

Deliverable report

D5.2 Market development potential of most promising lignin valorisation chains

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Working Group 5

Introduction

Working group 5 intended to support the most promising lignin valorization chains via a multi-criteria evaluation of sustainability aspects. One of the main criteria was the process profitability so as to achieve maximal use of lignin's market potential and support its market deployment. During LignoCOST, the non-technical deployment barriers were identified and strategies in order to overcome them were assessed. Techno-economic, environmental and social aspects were evaluated to justify the utilization of renewable resources for the production of bio-based products, as well as biorefinery development was applied for the improvement of the process efficiency and sustainability. Economic sustainability indicators were estimated to help convincing relevant stakeholders to focus on lignin valorization schemes. The potential development of large-scale production units, the evaluation of the time required to achieve technological maturity, market stability and expansion were also considered so as to compare the current status with the future potential and quantify the current gap for certain processes to reach the market performance. Finally, the policy and legislation amendments were assessed to facilitate industrial implementation of novel lignin valorization technologies.

Deliverable 5.2 focuses on the assessment of the prospective global lignin market and provide up-to-date information on lignin market share based on products, applications and major companies in the relevant fields. Promising lignin derived products, including adhesives, bitumen, vanillin and epoxy resins, are discussed in this deliverable.

Lignin market

Lignin occurs naturally in lignocellulosic plants and accounts for about 300 billion t worldwide. Of this immense amount, about 100 million t per year are technical lignins, mainly produced from the pulp and paper industry (Dessbesell et al., 2020). However, only about 2% is produced as lignin product. The global lignin market is predicted to grow at a rate of 4.6% from \$1.1 billion in 2022 to \$1.8 billion in 2032 (Fact.MR, 2022b). The development of bitumen, biorefinery catalysts and biofuels contributes to the expected market growth. Furthermore, the high demand for concrete mixtures, adhesives and binders in the construction industry is expected to increase the market potential of lignin (Fortune Business Insights, 2022).

Lignin prices depend on lignin purity and the origin of the lignin, e.g., prices for low purity lignin range from \$0.1 to \$0.3 per kg, while prices for high purity laboratory scale lignin can range from \$400.1 to \$896.0 per kg. Differences on the prices are related to the purity and possible applications, as high purity lignin can be used as standards for laboratory analysis, while low purity lignin is suitable for low-cost industrial applications (Nadányi et al., 2022). Europe holds a share of 40.7% on global lignin market (Fact.MR, 2022b). Figure 1 presents possible applications and indicative market price ranges of various types of lignin.

The market is segmented based on the product resulting from lignin (e.g., lignosulfonates, Kraft lignin, organosolv etc.) while based on applications, the market is categorized into macromolecules and aromatics, among others. North and Latin America, Europe, Asia Pacific, Middle East and Africa are the main regions involved in these markets (Fortune Business Insights, 2022).

Lignosulfonates

Lignosulfonates hold the main share (69.6%) of global lignin sales (Maximize Market Research, 2023). The global lignosulfonates market size was estimated at \$659.9 million in 2022 and is expected to reach \$886.4

million by 2030, at a compound annual growth rate (CAGR) of 3.8% during the forecast period. The U.S. lignosulfonates market is estimated to reach \$178.7 million by 2022. China, the world’s second-largest economy, is predicted to reach a market size of \$180.3 million by 2030, growing at a CAGR of 6% from 2022 to 2030. Other significant markets are Japan and Canada, with a CAGR of 2.2% and 3.2%, respectively, during the period 2022-2030 while Europe and Germany are expected to increase at a CAGR of around 2.7% (Research and Markets, 2023). In the United States of America (USA), the Kraft and lignosulfonates manufacturing costs are estimated between \$870 and \$1170 per t with minimum selling prices varying from \$1240 and \$1560 per t (Abbati et al., 2018). The demand for lignosulfonates in the USA accounts for 85.8% of the market in 2022 and it is expected to expand at a CAGR of 1.9% over the forecast period (Grand View Research, 2023).

