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Identifying emerging biorefinery technologies & potential markets: A technometric approach

Michael Novotny michael.novotny@indek.kth.se / Department of Industrial Economics & Management, Royal Institute of Technology, Lindstedtsvägen 30, Stockholm, 10044 (Sweden)

Ulf Sandström ulf.sandstrom@indek.kth.se / Department of Industrial Economics & Management, Royal Institute of Technology, Lindstedtsvägen 30, Stockholm, 10044 (Sweden)

Abstract

Biorefinery activities have the potential to partly substitute oil, fossil and metal industries in a wide range of sectors in a near future (Kamm et al 2010; Axegård 2010). This paper is about methodologies and mapping of "biorefinery" technologies, constellations and potential markets thereof. The methodology is characterized by a technometric approach. The aim is, firstly, to track science and technology frontiers in the biorefining field and, secondly, identify the key agents involved through bibliometrics of applied science and engineering – which then can be matched with patent data and tracking demonstration plants close to commercialization. This paper has been guided by the theory on technological paradigms and socio-technical communities Kuhn, 1962; Dosi 1982; Thagaard, 1986) epistemological communities (Haas, 1992) or learning communities (Wenger, 1998). On the basis of this theory we formulate a hypothesis predicting that traditional forest industry countries (high exports/share of GDP) may face a lock-in effect of concentration for research to traditional industries. Our results indicate that countries like Sweden, Finland, Austria, and Germany – which to a considerable extent have been the frontrunners of forest industry technologies both with regards to exports, production volumes, R&D new equipment – are at risk due to lock-in effects.

Introduction

Growing environmental concerns, emerging economies and strong uncertainties of future supply of fossil feedstock contribute to a renaissance for biomass industries. Biomass is being increasingly regarded as an important raw material for industries that traditionally have had other feedstocks, e.g. oil, (petro)-chemical, automotive, metal and material industries. The increasing struggle for finding solutions to possible oil shortage and environmental impact abatement in different sectors (energy, automotive, chemical, basically all large scale industries) is in turn resulting in a global scramble for biomass in particular in the EU (UNECE/FAO, 2009, 2011).

This paper focuses mainly on mapping of "biorefinery" technologies, R&D constellations and potential markets thereof. The methodology is characterized by a technometric approach. The aim is, firstly, to track science and technology frontiers (S&T communities) in the biorefining field and, secondly, identify the key agents involved through scientometric methods – which then can be matched with patent data and tracking of emerging technologies expressed by demonstration plants close to commercial introduction. A bibliometric analysis is useful in order to process a large amount of information from database material; in this case it particularly facilitates the mapping and identification of the frontiers of emerging technology fields. This quantitative method will, in a second part of the study, be supported by qualitative input i.e. expert opinion in picking relevant clusters, identify S&T/industry constellations and develop analysis from selected key words/cluster labels (bibliometrics combined with Derwent Index patent database).

The aim of the paper is to analyze emerging technology frontiers, the S&T communities behind them, and potential new entrants in the field of biorefinery. The questions that arise are: where are R&D efforts (publications primarily) done globally and who is in the front seat; country- and sector/company-wise? Since emerging fields probably are at rather early phases of technology development the unit of analysis is more on S&T communities – so called fronts or clusters.

Technological paradigms and methodological issues

Technological paradigm shifts or even larger regime shifts (Geels, 2002) usually involve series of interconnected events of industrial activities or technical development (Dahmén, 1950). In an era of high uncertainties due to climate change, environmental concerns, and competition from the BRICs (emerging economies/markets) the transformative pressure on energy-intensive and natural resource based industries (NRBI:s) has increased (UNECE/FAO 2009/2011).

A technological paradigm is made by a pattern of the technology at stake and by the specific technological challenges caused by such pattern (e.g. increasing capacity and dimensions in a process industry). It is "a set of procedures, a definition of the 'relevant' problems and of the specific knowledge related to their solution" (Dosi, 1982, p 149). Therefore, technology is identified as a problem-solving activity in which the problems to be solved are selected by the paradigm itself and its engineering and scientific communities (Thagaard, 1986). In this sense, a technological paradigm involves a strong trend on the trajectory of technological change that is the direction toward which future technical progress will converge. Such gradual improvements along specific lines set by the paradigm are what represent technological trajectories and progress (Dosi, 1982; Teece, 2008).

