio and Coskata are mistakenly under Y02E50/17 classification (grain bioethanol). On the other hand, 2G cellulosic bioethanol patents were identified with very high accuracy. Next we present the results of co-classification analysis of the validated 2G cellulosic bioethanol patents. In the anomaly analysis the focus is on search 2 where co-classification could reveal the reasons for poor accuracy.

4.2. Patent co-classification analysis

Co-classification analysis of patents uses a fact that patent is typically classified into more than one patent class. In this section, 2G lignocellulosic (search 1) is presented in a more detailed level (see Fig. 2).

4.2.1. Lignocellulosic bioethanol IPC patent co-classification

The cellulosic bioethanol (2G) search accuracy was very good (92.1%) and provides a solid ground for further analysis. Table 4, Table 5, Figs. 1 and 3 show that many of the patents belong to IPC and CPC classes C12P7/10, which is not surprising as the feedstock used for ethanol production contains lignocellulosic material. Interestingly, other important classes C12P19/14 (preparation of compounds containing saccharide radicals, produced by the action of a carbohydrase, e.g. by *alpha*-amylase) and C12P19/02 (preparation of non-beverage alcohol: monosaccharides) are very much the same as in the first-generation bioethanol patents, indicating the same conversion technology process in technology generations.

4.2.2. Cellulosic bioethanol CPC co-classification

Recently, in the cellulosic bioethanol patenting especially enzymes have been actively developed. Novozymes patent (WO2014092832) emphasize “… a need in the art for new enzyme compositions to increase efficiency and to provide cost-effective enzyme solutions for saccharification of lignocellulosic material. The present invention provides processes for degrading a lignocellulosic material, comprising: treating the lignocellulosic material with an enzyme composition in the presence of a GH61 polypeptide having cellulolytic enhancing activity.” Some of the patents focused on pretreatment (IFP Nouvelles, WO2013107948), hydrolysis (Iogen WO2015081439), and some were related to all major stages in 2G bioethanol production (Novozymes, WO2012058293).

Table 1
Workflow of the study.

Steps	Workflow
1. Define the field or sector of research	Bioethanol
2. Finding the relevant classes and sub-classes	Green Inventory IPC
3. Define the scope (national, regional, global) and timeframe of search	Climate Change Mitigation technologies in the CPC.
4. Initial search strategy[a]	Patent Cooperation Treaty (PCT) publications 2010–2016.
5. Co-classification of bioethanol patents	**1.** Cellulosic bioethanol (2G)
6. Content analysis of patents	**2.** Grain bioethanol (1G)
7. Identify potential anomalies in the data	**3.** Grain and eellulosic bioethanol (1G2G).
8. Revise search strategy	Identify key IPC and CPC classes on the basis of frequency and co-classification-based 'clusters' of patents.
	Manual screening of patents based on the feedstock and conversion technology used.
	Identification of anomalies and new technology trajectories.
	Optimise search for patent landscaping and other types of searches.

[a] 1. Cellulosic bioethanol (2G): WO as the publication number AND 2010:2016 as the publication date AND Y02E50/16 NOT Y02E50/17 as the Cooperative Patent Classification AND C10L1/02 OR C10L1/182 OR C12N9/24 OR C12P7/06 OR C12P7/08 OR C12P7/10 OR C12P7/12 OR C12P7/14 as the IPC classification2. Grain bioethanol: WO as the publication number AND 2010:2016 as the publication date AND Y02E50/17 NOT Y02E50/16 as the Cooperative Patent Classification AND C10L1/02 OR C10L1/182 OR C12N9/24 OR C12P7/06 OR C12P7/08 OR C12P7/10 OR C12P7/12 OR C12P7/14 as the IPC classification3. Grain and cellulosic bioethanol: WO as the publication number AND 2010:2016 as the publication date AND Y02E50/16 AND Y02E50/17 as the Cooperative Patent Classification AND C10L1/02 OR C10L1/182 OR C12N9/24 OR C12P7/06 OR C12P7/08 OR C12P7/10 OR C12P7/12 OR C12P7/14 as the IPC classification.