Lignosulfonates have superior quality and cost-effectiveness in industrial applications (e.g., pulp & paper, oil exploration, and building). The main applications of lignosulfonates are vanillin, additives, and dispersants (Dessbesell et al., 2020). The increasing demand for lignosulfonates in the construction and oil drilling industries, as well as the growing demand for animal feed and agrochemicals, are key drivers of market growth to improve efficiency and the reduction of pollution (Maximize Market Research, 2023; Verified Market Research, 2021).

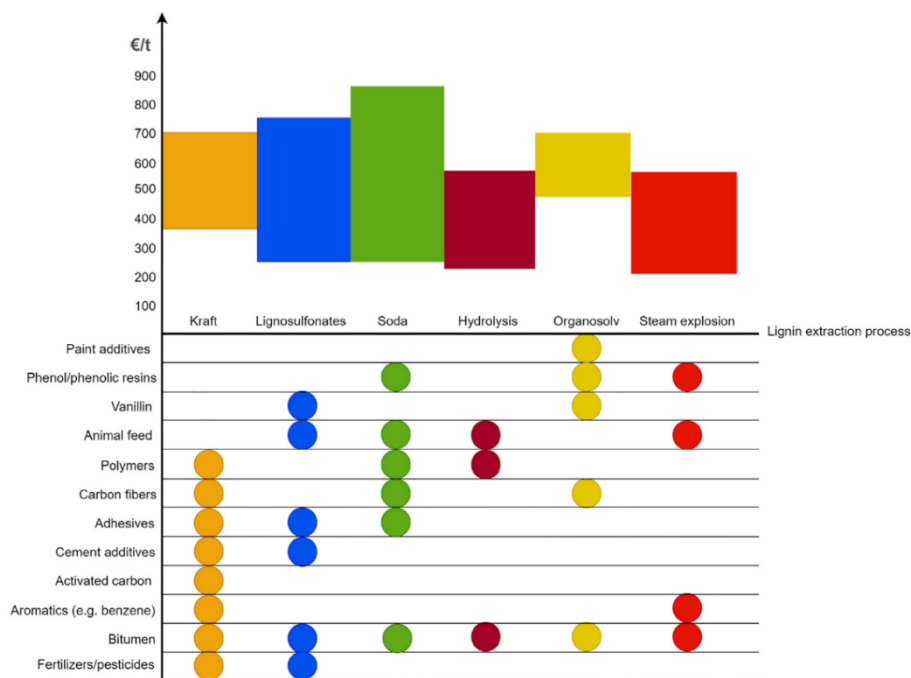


Figure 1: Possible applications and indicative market price ranges of various types of lignin (Moretti et al., 2021)

Kraft Lignin

According to Dessbesel et al. (2020), almost 90% of the pulp production comes from the Kraft process. North America and Europe are leading initiatives to process Kraft lignin at the laboratory, pilot and commercial scales. Nevertheless, there is a gap between Kraft lignin producers and buyers, which slows the market penetration of lignin. New lignin applications should be evaluated to meet market specifications and be suitable for end users.

In 2022, the Kraft lignin market was estimated at \$574.33 million and it is expected to grow to \$924.32 million by 2028 with a CAGR of 8.25% (Market Watch, 2023a). The main factors that affect the growth of

the Kraft lignin market are the increasing demand for animal feed, the consumption of paper, the world population and global warming. Some other key factors that the Kraft lignin market is dependent on are the high demand for lignin in construction due to its properties (high reactivity, water binding) that make it suitable as concrete additive (Data Intelo, 2022). The increasing demand for Kraft lignin product consumption is contributing to the increasing market of Kraft lignin. For example, industries have been shown a great interest in biobased products in order to reduce the usage of fossil sources resulting as a key driver in market growth of Kraft lignin products (Mordor Intelligence, 2023b). The Kraft market analysis is divided by application, geography and market. Fertilizers and pesticides are the dominant in the kraft market share (Industry ARC, 2023).

North America (Canada, USA) is the largest producer of Kraft lignin derived products with a share of 35%. Specifically, 1.06 million metric t per year Kraft lignin surplus from 23 pulp mills are produced and they can be used for the production of value-added products. The key leaders for Kraft lignin products are Stora Enso, WestRock company (Ingevity), Domtar Corporation, West Fraser and RISE (Data Intelo, 2022; 15).