Inspired by Kuhn (1962), Constant used the concept 'technological community' to examine the practitioners of the technological change, i.e. the professional engineers who have both common educational backgrounds and common career expectations. Thagaard (1986) did the same for the scientific communities which in the industrialized world have been strongly connected with technological development. Technological communities with relatively homogenous cognitive view and expectations on knowledge formation could therefore develop considerable lock-in.

Constant demonstrated that old engineering communities seldom initiate radically new innovations. In his example, engineers of piston aircraft engines did not play any role in the development of the turbojet aircraft. As a consequence a lock-in usually takes place and whenever a radical shift occurs the incumbents rarely are the initiators (Christensen, 2000).

The biorefinery field is not a completely new field of knowledge, its roots derive from organic chemistry of the first half of the 20th century (Kamm, Gruber, Kamm, 2010). However, it has to a large extent been used as an industrial multi-product concept rather than a coherent science field, since there are a few established examples out there already (ethanol, sulfite and pine oil plants expressed by DuPont, Arizona Chemicals, Borregaard, Domsjö). However, by defining biorefineries as innovative activities rather than established production units we are able to overcome the academy-industry problematique.

There are several steps in a technometric delineation of an area. Firstly, the definition of the research field via keywords selection (a dozen keywords from the biorefinery field have been picked from recent conferences and academia – e.g. the definition of lignocellulosic biorefinery in Kamm et al 2010 and key concepts from conferences, e.g. Biorefinica and Nordic Wood Biorefinery Conferences). By selecting frequently used topics in the field such search terms aroused.

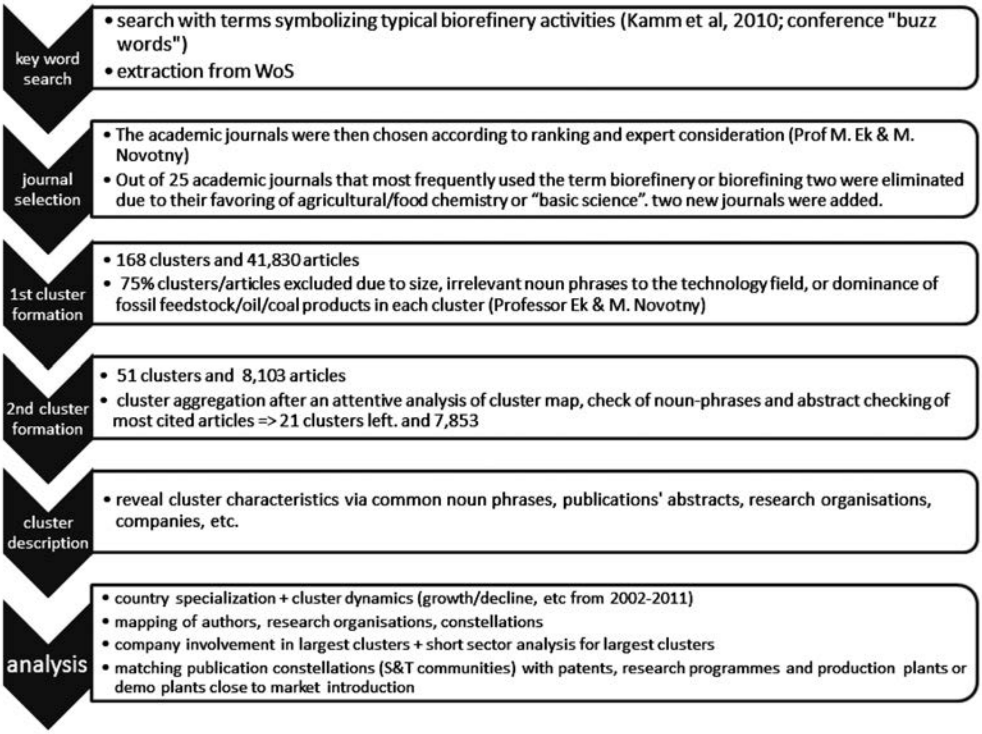
Our study design is based on findings from the most cited academic publications in applied science journals of biofuels, biochemicals, biomaterials and biomass fields which most frequently have used the term "biorefinery" and/or "biorefining" indexed by Thomson Reuters in Web of Science (WoS). In turn WoS was centered on the data base commonly known as SCI-EXPANDED.