4.3. Bioethanol anomalies

4.3.1. Grain bioethanol anomalies

Feedstock analysis of grain bioethanol patents revealed that 45 patents of the 145 patents were from sugar/starch-containing material. In the analysis, in 61 patents (42.1% of patents) the feedstock was related to totally different indirect second-generation synthesis gas to ethanol conversion technologies (Table 6).

The key developer firms in indirect 2G bioethanol technology trajectory were LanzaTech (New Zealand, 26 patents), Ineos Bio SA (Denmark, 19 patents) and Coskata (USA, 12 patents).

In addition, in 15 patents the bioethanol feedstock was algal biomass or carbon dioxide, utilizing sunlight and mostly cyanobacteria, relating to photosynthetic or algal bioethanol technologies (Table 7). These are sometimes called third-generation (3G) biofuel technologies. The key developers were Algenol Biofuels (Deutschland, 8 patents) and Joule Unlimited (USA, 7 patents).

4.3.2. Grain/cellulosic bioethanol anomalies

In the third structured query of starch-containing (grain) and cellulosic bioethanol patents (1G2G), the feedstock analysis of the 111 patents revealed that 85 patents were incorrectly classified. In the content analysis, 78 patents of these 85 patents were pure cellulosic bioethanol patents (2G) and 7 of them were 1G patents. The co-classification analysis revealed that ICP and CPC classes are identical to the cellulosic bioethanol classes (section 4.2.3), which confirms the

Table 2
Results of initial queries of the PCT patent publications 2010–2016.

Search criteria	Total sample (applicants)	Top 10 firms (% of all)	Top 10 firms patent count
Search 1: Cellulosic bioethanol (2G)	476 patents (193 applicants)	164 patents (34.5%)	1. Novozymes AS (DK): 39 2. IFP Energies (FR): 27 3. DSM (NL): 22 4. Iogen (CA): 18 5. Xyleco (US): 12 6. Mascoma (US): 11 7. API IP Holdings (US): 9 8. Danisco (US): 9 9. Du Pont (US): 9 10. Codexis (US): 8
Search 2: Grain bioethanol (1G)	403 patentsn (188 applicants)	145 patents (35.9%)	1. LanzaTech (NZ): 29 2. Novozymes AS (DK): 26 3. Ineos Bio SA (CH): 19 4. Danisco (US): 17 5. KAIST (KR): 13 6. Coskata (US): 12 7. Joule Unlimited (US): 8 8. Du Pont (US): 7 9. Algenol Biofuels (DE): 7 10. POET (US): 7
Search 3: Grain and cellulosic bioethanol (1G2G)	348 patents (169 applicants)	111 patents (31.9%)	1. Du Pont (US): 22 2. DSM (NL): 15 3. Novozymes (DK, US): 14 4. Qteros (US): 12 5. Mascoma (US): 11 6. Toyota (JP): 9 7. POET (US): 8 8. Xyleco (US): 8 9. Danisco (US): 6 10. Deinove (FR): 6
SUM	**1227**	**420** (34.2%)	**420** (34.2%)

Table 3
Validation results for the bioethanol technology generations.

Bioethanol generations	Correctly classified	Incorrectly classified	Total sample	Classification Accuracy	Comments
Search 1: Cellulosic bioethanol (2G)	150	14	164	92.1%	Validated
Search 2: Grain bioethanol (1G)	45	100	145	31.5%	Anomaly analysis
Search 3: Grain AND cellulosic bioethanol (1G2G)	26	85	111	23.4%	Anomaly analysis
SUM	221	199	420	52.6%	

Table 4
IPC's 2G cellulosic bioethanol patents (cleaned sample, 150 patents).