Organosolv lignin

The worldwide market for organosolv lignin is estimated to reach \$18 million by 2030 due to their widespread application as inks, paints and varnishes (Global Market Insights, 2022). The demand for organosolv lignin is expected to increase with the production of carbon fiber, activated carbon, vanillin, phenol derivatives and phenolic resins. North America has dominated the market for organosolv lignin due to the high demand for renewable and sustainable products. Also, the European market is also expected to grow due to the strict environmental regulations (Reports and Data, 2020).

The key players in the organosolv lignin market are Nippon Paper Industries, Northway Lignin Chemical, Domtar Corporation, The Dallas Group of America, Tembec, Borregaard, Liquid Lignin Company, Asian Lignin Manufacturing, Aditya Birla Group, WestRock (Ingevity), Green Value and Metsa Group (Market Watch, 2023b).

Global lignin derived product market

Adhesives market

Adhesives are crucial auxiliary materials. They are widely employed in renewable energy, building, manufacturing, transportation, packaging and other industries. The global market demand for adhesives reached \$60 billion in 2021 and it is anticipated to grow at a CAGR of 5% between 2022 and 2032, reaching a value of \$102.6 billion (Figure 2). The adoption of high-performance adhesives in automotive applications for the interior and exterior, as well as in the construction sector, boosts the market growth of adhesives (Fact.MR, 2022a).

Some factors that are important for lignin adhesives production are the geographic region and the ability of that region to utilize the resources. Both Asia-Pacific and Latin America have large areas of green fields that can be used for this purpose. In addition, countries in the Asia-Pacific region such as China and India have made the Asia-Pacific region an important producer of lignin for adhesives. The main adhesives providers are 3M, Arkema S.A., Henkel Corporation, Ashland Inc., BASF SE, Evonik Industries, H.B. Fuller Company, PPG Industries, RPM International Inc., Sika AG and Wacker Chemie AG (Market Watch, 2023b).

The lignin-based adhesives could evolve into a large global market. There are various companies (e.g. Nippon Paper Industries Co., Ltd) that have invested in research and development of lignin-based adhesives to provide sustainable and competitive products (Market Watch, 2023b). There are various types of lignin-based adhesives, which can be divided into two groups: lignin-based formaldehyde resins and lignin-based

formaldehyde-free resins. The former group includes the most widely used types of adhesives: lignin–phenol–formaldehyde, lignin–urea–formaldehyde, and lignin–melamine–formaldehyde resins (Market Watch, 2023b).

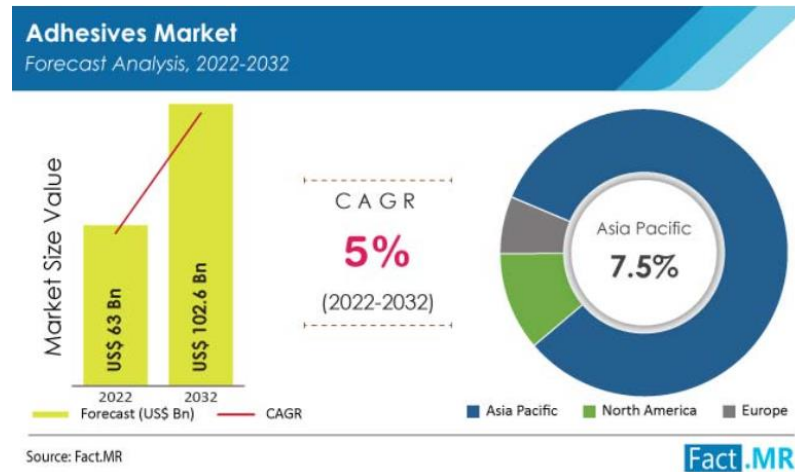


Figure 2: Adhesives market forecast analysis 2022-2032 (Fact.MR, 2022a).

Because of its chemical structure, lignin is considered to be an attractive biopolymer that can be directly incorporated into polyurethane (PU) formulations or into phenol-formaldehyde (PF) resins. The global market size of both PU and phenolic resins is growing over the forecast period 2023 and 2032. The PU resin market is expected to reach around \$1.1 billion by 2032, whereas the phenolic resin market is projected to reach \$12.8 billion by 2031. It is important to emphasize that the larger revenue share of the global phenolic resin market in 2021 was the adhesives and binders segment. In conjunction with what was stated above, increasing research and development of eco-friendly and sustainable raw materials is expected to boost market growth over the forecast period (Devashree et al., 2022).