Following this keyword selection process, out of a first draft, 41,830 scientific publications were picked. A clustering procedure was then performed based on shared references between articles – i.e. bibliographical coupling (Kessler, 1963). For each research front a matrix is constructed which consists of a set of publications (connected to researchers). We receive a "similarity matrix" – a necessary input for cluster analysis. For the clustering we have used the MAM-method, a program that uses a clustering algorithm, which also suggests the optimal number of clusters (Zhang et al., 2010). Each front is a sub-set of publications on the basis of reference-similarity profiles and was mapped as a cluster or technological community. The idea is that researchers and engineers (connected to universities, institutes and companies) that use similar references establish communities with a common terminology and problem-solving issues, similar to those who Dosi labeled "technological paradigms" (Dosi, 1982).

Specifically, out of 168 clusters based on 41,830 articles, 46 clusters (and roughly 10,000 publications) were chosen as relevant. Three parameters were used in this selection process; a) the 20 most frequent noun phrases of each cluster indicating one or more of typical biorefinery activities (biomaterials, biochemicals, biofuels); b) expert advice on cluster description; c) most cited publications in a dozen "borderline clusters" with few relevant noun phrases (in short: when very few noun phrases indicated technologies or products based on biomass as a complement, abstracts of the most cited articles indicated whether the research field was to be considered relevant or not).

A challenging step is the integration of mapping and performance. It helps us to position researchers from universities, research organizations and firms on the worldwide map of their field and to seize their influence in relation to impact-levels of the different clusters and research fields/communities. In that way we aim to map applied science, technology development and the agents from R&D and industry in the field. Individuation of researchers, research teams can then be connected country-wise or to corporation's R&D divisions. Here, a more qualitative approach comes at stage in order to identify links, R&D constellations, etc.

Figure 1. The methodological process of the study.



After the second clustering process we ended up with 21 S&T frontiers:

Table 1. Cluster description (label, characteristics, number of publications, prominent organizations and companies).