IPC (frequency)	Description
C12P7/10* (141)	Preparation of non-beverage ethanol: substrate containing cellulosic material
C12P19/14 (62)	Preparation of compounds containing saccharide radicals, produced by the action of a carbohydrase, e.g. by *alpha*-amylase
C12P19/02 (58)	Preparation of non-beverage alcohol: monosaccharides
C12N9/42* (29)	Hydrolases, acting on glycosyl compounds, acting on *beta*-1, 4-glucosidic bonds, e.g. cellulase
C12N9/24* (25)	Enzymes acting on glycosyl compounds
C13K1/02 (23)	Glucose obtained by saccharification of lignocellulosic materials
C08H8/00 (12)	Macromolecular compounds derived from lignocellulosic materials
C12P7/14* (12)	Multiple stages of fermentation; multiple types of micro-organisms or reuse for micro-organisms
C12P7/16 (11)	Butanols
SUM 373	**55.6%**
ALL 672	

Note (*) denotes classes included in search strategy.

effectiveness of the Y02E50/16 class for identifying cellulosic bioethanol patents and problems with the Y02E50/17 class. The key developers of cellulosic bioethanol with this search strategy were Dupont (USA, 14 patents, DSM (Netherlands, 14 patents), Mascoma (USA, 11 patents), Toyota (Japan, 9 patents), Novozymes (Denmark, 7 patents), POET (USA, 6 patents), Deinove (France, 6 patents), Qteros (USA, 5 patents) and Xyleco (USA, 4 patents).

4.4. Discussion of the results

The empirical results reveal that based on the selected search strategy second-generation cellulosic bioethanol patents could be identified with a reasonable good match. Patents related to climate change mitigation technologies usually belong to many areas of technology and may not fall under one single classification section. In the cellulosic bioethanol technologies, the IPC or CPC class C12P7/10 (preparation of non-beverage ethanol: substrate containing lignocellulosic material) is connected to the Y02 tagging scheme classification Y02E50/16 (cellulosic bioethanol) providing precise and complete results in the search. The second-generation cellulosic bioethanol technology utilizes also traditional methods in ethanol production (C12P19/14).

The first-generation bioethanol sector classification was more challenging. In the grain bioethanol technologies, the IPC or CPC class C12P7/06 (preparation of non-beverage ethanol) was clearly related to the Y02E50/17 class (grain bioethanol). This seems to be problematic as the C12P7/06 class could be found also in other technology generations. It has to be remembered that patent examiners have not made mistake in their classification, but the automated tagging scheme does not classify all patents correctly. Based on anomalies found in the Y02E50/17 classification, emerging technology trajectories of second-generation indirect syngas conversion [22] and the so-called third-generation photosynthetic microorganism technology trajectories [34] could be found in the bioethanol sector. Both 2G indirect synthesis gas and 3G photosynthetic technologies are not related to 1G bioethanol technologies as the co-classification clearly suggests, e.g. the class C12N1/20 is not linked to grain ethanol. The results are not at all in line with the Kessler & Sperling's [3] study, in which the first-generation biofuel technology classification was validated with a very high 92% accuracy utilizing for instance the same Y02E50/17 grain based biofuel classification. Our content and co-classification analysis shows strong evidence to support our findings.

Table 8 and Table 9 summarize the main co-classification results of the 311 PCT patents, which formed the foundation to the identified technology trajectories.[3]

The Y02 classification is potentially a great search tool for patents in a very detailed level of technologies. However, problems can arise if the automated algorithm does not provide reliable search results. The patent co-classification can be a useful tool to make Y02 tagging scheme more reliable and accurate. The Y02 classification scheme is a great joint effort of the EPO for climate change mitigation technologies and with this one very specific example it is not possible to say anything about overall usefulness of the tagging scheme. The identified top IPC's and CPC's co-classification could be used in the future studies as a basis for search strategies for emerging bioethanol sectors. It has to be remembered that the biofuels sector is very demanding and complex sector to analyze. Our study has also many limitations. The analyzed dataset includes only a very small dataset of relevant 1G patents. Generally it is challenging to identify very emerging technologies as there is not much historical data available. Overall, patent data provide useful data and unique source of information, since they are collected, screened and published according to internationally agreed standards [35].

5. Conclusions

Biofuels is one of the most rapidly growing sectors in the world and the sustainability criteria are currently under hot political debate in the European Union. Patent databases are potentially a valuable tool for monitoring green inventions and help environmental planning for sustainable biomass utilization. Patent analytics support decisions to be made with data-driven approaches. In order to support policy making for climate change and mitigation technologies innovation, the importance of getting high quality data is obvious.