Bitumen market

The global bitumen market share size was estimated at \$100 billion in 2021 and it is expected to reach \$135.1 billion by 2030 at a CAGR of 3.49%. The bitumen market, based on the product, is segmented into the pavement, oxidized, cutback, emulsion and polymers among others. The paving segment holds the largest share of the market with 21.6% with a market revenue of 21.6 million in 2021. Based on the application, the markets are roadways, waterproofing, adhesives, insulation and others where the roadways hold the leading position with 29.3% of the market share (Spherical Insights, 2022).

North America is the dominant producer in the global bitumen market with a market share of 32.9% with a revenue of 32.9 million in 2021 due to the high demand of bitumen for repair and rebuild roads. However, the Asia Pacific market is anticipated to increase at the fastest CAGR within the period 2021-2030 (Devashree et al., 2022). Moreover, the global bio-based asphalt market is estimated at \$105 million in 2021 and it is estimated to reach \$153.37 million by 2030 with a CAGR of 4.3%. Based on the products, the market is categorized into paving bitumen, oxidized, cutback, bitumen emulsion and polymer-modified bitumen, where the paving bitumen has the main share in the market, and it has contributed to the raise of infrastructure development. However, based on the application, the road construction is predicted to dominate the market (Straits Research, 2021). The key leaders in bioasphalt market are H4A, Avello, Stora Enso, Avantium, Peab Asphalt, Roelofs, Beijing Jiage Weige and Habei Longhai Bionergy (Spherical Insights, 2022).

Lignin is used in bio-asphalts. In particular, 5% of the weight of asphalt is bitumen, one of the most environmentally damaging component of asphalt formulations, and lignin can replace up to 25% of this bitumen (Tokede et al., 2020). Although the market price is low, lignin has a great potential market as bitumen. The production of lignin as an additive in bitumen asphalt was 5 kt in 2015 that could be increased to 10,000 kt considering 30% of the demand (Dessbesell et al., 2020).

Epoxy resins market

Currently, the dominant markets for bio-based epoxy resins are in North America and Europe, and this is not expected to change since epoxy resins derived from fossil fuels have been banned in Canada and France for food packaging. In addition, the rapid growth of the consumer electronics industry is expected to further increase the demand for bio-based epoxy resins in the relevant regions. Asia Pacific is an emerging market due to the increase in electronics and communication devices.

The global bio-based epoxy resin market was valued at over \$4.8 billion in 2020 and it is estimated to expand at a CAGR of 5.5% from 2021 to 2031. By the end of 2031, the global bio-based epoxy resin market is expected to reach a value of \$8.6 billion. Bio-based epoxy resins have lower tensile strength and malleability than their fossil fuel-derived counterparts, a major factor counteracting their growth. For this reason, the use of these products may not find greater acceptance worldwide. However, the mechanical properties can be improved and new properties, such as UV blocking and antioxidants, are induced when lignin or its fractions (phenolic monomers/oligomers) are utilized for the production of lignin-epoxy polymers or composites (Pappa et al., 2022; Pappa et al., 2023). With regard to lipid-derived epoxy resins, the soybean oil-based segment was the predominant global bio-based epoxy resin market in 2020. This may be attributed to the lower production in contrast to other epoxy resins and their utilization in adhesives, composites, laminates, and various other applications. Some of the major providers are Kukdo Chemical, Supreme, Silicones, Entropy Resins and Cardolite Corporation Pvt. Ltd (Transparency Market Research, 2022).

In 2021, the global epoxy resins market was estimated at \$12.5 billion, while it is expected to grow to a value of around \$23.4 billion by 2030. The CARG of epoxy resins is expected to increase to 7.22% during the forecast period from 2022 to 2030 (Figure 3).