Cluster	Label	Characteristics	Publication count 2002-2011
1	Pyrolys	The biofuels cluster per excellence. Bio-oil (gasification and pyrolysis technologies dominating). Most frequent universities/research org: China Acad Sci and main Chinese Uni, VTT, Maine Uni, Zaragoza Uni. Companies: Foster Wheeler, Shell, BTG, Fortum	844
2	Biodiesel	Biofuels with emphasis on bioethanol and biodiesel based biomass, in particular microalgae and switchgrass. Most frequent universities/research org: US Doe, Beijing Chem. Uni, many US uni,, Comp: DuPont, Shell and small US firms	283
3	Nanowhisker	Nanocomposites, nanocellulose, nanocrystals, advanced bioplastics Org: USDA Ars, Giorgia Tech, Univ Saskatchewan, Wuhan Uni, Luleå Uni, Pais Vasco Uni, Helsinki Uni, VTT, Åbo Akademi, Innventia/STFI, BIM Kemi, Mitsubishi, BASF Inc,	203
4	Nanofiber	Nanocellulose, nanowhisker Org: Cornell, Penn State, USDA, Tianjin Uni, Donghua Uni	105
5	MFC	Microfibrillar cellulose, nanocellulose Org: Kyoto/Tokyo Uni; Innventia/STFI, USDA; Georgia Tech, KCL, Åbo, Donghua,	253
6	Biochemicals	Biorefinery products (compounds/platform chemicals) based on biomass among others: stover, algae, cellulose pulp. Lignin, saccharification, hemicellulose derivatives, xylanase, cellulase, enzymatic treatment, arabinoxylan Organisations: Wisconsin, Maine Uni, vTi, Vigo/Huelva Uni, Lappeenranta, Georgia Tech, Beijing Forest Uni, Exxon, Chevron, UPM, Ciba, Biopulping, Mead Westvaco, Lenzing.	923
7	Fractionation	Separation/fractionation of product streams in pulp mills: lignin, (dissolving) pulp, delignification, kraft. lignin-carbohydrate, black liquor, xylan Org: British Columbia Uni, Royal Inst. Tech (KTH), Georgia Tech, Domtar, Södra, MeadWestVaco.	370
8	Lyocell	Advanced wood based cellulose textiles substituting cotton and oil polyesters. Org: Lenzing AG; Innsbruck Uni, Vienna Uni	107
9	Pulping	New applications for cellulose pulp and optimization of by-products. Company-intensive cluster. Org: Paprican/FPI, Georgia Tech, Tianjin Uni,Helsinki Uni, Stora Enso, International Paper, Tembec, Bowater, Metso, Andritz, Noss, Eka (traditional p&p research organizations/firms). Exceptions: Mitsubishi, Specialty Minerals	584
10	Wood composites/ morphology	Focus on mostly woody compounds (e.g. fiber strength) of softwoods and some lignins (phenols/resins). Org: Kyoto Uni, Georgia Tech, BC Uni, Helsinki Uni, VTT, FPI, Beijing Uni, Canfor	218
11	Hydrogels	Advanced biomaterials; Chitosan-based hydrogels and films. State financed cluster. Org: Mostly Chinese Uni and R&D inst, Montreal Uni,Birmingham Uni, Unilever, Birla	841
12	Ionic liquids	Ionic liquids, levulinic acid Org: Beijing Uni. Chem Tech, Colorado Uni, DuPont	301
13	Jet fuel	USA-dominated cluster. Org: Ford Motor, National Institute of Standards & Technology, US DOE	74
14	Biogas	Anaerobic digester; sludge; biogas; methane Org: State-dominated, many US and Spanish R&D org; Dublin/Cork Uni, Lund Uni, Beijing Uni Chem Tech, NRC, Corp: Domtar Veolia, GIRO, Birla	265
15	CMC	Carboxymethyl cellulose, e.g. additive for food and medicine app's. Org: Nanyang Tech Uni, Karlstad Uni, Jena Uni, Sao Paolo Uni, Astra Zeneca, Pfizer, Danone, Unilever	190
16	PLA	PLA, bioplastic. foam, starch filmOrg: Chinese & US Uni's, Sao Paolo Uni, INRA, VTT Firmenich, Birla	538
17	Cellulose film	Bioplast from MFC, nano, pulp,ionic liquid,chitosan Royal Inst Tech, Innventia, Georgia, Kyoto, Donghua, Åbo/VTT, Corp: Kemira, BIM, SCA, Domsjö/Processum, Lenzing, Biorefinery GmbH, BASF, KFA, KAO, small US firms	681
18	Wood extracts	Wood by-products (e.g. lignan, flavonoid, bark). Org: Åbo Akademi, SLU, Maine Univ. Max Planck,FPI, Lenzing, Afocel, Meadwestvaco, Suzano, Andritz, Forintek, M-real,	334
19	bioplast (lipase)	Sugars, films based on algae and fast growing biomass feedstock. Org: Kyoto, Polytech NY, Innventia	197
20	SCWO	Supercritical water oxidation, supercritical water gasification. Org: Japanese, German & US Universities,	266
21	Biomethanol	Methanol, DME, biodiesel, research org mainly from Spain, China, USA. Org: Pais Vasco Uni, Utah Uni, National Petrochem Corp, Korea Research Institute of Chemical Technology	137

Analysis from scientometrics

The analysis has, hitherto, been performed based on four types of data processing in order to answer our research question: 1) cluster dynamics (growth/decline, etc from 2002–2011); 2) country specialization; 3) mapping of authors, research organizations, constellations in clusters; 4) company involvement in the largest clusters plus a short sector analysis for largest clusters. Later on, a fifth analysis will be performed; i.e. matching publication constellations (S&T communities) with patents and demonstration plants with technologies/products close to commercialization.

Firstly, which clusters are growing and which countries are positioned in the fast growing ones? We analyzed publications per year, and cluster and their progressions (table 2). Five clusters had a strong progression the last couple of years – hydrogels, cellulose film (nanoplastics), biochemical, biodiesel and pyrolysis clusters took off around 2005, more or less when "biorefinery" was becoming a recurrent term in research programs. More forest industry related clusters are somewhat slow growing – with the exception of the biochemicals and fractionation clusters. This is probably due to the older research and technology community and non-expansive public and industrial (private) R&D funding.