Patent documents are categorized using the International Patent

[3] 91.8% of the misclassified 1G2G patents were 2G lignocellulosic patents with the very same top IPCs.

Table 5
CPC's 2G lignocellulosic patents (sample: 150 patent publications).

CPC (frequency)	Description
Y02E50/16* (171)	Cellulosic bioethanol
C12P7/10* (137)	Preparation of non-beverage ethanol: substrate containing lignocellulosic material
C12P19/02 (91)	Preparation of non-beverage alcohol: monosaccharides
C12P19/14 (89)	Preparation of compounds containing saccharide radicals, produced by the action of a carbohydrase, e.g. by *alpha*-amylase
C12P2201/00 (55)	Pretreatment of cellulosic or lignocellulosic material for subsequent enzymatic treatment or hydrolysis
C12P2203/00 (46)	Fermentation products obtained from optionally pretreated or hydrolyzed cellulosic or lignocellulosic material as the carbon source
C12N9/2437 (33)	Enzymes: cellulases
C13K1/02 (32)	Glucose obtained by saccharification of lignocellulosic materials
C12P7/14* (29)	Multiple stages fermentation; Multiple types of microorganism or reuse for microorganisms
Y02E50/10 (23)	Biofuels
C08H8/00 (21)	Macromolecular compounds derived from lignocellulosic materials
C12P7/16 (19)	Butanols
C12N9/2445 (15)	Enzymes: Acting on glycosyl compounds: *beta*-glucosidase
C12Y302/01004 (14	Enzymes: hydrolases acting on glycosyl compounds: cellulase (*i.e. endo*-1,4-*beta*-clucanase)
C12N9/2402 (12)	Enzymes: acting on glycosyl compounds: hydrolyzing *O*- and *S*-glycosyl compounds
C13K13/002 (12)	Xylose (sugars not otherwise provided in this class)
Y02E50/343 (12)	Methane: production by fermentation of organic by-products, e.g. sludge
C12Y302/01021 (11)	Enzymes: hydrolases acting on glycosyl compounds: *beta*-glucosidase
D21C5/005 (11)	Treatment of cellulose-containing materials with micro-organisms or enzymes
SUM 833	**54.2%**
ALL 1536	

Note (*) denotes classes included in search strategy.

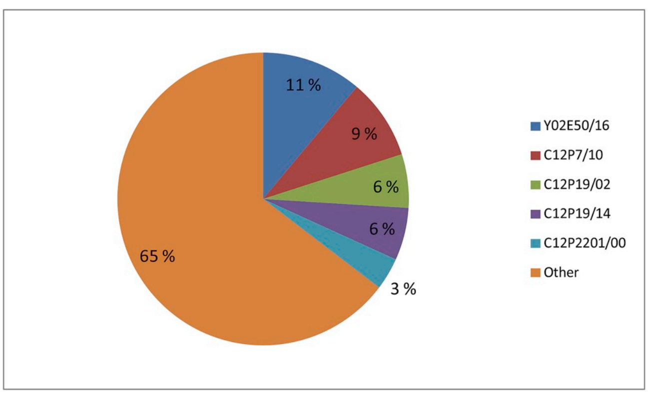

Fig. 3. CPC co-classification of 2G lignocellulosic patents (sample: 150 patent publications).

Classification (IPC), Cooperative Patent Classification (CPC) and national classification systems. The IPC, a means for obtaining an internationally uniform classification of patent documents, has its primary purpose in the establishment of an effective search tool for the retrieval of patent documents used in various kind of searches [36]. The IPC Green Inventory (GI) facilitate searches for patent information relating to green inventions. However, previous research has shown major difficulties in linking patents to specific economic activities in the biofuels sector. In addition, the major limitation for assessing bioethanol inventions is that the GI database does not facilitate the comparison between first- and second-generation technologies. For the climate change mitigation technologies, EPO has further developed a dedicated classification scheme as part of the CPC available for public use within Espacenet services. The important aspect of this new tagging scheme is that it allows identification of technologies with a very detailed level even by a non-specialist, and in our case provide opportunities to identify technology generations from the patent data. The purpose of this study was to evaluate the effectiveness of the combined Green Inventory and the new Y02 classification-based search strategy in finding bioethanol technology generations based on the feedstock used.