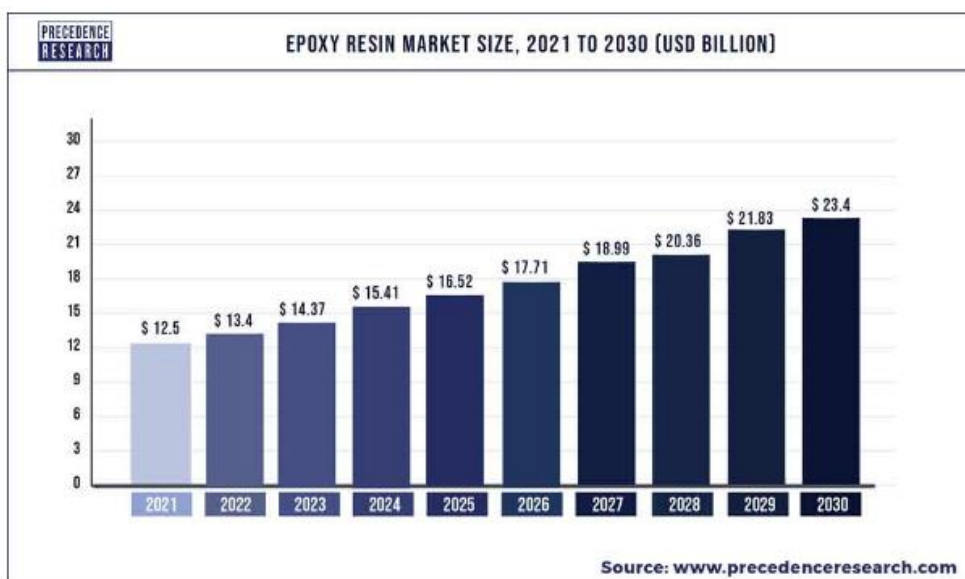


Figure 3: Global epoxy resin market size, 2021 to 2030 (\$ billion) (Precedence Research, 2022).

Increasing demands from the electric vehicle (EV), marine and aerospace sectors, as well as the increasing production of lightweight and commercial vehicles, are driving the growth of the epoxy resin market

(Transparency Market Research, 2022). Regarding the final application, the epoxy resins market is segmented into different applications with paints and coating being the predominant as presented in Figure 4.

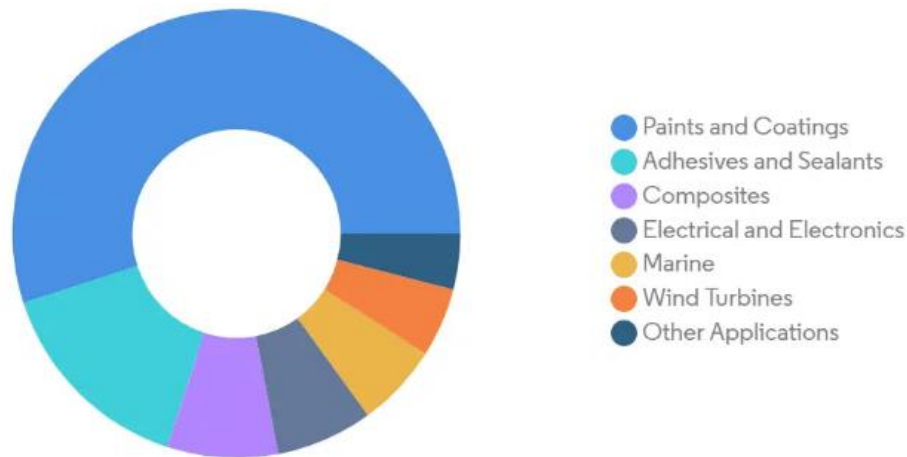


Figure 4: Global epoxy resins market, volume (%) by application in 2021 (Mordor Intelligence, 2023a).

Based on the final use of the epoxy resin, the GAGR was evaluated for specific regions. More specifically, the application in the paints and coatings segment reached a revenue share of 41% in 2021, while the construction segment will grow at a remarkable CAGR from 2022 to 2030. Moreover, the adhesives and sealants epoxy resin segment is growing at a CAGR of 8.35% from 2022 to 2030. Based on physical form, the solid segment is growing at a CAGR of 7.47% over the forecast period, while the novolac segment is expected to exhibit a remarkable CAGR of 7.83%. By end-use applications, the aerospace segment is growing at a CAGR of 8.51% in 2021. Key leaders of the epoxy resins market are Atul Ltd, BASF SE, Dow Inc, Hexion, Olin Corporation, Huntsman International LLC, Dupont and Kukdo Chemical Co. LTd, Nan Ya Plastics Corporation and Solvay SA (Transparency Market Research, 2022).

