Renewable and Sustainable Energy Reviews 77 (2017) 318–326

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

The emergence of patent races in lignocellulosic biofuels, 2002–2015

Hannes Toivanen[a,b,c,*], Michael Novotny[d]

[a] VTT Technical Research Centre of Finland, P.O. Box 1000, 02044-VTT, Finland
[b] Lappeenranta University of Technology, School of Business and Strategy, Lappeenranta, Finland
[c] Teqmine Analytics Oy, Helsinki, Finland
[d] KTH Royal Institute of Technology, Department of Industrial Economics & Management, Stockholm, Sweden

ARTICLE INFO

Keywords:
Biofuels
Lignocellulose
Patent analysis
Patent landscape
Policy
Emerging technology
Business strategy

ABSTRACT

How does increasing economic and technological interest in biofuels shape the nature of the intellectual property rights (IPR) in the industry? Is the technological nature of biofuel patents and inventions, as well as the business itself undergoing a transformation? This article provides a patent analysis of lignocellulosic biofuels with U.S. patent publications between 2002 and 2015 in order to shed light on the broader economic and regulatory factors affecting the development of new technologies in the area. Patent applications in the technology have increased about eightfold in this period and count about 130–150 per year currently, and could soon reach 200 annual filings. Specifically, we analyse in what ways the nature of lignocellulosic biofuel technologies is changing, and our results suggest that this business is indeed being transformed by increasing research and development (R & D) and IPR efforts, material in an evident patent race. We document a relatively small, but nascent technology, with some key technology areas increasing between four- and tenfold, over the last decade. Technologically leading countries are the U.S., followed by Germany, Japan, France and the U.K. We argue that intensified global and industry-wide claims for IPR reveal an ongoing patent race with multiple implications for the industry and engineering community. Most importantly, industry's technological interdependence is likely to increase as the likelihood for broad, exclusive patent regimes diminishes, making the industry more likely to explore increasingly collaborative technological solutions when carrying out R & D and investing in new production facilities in the future.

1. Introduction

In global energy research, renewable energy sources have since 2000 become the fastest growing nexus of technological research and invention, evident in rapidly growing patent rates that outpace other energy technologies [1]. This global search for economically, politically and environmentally sustainable energy sources underpins broad global changes, and the nature and direction of innovation in renewable biofuels is, therefore, of great importance for policy makers and industry leaders as well as the research and development community. Increased patenting has raised the issue of how emerging intellectual property rights (IPR) regimes may affect the rate, direction, and diffusion of innovation. One manifestation of this has been the policy debate on IPR rights in renewable energy technologies. This discussion has been polarized on to what extent IPR rights work as incentives for firms to invest in renewable biofuel technologies, and to what extent patents effectively deter critical innovation [2,3].

In this context, this paper offers a careful patent analysis of the lignocellulosic biofuels technology. Lignocellulose-based biofuels embody one of the most potent new sources of renewable energy. Abundant in nature, they are one of the largest sources of carbohydrates, yet the exploitation of lignocellulose on a large scale and in an economically feasible fashion is limited by technological difficulties of efficiently converting biomass into ethanol and other chemicals. The potential of lignocellulosic biofuels as energy and a bioeconomy platform technology, as well as the increasing possibilities of mobilizing related production technologies on an industrial scale, have fuelled and continue to fuel an increasing technological and commercial interest in the area [4,5].

With patent analysis, this article documents a rapidly increasing technological effort in the area, whereby technology can best be characterized as “emerging technology”, and explores how this intensified activity and interest is reshaping the broader social, economic and regulatory environment of lignocellulosic biofuels. By using advanced patent analysis tools, such as a mix of supervised and unsupervised machine learning techniques and text-mining, on the complete United States Patent and Trademark Office (USPTO) patent database consisting of approximately 7 million full-text patents, we

* Corresponding author at: Teqmine Analytics Oy, Helsinki, Finland.
E-mail addresses: Hannes.Toivanen@vtt.fi (H. Toivanen), Novotny@kth.se (M. Novotny).

http://dx.doi.org/10.1016/j.rser.2017.03.089
Received 1 April 2016; Received in revised form 30 January 2017; Accepted 20 March 2017

describe a technological area characterized by rapidly increasing patenting rates and clear signs of patent races. Such a phenomenon signals increasing industrial technological viability, but also suggests changes in the nature of inventions and intellectual property rights claims. To summarize, inventive steps in the industry are becoming smaller, more incremental and more tightly connected, and the technology as a whole is becoming increasingly covered by exclusive IPR. If true, such changed circumstances are bound to limit the strategic choices available to firms and research organizations, and are likely to induce more collaborative practices between leading holders of IPRs.

2. Background

2.1. Wood-based biofuels and biorefineries

Recent interest in lignocellulosic biofuels is part of a global search for technologically, economically, and environmentally viable energy sources. One manifestation driving increased energy demand has been the wide changes in agricultural practices, especially irrigation systems [6]. As a non-food crop, wood-based renewable biofuels embody a particularly attractive solution, and were already identified as such at the beginning of the chemical wood processing industry. The first non-food, crop-based, biofuel solutions were introduced roughly 100 years ago, when bioethanol was one of the major industrial products from wood-based, sulphite and pulp mills in Scandinavia, Germany and the USA [7].