The results reveal that based on the selected search strategy second-generation cellulosic bioethanol patents could be identified with a good match. Based on co-classification analysis and content analysis of patents, anomalies were found (Y02E50/17) in initial search strategies related to grain based bioethanol technologies. Classes in section Y02 are assigned algorithmically by automated search using a combination of classes and keywords. The challenge of the automated search is that the population of patents from which such searches draw is unknown. With this one very specific case example it is not possible to evaluate how well EPO statement ‘using the single tagging codes to retrieve relevant documents cross all technological fields reduce the amount of noise and results, and it shows that document found are relevant’ holds in other cases, especially in emerging and complex industry sectors. We propose that more precise and complete search results with Y02 tagging scheme would be possible with more systematic utilization of co-classification methodology.

Manual screening of patents based on feedstock and conversion technology used is very time consuming, but further research is needed

Table 6
2G indirect synthesis gas fermentation patents (sample: 61 patent publications).

IPC 2G Indirect	Description	CPC 2G Indirect	Description
C12P7/06 (56)	Preparation of non-beverage ethanol	Y02E50/17 (60)	Grain bioethanol
C12P7/16 (15)	Butanols	C12P7/065 (51)	Preparation of non-beverage ethanol with micro-organisms other than yeasts
C12N1/20 (12)	Micro-organisms: bacteria; culture media therefor	C12P7/08 (23)	Non-beverage alcohol produced as by-product or from waste or lignocellulosic material substrate
C12P7/08 (11)	Non-beverage alcohol produced as by-product or from waste or lignocellulosic material substrate	C12P7/54 (20)	Preparation of acetic acid
C12P7/54 (11)	Preparation of acetic acid	C12P7/06 (15)	Preparation of non-beverage ethanol
Sum 105 (41.3% of the patents)		SUM 169 (34.8% of the patents)	

Table 7
3G photosynthetic organisms (sample, 15 patent publications).

IPC 3G Photo	Description	CPC 3G Photo	Description
C12P7/06 (13)	Preparation of non-beverage ethanol	Y02E50/17 (15)	Grain bioethanol
C12N1/12 (3)	Micro-organisms: Unicellular algae	C12P7/065 (13)	Preparation of non-beverage ethanol with micro-organisms other than yeasts
C12N1/20; (3)	Micro-organisms: bacteria; culture media therefor	C12N15/74 (7)	Vectors or expression systems specially adapted for prokaryotic hosts other than *E. coli*, e.g. Lactobacillus, Micromonospora
C12N15/74 (3)	Vectors or expression systems specially adapted for prokaryotic hosts other than *E. coli*, e.g. lactobacillus, micromonospora	C12N9/0006 (7)	Enzymes: oxidoreductases acting on CH-OH groups as donors
		C12N9/88 (7)	Enzymes: Lyases
SUM 22 (43.1% of the patents)		SUM 49 (37.4% of the patents)	

Table 8
Top 5 IPC bioethanol technology trajectories.

2G cellulosic bioethanol (164 patents)	1G grain bioethanol (45 patents)	1G2G bioethanol (26 patents)	2G indirect bioethanol (61 patents)	3G photosynthetic or algal bioethanol (15 patents)
C12P7/10* (141)	C12P7/06* (37)	C12P7/06* (20)	C12P7/06* (56)	C12P7/06* (13)
C12P19/14 (62)	C12P19/14 (13)	C12P7/10* (11)	C12P7/16 (15)	C12N1/12 (3)
C12P19/02 (58)	C12N9/24* (5)	C12N1/22 (6)	C12N1/20 (12)	C12N1/20; (3)
C12N9/42* (29)	C12C11/00 (4)	C12N1/21 (3)	C12P7/08* (11)	C12N15/74 (3)
C12N9/24* (25)	C12N9/34 (4)	C12R1/145 (3)	C12P7/54 (11)	
SUM 315	**SUM 63**	**SUM 43**	**SUM 105**	**SUM 22**
Total 672 (46.9%)	**Total 149 (42.3%)**	**Total 86 (50.0%)**	**Total 254 (41.8%)**	**Total 51 (43.1%)**

Note (*) denotes classes included in search strategy.