Table 2. S&T clusters in biorefinery activities: number of published papers per year

AREA-CLUSTER#	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Growth RANK	DELTA 2005-2011
Hydrogels chitosan-11	57	53	70	80	151	148	191	220	284	529	1	60,2
Biochemicals-6	99	88	91	84	85	143	184	321	373	374	2	58,0
Cellulose film-17	45	45	38	75	86	91	129	150	165	470	3	50,1
Biodiesel-2	1	2	0	1	4	8	27	133	171	237	4	41,7
Pyrolys-1	43	68	60	70	128	118	216	227	301	125	5	22,1
PLA-16	35	49	70	54	89	98	144	163	176	153	6	19,1
Biogas-14	5	20	10	16	26	51	73	78	119	94	7	16,0
Biomethanol-21	5	2	6	8	2	9	27	21	24	111	8	13,0
Ionic liquid-12	2	8	25	32	29	61	113	93	88	69	9	9,3
Nanowhisker-3	6	12	10	14	25	73	52	86	150	5	10	8,4
MFC-5	35	40	35	44	62	42	55	57	75	101	11	7,6
Nanofiber-4	0	2	7	1	11	32	31	41	88	16	12	7,4
Wood composite-10	25	14	42	29	30	32	35	52	86	43	13	6,2
Jet fuel-13	0	0	3	5	3	8	11	19	26	15	14	3,1
Fractionation-7	75	53	37	63	71	73	91	100	67	84	15	2,9
Lyocell-8	8	3	16	17	24	17	32	57	29	19	16	2,0
SCWO-20	46	44	45	36	49	48	38	51	43	44	17	0,5
Bioplast (lipase)-19	7	21	11	8	13	12	16	12	16	3	18	-0,3
Pulping (TMP)-9	104	87	103	126	114	90	89	127	152	72	19	-1,8
CMC-15	34	38	21	44	51	39	28	34	45	23	20	-2,9
Wood extracts-18	66	87	58	91	80	42	70	70	85	31	21	-5,1

Secondly, what about country specialization? In order to perform such an analysis countries with less than 70 publications were excluded and considered obsolete. The mapping procedure resulted in 21 clusters based on 7,853 articles. These clusters were analyzed country-wise, mainly the largest forest industry based nations plus emerging countries, according to their relative comparative advantages (RCA) per research front/cluster see table 3 below (Balassa, 1965). RCA shows the relative specialization of each country over clusters. For this analysis the 18 countries with the highest number of publications were selected. Therefore, the analysis using RCA is based on 6,167 articles. Traditional forest rich countries (largest exporters, production volumes or industry's share of GDP) such as USA, Canada, Sweden, Germany and Finland are frontrunners in some of the clusters. USA is at the first position by article production rate (#1228, 20% of publications in relation to considered 18 countries). China is at second place and probably first within a few years (#1121). Japan is third (#530), followed by Canada (#433), then France (#312) and Spain (not renowned for possessing a strong biomass/forest export sector) on a surprising sixth place (#298). Germany (#293), Sweden (#283) and Finland (#257) were not far behind.[i]

Depending on our theoretical hypothesis we have grouped countries in three structures: old countries, new world countries (BRIC and Tiger Economies). In between, we propose that there are the new European biomass countries. Traditional forest industry nations (called "old forest nations", see table 3), such as Sweden, Finland, Germany, Japan, Canada, USA are present in many clusters, but often in slow-growing clusters.. In the old world large incumbents demonstrate strong interaction with the S&T communities which may confirm the trend that they are related to established clusters where many firms are involved in research publication. Small firms, in many cases spin-offs from Universities, are also particularly present in USA.

Traditional forest industry nations are particularly prominent in clusters where wood compounds (cellulose, lignin, hemicellulose) or separation technologies are the main focus (e.g."fractionation", "wood extracts", "wood composite", i.e. cluster 7, 10, 18). To some extent this is also the case of Brazil we placed in the "new World section" in table 3 – a forest rich nation that has had a strong industrial development since the 1980s. The old forest nations are positioned in many slow-growing clusters which were established early around 2002–2003 (cluster 34, 18, 77) and in few occasions in fast-growing clusters ("cellulose film"). Old forest nations such as Canada, USA and Japanhave slightly better positions than Scandinavia in "hot" clusters, but lag behind "New European Biomass" (Spain, Portugal, etc) and "New World" (Asia and Brazil).

US organizations are a prominent players in many areas, but not unexpectedly they often demonstrate a stronger specialization in different forms of bioenergy/fuels (policy and energy security reasons), while Asia, i.e. China, Taiwan, South Korea, India are strong in fast growing clusters – e.g. in particular hydrogels chitosan based, PLA films and more than average in most biofuels clusters (not in US dominated jet fuel). Fast growing clusters may be labeled as per se a function of China's fast publication growth.