Considering the region, the Asia Pacific dominated the epoxy resin market based on volume and value in 2020 and it is expected to maintain its dominance during the forecast period. The growth in Asia is based on rapid industrialization and increasing demand from end-use industries such as automotive, construction, consumer goods, marine and aerospace. Asia Pacific is the leading producer of epoxy resins, owing to the increase in alliances between leading companies that are contributing to the discovery of new commercial products in this market (Mordor Intelligence, 2023a).

Certainly, COVID-19 pandemic led to a ban on imports and exports, which disrupted the supply chain and hindered the growth of the epoxy resin market. As a result, a gap was created between supply and demand. The fluctuating prices of epoxy resin during COVID-19 was a major obstacle to market growth. All industries were closed, which negatively affected the demand for epoxy resin in 2020 due to the lockdown (Mordor Intelligence, 2023a).

Vanillin Market

Ten thousand tons of vanillin is produced annually. It is mainly used as fragrance and flavoring agent in the food and cosmetics industries and as a starting material for pharmaceuticals. Natural vanillin cannot meet the increasing demand created by its wide range of applications. In addition, the product obtained from the fermented capsule fruits of vanilla costs about €1100 per kg. Therefore, the market is using chemically produced vanillin. In a multi-step process, benzene is converted into guaiacol, which is then reacted with glyoxylic acid to produce vanillin. Despite the many reaction steps, chemically produced vanillin is

significantly cheaper at around €10 per kg. However, this process consumes fossil resources and also produces toxic byproducts and waste. Therefore, the use of synthetically produced vanillin in the food and pharmaceutical industries is restricted by various food safety organizations worldwide. These drawbacks can be circumvented by producing vanillin from the wood component lignin, a byproduct of the pulp industry. This method is used in a new electrochemical approach to producing vanillin, the quality of which is comparable to "natural vanillin" due to the reagent-free conversion (Breiner et al., 2021).

The global bio-vanillin market is expected to reach \$454.08 million in 2023, while it is estimated to reach \$901.62 million by 2033, at a CAGR of 7.1%. In 2019, the bio-vanillin market revenue is estimated to reach \$333 million. The key bio-vanillin market leaders are Evolva Holding SA, Borregaard and Solvay SA, which afford resources to develop new bio-vanillin production methods and increase their production capacity. Rice bran and wood are the two main sources of vanillin. Depending on the final application, the global bio-vanillin market is separated into different segments such as the food and beverage, cosmetics, personal care and pharmaceuticals industries (Persistence Market Research, 2023).

Key leaders of Lignin market

There are several companies active in lignin and its derivatives. The leading company is Borregaard LignoTech, based in Norway, which operates in the field of biorefineries, producing biochemicals and biomaterials to replace petrochemical products. The company is divided into four business units, one of which, Borregaard LignoTech, is responsible for lignin-based products and trading activities (Trading Economics, 2023). Specifically, Borregaard LignoTech is active in the production of technical lignin and lignosulfonates, while production has expanded to include binding and dispersing agents, crystal growth modifiers, emulsion stabilizers and complexing agents.

Stora Enso is a key leader in the technical and commercial developments to find uses for renewable, low-carbon lignin. Lignode and Lineo are two of the main products manufactured by Stora Enso. Lignode is lignin refined into a fine carbon powder that serves as the active material for the lithium battery's negative anode. Lineo is used in a variety of applications, ranging from replacing phenol in resins for plywood, to developing bio-based and biodegradable polymers. It is even used to partly replace the crude oil-based binder in asphalt. In 2015, Stora Enso invested in an industrial-scale LignoBoostR Kraft lignin production plant in Finland with a line capacity of 50,000 t per year of extracted lignin making Stora Enso the largest producer in the world. Also invested €10 million in 2019 to build a pilot facility for producing lignin-based carbon materials. Domtar in the USA is second, with 25,000 t of lignin per year (Valmet, 2021).