Table 9
Top 5 CPC classes of bioethanol technology trajectories.

2G cellulosic bioethanol (164 patents)	1G grain bioethanol (45 patents)	1G2G bioethanol (26 patents)	2G indirect bioethanol (61 patents)	3G photosynthetic or algal bioethanol (15 patents)
Y02E50/16* (171)	Y02E50/17* (45)	Y02E50/16* (26)	Y02E50/17 (60)	Y02E50/17 (15)
C12P7/10* (137)	C12P7/06* (41)	Y02E50/17* (26)	C12P7/065 (51)	C12P7/065 (13)
C12P19/02 (91)	C12P19/14 (24)	C12P7/10* (15)	C12P7/08 (23)	C12N15/74 (7)
C12P19/14 (89)	C12P19/02 (14)	C12P7/06* (12)	C12P7/54 (20)	C12N9/0006 (7)
C12P2201/00 (55)	C12P7/14* (12)	C12P7/065 (10)	C12P7/06 (15)	C12N9/88 (7)
SUM 543	**SUM 136**	**SUM 89**	**SUM 169**	**SUM 35**
Total 1536 (35.4%)	**Total 333 (40.8%)**	**Total 195 (45.6%)**	**Total 486 (34.8%)**	**Total 131 (37.4%)**

Note (*) denotes classes included in search strategy.

in relation to the new tagging scheme and generally adapting reliable search strategies before utilizing advanced patent-based indicators. After careful design of search strategy, patent landscaping and patent-based indicators could be used for various purposes, *e.g.* in identifying dynamics of technology evolution. The IPC co-classification has been used as a method in the convergence studies [37–39], and patent data provide research opportunities in identifying the potential break-through environmental technologies [40] or identifying innovation-science link in the development of environmental technologies. One area of future studies is how the new and rising developments of artificial intelligence, machine learning, deep learning and artificial neural networks will affect the way how the IP data are analyzed in the growing patent analytics field [41]. For the authors, manual patent reading and content analysis was also quite a deep learning process and increased substantially their understanding of technology development in this specific sector.

Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wpi.2019.03.004.

Appendix A. Search strategies in biofuels sector

Source	Search strategy	Method
[28]	Domain experts identified the main classes - C12N9/42, C12P7/10, C12P19/14, C12P19/02, C12N1/15, D21C9/10, C12N9/24, C12N15/56, and C12P19/00 Keywords: 'Cellulose' AND 'Ethanol'	Co-classification and content analysis of 300 patents
[3]	Green Inventory IPC + CPC Bioethanol: - Green Index (IPC): C10L 1/02, C10L 1/182, C12N 9/24, C12P 7/06-7/14 - CPC: Y02E50/17 Cellulosic ethanol: - Green Inventory IPC: NA - CPC: Y02E50/16	Natural language processing (NLP) and machine learning (125 keywords)
[27]	Keywords: 'lign' AND 'fuel'	Topic modeling (LDA) + data cleaning Advanced patent analysis tools, such as a mix of supervised and unsupervised machine learning techniques and text-mining

Appendix B. CPC and biofuels patents

Class	Definition
Y02E	Reduction of greenhouse gases (GHG) emission related to energy generation, transmission or distribution
Y02E 50/00	Technologies for the production of fuel of non fossil origin
Y02E 50/10	. Biofuels
Y02E 50/11	.. CHP turbines for biofeed
Y02E 50/12	.. Gas turbines for biofeed
Y02E 50/13	.. Biodiesel
Y02E 50/14	.. Bio-pyrolysis
Y02E 50/15	.. Torrefaction of biomass
Y02E 50/16	.. Cellulosic bioethanol
Y02E 50/17	.. Grain bioethanol
Y02E 50/18	.. Bio-alcohols produced by other means than fermentation
Y02E 50/30	. Fuel from waste
Y02E 50/32	.. Synthesis of alcohols or diesel from waste including a pyrolysis and/or gasification step
Y02E 50/34	.. Methane
Y02E 50/343	... production by fermentation of organic by-products, e.g. sludge
Y02E 50/346	... from landfill gas

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