After World War II, the success of the oil and petroleum industries, as well as the pulp and paper industry completely shifted to sulphate pulp processes [8], which quickly eclipsed substantial efforts to develop and expand wood-based biofuel technologies [9]. Continued interest in bioethanol based on other crops secured the development of key technologies, mostly fermentation technologies, the key nexus being the Brazilian effort to develop sugarcane-based bioethanol.

The rise of second generation biofuel technologies, fuelled by the global search for more environmentally sound fuel sources, especially those focused on the exploitation of various biomasses, has more recently expanded the technological search and business interest in lignocellulosic biofuels [10]. Basically, any lignocellulosic biomass – agricultural residues, municipal waste, wood residues, (micro)algae, switchgrass, to mention the most common feedstocks – can be extracted and converted into carbohydrate sugars, alcohols, lignin phenols and oils in a first stage and biofuels in a second stage [7].

More recently, the food/fuel rivalry has triggered a scramble for alternative feedstocks, i.e. lignocellulosic material, which form the basis for the next generations of biofuels. Lignocellulosic components, such as cellulose, hemicellulose and lignin, represent an interesting and challenging opportunity for producing sustainable and renewable liquid fuels.

Wood-based biofuels enjoy several potential advantages. One advantage is that carbohydrates (cellulose and hemicelluloses sugars) are the most abundant organic feedstock on Earth, with lignin, comprising about 25% of all biomass compounds, being the second most abundant. Roughly 75% of the lignocellulosic feedstock is composed of carbohydrates. Some technological bottlenecks arrest their exploitation, especially the difficulty of efficiently separating out the lignin, with only about five percent of all carbohydrates being used by humankind.

There are three main technology platforms for biofuels: (a) hydrolysis – enzymatic (biochemical) or thermochemical hydrolysis, (b) pyrolysis (solid biofuels or bio-oil), and (c) gasification [7,11]. Liquid biofuels are usually produced via gasification or hydrolysis technologies. Hydrolysis or fermentation is usually related to ethanol production, and gasification is a syngas conversion of carbon monoxide, carbon dioxide, methane and hydrogen. Syngas, as a gas, can serve as fuel for power or as a liquid fuel, in particular, methanol. Methanol is a versatile platform compound for several chemicals and fuels (e.g. acetic acid and dimethyl ether) (Table 1).

Dimethyl ether (DME) has in turn emerged as an efficient energy carrier and transportation fuel in the form of biodiesel [7,12]. The advantages of biodiesel fuels are the same as for ethanol. Ethanol can easily be used by the established transportation system, that is in fossil based liquid blends, for transportation fuels at established gasoline pumps. Furthermore, it can be processed from almost any abundant lignocellulosic material (e.g. wood and/or agricultural residues or energy crops such as algae). This, so called Third Generation of biofuels, is based on upgrades in the production of biomass, which takes advantage of specifically engineered energy crops such as algae [13].

Biofuel production is often part of biorefinery infrastructures in facilities that convert biomass feedstock, including lignocellulosic material such as wood, into a wide range of valuable and sustainable materials, chemicals and multiple fuels [7]. The biorefinery concept embraces several renewable raw materials, separation and conversion technologies, and intermediate and final products. A biorefinery potentially has the advantage of producing more classes of products than can petroleum refineries, thus offering more opportunities for product development and diversification. A bottleneck consists of the logistics of heterogeneous raw materials which makes access to biomass a strategic factor when locating a biorefinery production unit. Currently, there are not many global examples of cost-competitive alternatives to oil refineries, but in the 2000s, the uncertainties related to climate change, volatile energy prices and fossil-based energy supplies, 'cotton peaks' and the like, have contributed to making biomass appealing as a feedstock for many industries and industrial processes. In a lignocellulosic context, a range of technological barriers and economic and industrial opportunities have been identified, and resulted in a nexus of highly active research and development [14].

Given the political, economic and societal pressures to move towards cleaner and environmentally sustainable energy systems and economic factors, the business interest to develop a cost-efficient and technologically sound wood-based biorefinery concept has surged during the last decade. This interest has materialized as a rapidly growing research effort, as evidenced by the surge in scientific publications and patent applications. Naturally, when investment in a wood-based biomass biorefinery easily exceeds 1 billion euros, the need to secure a return on investments for the development of necessary new technologies affects the balance between scientific research and claim on exclusive intellectual property rights.

2.2. Emerging technologies and patent races

The notion of "emerging technologies" is usually applied in a practical sense to define a given technological nexus being capable of overturning or replacing existing mainstream solutions. It is invoked, typically, as a framework to guide expectations and focus R & D and business efforts. In the context of this paper, we label lignocellulosic biofuels as an "emerging technology" because of their potential as a new biofuel production method, as well as because of the rapidly increasing volume of research and development efforts (see below).

Whereas nanocellulose or biofuels are perhaps the current embodiments of emerging technologies in the forest based industries, Toivanen [8,9] has argued that the industry has, since the 1850s, been swept by a succession of emerging technologies. The first wave was the introduction of wood pulp and the first sulphite pulping process, followed by different product innovations (newsprint, tissue paper, corrugated board, etc.). This was followed by the second wave that included the sulphate pulping process, and eventually by the third wave, the introduction of engineered fast-growing tree species and adapted pulp processes. Each of these waves either substituted existing production processes or products or introduced completely new ones. Moreover, each of these emerging waves sparked an industry-wide