Table 3. Revealed Comparative Advantage, RCA (Balassa, 1965) per country and research cluster (1,0 = expected value). Rank follows figures in brackets, higher number means high publication production in areas with low growth, i.e. added five areas' placement with strongest specialization, in red) Instead, low figures (in bold) indicate activity in growing (hot) areas. RCA=the share of country y in cluster x in relation to the total of cluster x divided by country y's total publication production in relation to the grand total of publications (#7583). Growth trend in each cluster is due to the regression coefficient and demonstrate long term trend over ten years, see rank column

Region	New World					New European Biomass					Old Forest Nations										
CLUSTER																			Expect	1stTerm	RANK
11	1,7	2,3	2,9	4,5	1,2	0,6	0,7	0,7	1,0	0,6	0,5	0,4	0,1	0,8	0,1	0,4	0,0	0,2	1	hydrogels chitosan	1
6	1,5	0,9	0,3	0,8	1,3	1,1	1,0	0,4	1,8	1,6	0,6	1,0	1,0	0,8	0,8	1,1	0,7	0,7	1	biochemicals	2
17	0,7	1,3	1,0	0,4	0,7	1,5	1,4	0,2	0,9	0,6	0,7	0,7	1,3	1,2	1,4	0,8	0,9	1,3	1	cellulose film	3
2	0,9	0,8	0,4	1,3	1,9	0,7	0,4	0,8	2,3	0,5	1,9	0,4	0,5	0,5	0,4	1,9	0,1	1,0	1	biodiesel	4
1	0,9	1,3	0,6	0,4	0,1	0,3	0,2	5,3	1,4	1,6	0,9	0,8	0,5	0,9	0,4	0,9	0,3	0,3	1	pyrolys	5
16	1,7	1,2	1,4	0,8	3,2	1,8	0,5	0,3	1,2	0,6	1,2	0,7	0,5	0,5	0,6	1,0	0,6	0,6	1	PLA	6
14	2,6	1,6	0,8	2,8	0,8	1,1	0,4	1,3	0,6	3,4	0,6	1,4	0,1	0,2	0,6	0,2	0,0	0,7	1	biogas	7
12	0,9	1,3	0,5	0,8	0,6	0,4	2,0	0,1	1,0	1,8	0,1	0,4	0,2	0,4	0,0	1,8	0,1	1,6	1	ionic liquid	8
3	0,5	0,3	0,0	0,0	1,3	3,3	0,2	0,0	1,3	0,6	0,0	1,3	1,3	2,0	1,8	1,1	0,3	0,4	1	nanowhisker	9
21	0,7	1,2	2,4	0,5	0,0	0,6	0,0	1,0	0,3	3,8	0,2	1,2	0,2	0,7	0,0	1,2	0,5	0,9	1	biomethanol	10
4	1,5	1,1	5,2	1,4	0,4	0,0	0,9	0,0	0,0	0,3	1,8	0,3	0,2	1,7	0,7	1,3	0,0	1,3	1	nanofiber	11
5	0,1	0,5	0,9	0,0	0,3	1,8	0,4	0,4	1,3	0,4	0,3	0,4	0,9	2,4	2,4	1,0	1,7	2,0	1	MFC	12
10	0,7	0,3	0,2	0,7	0,1	2,4	0,5	1,7	0,2	0,0	1,7	2,6	1,9	1,3	1,1	0,5	1,2	2,8	1	wood composit	13
7	1,1	0,3	0,4	0,2	1,2	1,1	3,0	0,3	0,2	0,8	0,1	0,8	2,2	0,9	3,6	1,1	1,1	0,7	1	fractionation	14
8	0,9	0,5	0,2	0,0	0,1	0,7	0,0	0,0	1,5	0,1	1,4	0,1	0,5	0,3	0,1	0,5	29,6	1,8	1	lyocell	15
13	0,0	0,4	0,6	0,0	0,0	0,0	0,6	0,0	0,9	0,0	0,0	0,2	0,0	0,0	0,0	4,1	0,8	0,5	1	jet fuel	16
9	0,1	0,4	0,3	0,1	0,6	0,7	2,7	0,2	0,3	0,8	1,9	3,6	3,1	0,4	1,3	1,0	0,4	0,5	1	pulping (TMP)	17
20	0,2	0,5	2,0	0,3	0,0	0,5	0,0	0,5	0,8	0,8	1,0	0,2	0,1	3,5	0,1	1,6	0,0	1,8	1	SCWO	18
19	1,3	0,3	0,7	0,9	0,0	0,8	0,0	0,0	0,0	0,0	0,0	0,4	0,4	4,2	1,8	1,5	0,0	0,8	1	bioplast (lipase)	19
15	1,2	0,6	0,3	0,0	2,4	0,7	0,3	0,4	0,8	0,8	3,7	0,3	0,2	1,4	2,7	0,2	1,1	5,4	1	CMC	20
18	0,7	0,3	0,9	1,3	1,9	0,8	1,6	0,8	0,4	0,4	3,1	1,3	2,8	0,5	2,1	0,9	2,7	1,3	1	wood extracts	21
EXPECT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		
Five Rank	####	####	46	44	#####	####	63	39	####	####	73	67	####	####	86	65	81	####	Rank Max = 95; Rank Min = 15		
Avg Rank	40					43					74								Avg Rank All = 56		