Domsjö Fabriker AB is another biorefinery-based company in which lignin is one of the main products along with cellulose and bioethanol. It is also considered one of the key companies for lignosulfonates along with Borregaard LignoTech and Green Agrochem. Ingevity Corporation is a company that produces chemicals derived from lignin resulting from the Kraft pulping process. Ingevity Corporation has a Gross Profit of \$137.8 million in 2022 while its revenues have increased from \$1,391.5 million in 2019 to \$1,292.9 million in 2021 (Mordor Intelligence report, 2023b).

Other lignin market companies are Domtar Corporation, Liquid Lignin Company (LLC), Changzhou Shanfeng Chemical Industry Co., Aditya Birla Group, Shenyang Xingzhenghe Chemical Co., SAPPI Liquid Lignin Company LLC, Nippon Paper Industries Co. and others (Fact.MR). Figure 5 presents the main producers depending on the lignin type.

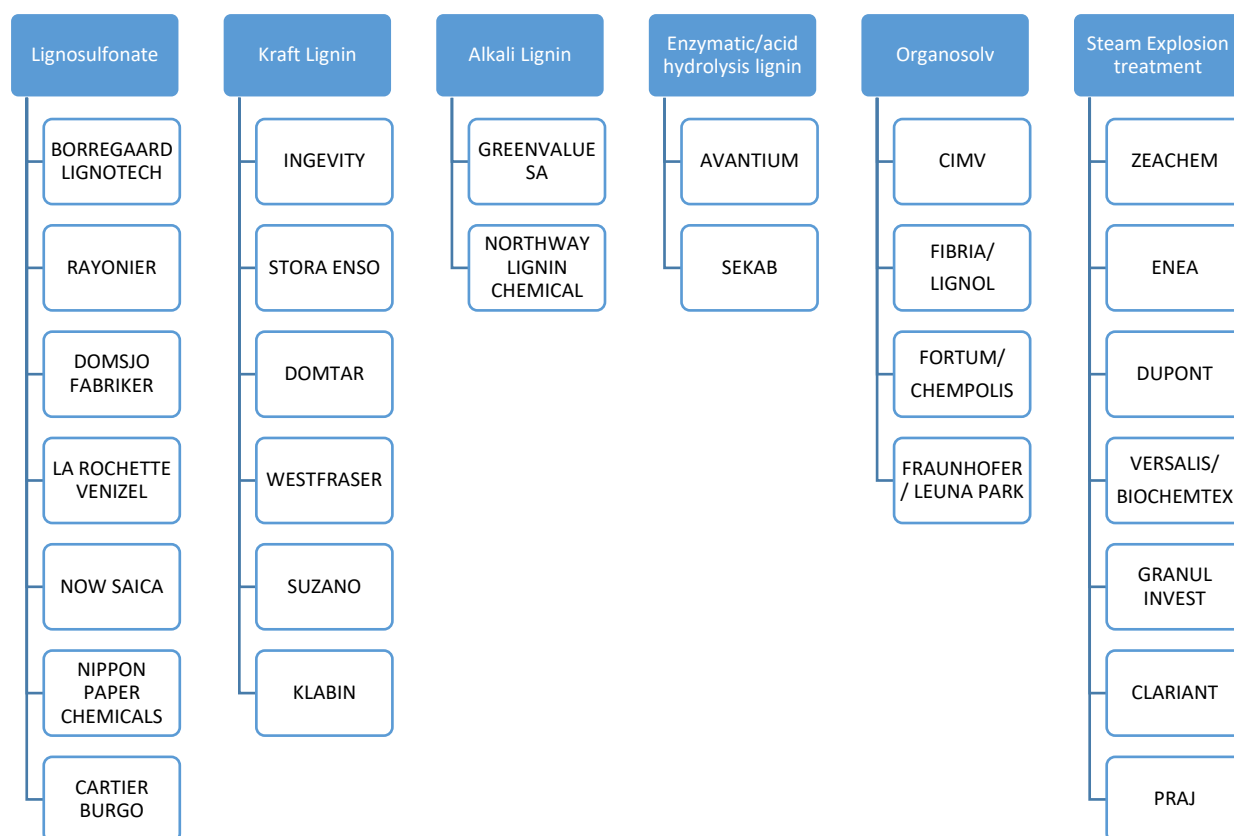


Figure 5: Lignin market companies, categorized based on the lignin production process.

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