China and USA, the two giants, are similar in total publication volume, but specialization is rarely in the same S&T clusters – only in the "ionic liquid" cluster. Specialization occurs in different clusters due to different policy prioritizing and sector/company involvement.

For analytical purposes we rank the clusters according to the progression for each cluster, i.e. the growth of publications over time. From that follows our ranking of clusters which is presented in Table 3 (see last column to the right). The sum of ranking number for the five clusters where each country has its relatively highest activity will give the "five rank" number (see row at bottom of Table 3). Accordingly, if a country (or region) has a lower five rank figure, then activities are more concentrated toward fast growing areas and vice versa. China (PRC) has the lowest figure of all countries and the group of new world countries has a markedly higher rank number. New European biomass countries seem to be at the same level as the new world.

Since we have identified company presence in most publication clusters we combined product and company search in the patent analysis. Industry involvement in both bibliometrics and patents is clear in – Austria's remarkable specialization in lyocell research (table 3 with score 29,6) – Lenzing, an Austrian company, has strong positions in the lyocell technology (wood based textiles), cluster (8) which reveals a strong correlation between publication counts, patents and specialization.

In our patent analysis we will focus on the largest publication clusters where the presence of Western and in particular Japanese corporations is prominent. Clusters with high company involvement in the publication analysis tend to be prominent also in the patent analysis i.e. these will be analyzed by using basically identical key words as in the bibliometric analysis. . Our subsequent study will analyze which companies that have accomplished patents with the most prominent researchers, i.e.to consider "linear" or circular innovation processes. In completely new clusters (i.e. advanced nanomaterials, bioplastics) on a first glance they tend to have similar characteristics as R&D biomedicine (patents/innovations connected to high-performing universities (this hypothesis will hopefully be discussed thoroughly in Berlin next fall).

Contributions and further research

This paper is guided by the theory on technological paradigms and sciento-technical communities (Kuhn, 1962; Dosi 1982; Thagaard, 1986). On the basis of this theory we formulated a hypothesis predicting that traditional biomass rich countries, in particular forest industry ones, will face a lock-in effect of concentration for research to traditional industries. Our results, so far, indicate that traditional European forest industry nations like Sweden, Finland, Austria, and Germany – that to a considerable extent have been the frontrunners of forest industry technologies during several decades both with regards to R&D, patents and machine supply (Laestadius 1998) – are risking lock-in effects. However, the analysis is two folded. Countries from New World and New European Biomass demonstrate a more conclusive national strategy within biorefinery research. They have fewer lock-in effects due to lower involvement from national industry. These countries have in common an absence from "national industry" which in turn could be understood as a lack of institutionalization of the research establishment.

However, the inclination for partnering with industry (and national champions) of S&T clusters in traditional forest industry nations is not necessarily a lock-in, but could be a "positive" incremental path dependency characterized by a "Dosian" technological community (engineers from university, research institutes and industry) and with greater impact on the economy than the more homogenous, fast growing science communities in the New World. It may be argued that the greater involvement of S&T communities with incumbents in traditional sectors in the Old World, such as the forest or chemical industry, have a larger economic impact since they are already rooted in the Old World where industry have a relatively larger share of GDP/employment/exports/patents, etc. For future research longer time spans than a decade may enable for higher validity for research on S&T frontier formations and trajectories.

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