Biononava submission

Building bio-based value chains

Circa Group AS

Changing chemistry for good™

Contents

Summary

The Hurdal Platform has set an ambitious agenda for the sustainable development of Norway's economy, establishing the basis for an active industry policy to generate new jobs and increased exports, with a focus on industrial sectors grounded in energy, fish and forestry. This reflects a Norwegian economy that is facing transition – global decarbonisation targets are driving a reduction in demand for oil and gas. Norway Towards 2025 states that the oil industry could lose 4,000 to 6,000 jobs annually between 2025 and 2050[1]. Acceleration of new sustainable industry sectors is required if Norway is to transition from a fossil-based economy, meet its carbon reduction targets, create jobs and reduce its non-petroleum trade deficit, which was NOK 316 bn for the year 2020 (Statistisk sentralbyrå[2]).

Norway has set a goal to reduce carbon emissions 55% by 2030 compared to 1990 levels. In 2017, 8.5 per cent of Norway's GHG emissions came from agriculture, corresponding to 4.5 million tonnes of CO_2[3]. Agriculture waste biomass currently contributes significantly to sector emissions, yet if properly managed, and with the appropriate bio-based value chain developments, it could become a resource that supports decarbonisation targets. The EU estimates that a shift to biological raw materials and biological processing methods could avoid up to 2.5 billion tons of CO_2 equivalent per year by 2030[4].

The bioeconomy provides the means for Norway to capture the full benefit of its natural resources. It also offers a transition to a low carbon economy that delivers new employment and non-fossil export opportunities through the active development of new value chains that valorise currently available raw materials and innovate bio-based products for downstream processing. The forestry sector can play a major role in this transition, and already contributes to the Norwegian economy while enabling carbon reduction. The Norwegian Forest holds around 395 million metric tonnes of carbon and this amount is increasing by around 8 million metric tonnes per year[5]. A typical sitka spruce tree absorbs different amounts of CO_2 over its lifetime, and absorption is maximised by felling and replanting after 70 to 110 years depending on the soil[6]. To maximise the benefit, new forest products and bio-based materials can be developed by sustainable value chains that leverage forestry biomass.

Bionova has primarily been established to provide a funding mechanism for climate action in agriculture. It will also contribute to innovation and value creation in the bioeconomy related to agriculture, forestry and aquaculture, which opens the potential for Bionova strategies and investments to positively affect jobs and the balance of trade. High value products derived from domestically generated biomass waste streams, protected by IP, and that require complex production processes can provide a sustainable contribution towards Norway's non-petroleum employment and exports. Bio-based chemical production is one such value chain. Replacements and substitutes for traditional fossil-based chemicals are in growing demand[7], and commercially available Norwegian cellulose feedstock provides an abundant and sustainable alternative to petroleum feedstock.

Bionova has the stated objective to increase value creation and jobs related to the use of biomass in Norway and it will contribute to the forest industry increasing the processing of biomass in Norway. To inform how it can best achieve these aims Bionova is now seeking input to three questions, including stakeholder views on the **challenges it could address that are not solved by current measures**, which forms the focus of this submission.

1 https://www.regjeringen.no/en/dokumenter/nou-2021-4/id2841052/

2 https://www.ssb.no/en/utenriksokonomi/utenrikshandel/statistikk/utenrikshandel-med-varer

3 https://unfccc.int/documents/215704

4 https://ec.europa.eu/research/bioeconomy/

5 FAO (2014) Global Forest Resources Assessment 2015. Country Report Norway. FAO

6 https://thundersaidenergy.com/2022/01/26/sitka-spruce-top-fact/

7 https://www.mckinsey.com/industries/chemicals/our-insights/the-third-wave-of-biomaterials-when-innovation-meets-demand

A key challenge and fertile opportunity is the **development of new bio-based value chains** that can replace fossil-based industrial processes. Addressing this challenge can realise many of the ambitions laid out in the Hurdal Platform. These value chains need a reliable and sustainable supply of waste biomass, with access to technology, skilled expertise and receptive markets for bio-based products. Norway offers these attributes and with additional support, they could be organised to form new value chains in a medium-term horizon (3-5 years). Taking a systemic value chain approach will foster a new generation of sustainable enterprises, utilising existing Norwegian corporations, and delivering outcomes across carbon reduction, employment and non-fossil export trade. The opportunity is to use key industrial processes which enable secondary and tertiary processing opportunities, i.e., true bioeconomy and biorefinery developments.

Circa Group AS is a Norwegian company, listed on Euronext, with Norske Skog as a cornerstone investor. We are a renewable chemicals company with the scalable technology to produce highly valuable bio-based chemicals from forest waste biomass to replace unsustainable fossil-based chemicals in a wide range of applications. Company information can be found in appendix 1 and our web site[8]. We are pleased to provide a submission that addresses the development of new, high value, biochemical value chains that will valorise forest waste biomass in Norway.

Circa recommends the following measures for Bionova to consider in order to foster this value chain:

- **Technology-push measures** that enable the supply of technology by providing financial support to subsidise the costs of plant development. This should cover activities not currently supported by the Research Council of Norway.
- **Demand-pull measures** that pursue the acceleration of technological change by providing incentives for early adopters. Co-funding the cost of adapting industrial processes could grows the market for bio-based substitutes for petroleum-based products. This support should be coordinated with other funding and regulatory bodies.
- **Capacity building measures** that support new value chain development, building new capability, fostering learning networks that advance adoption, and maturing of bio-based product innovations. This is a core domain for Bionova and should be coordinated with activities and support provided by SIVA (Norsk Katapult), Innovasjon Norges and the Cluster Program.
- **Support for measurement of outcomes** so that impact can be assessed and promoted to other industries / jurisdictions. This should include a customer benefits realisation study and social outcomes measurement so that the resulting impact can be quantified, demonstrating ROI and leading other organisations and jurisdictions to adopt what Norway has modelled.

Building bio-based value chains

Building as complete green value chains as possible, originating in Norwegian sourced raw materials, requires more than just individual projects to be funded – it requires a complete systems approach.

The Circa submission recognises the opportunity to build on major Norwegian strengths in forestry, biomass processing and engineering and develop a world class industry platform valorising the primary resource. While the paper and petroleum industries are undergoing structural change, and in many cases, long term decline, the opportunity to combine historical strengths to deliver new job and growth opportunities is very real. Bionova can selectively fund core investments that can credibly support a downstream value chain of manufacturing, research, and ancillary investments.

France has shown strategic foresight in supporting such an approach. The Pomacle / Bazencourt biorefinery in France is an excellent example of what can be achieved[9]. At Pomacle / Bazencourt, a core

[8] https://circa-group.com/

[9] https://www.univ-reims.fr/aebb-en/an-exceptional-ecosystem/an-exceptional-ecosystem,24872,41111.html

biomass-to-ethanol refinery is "surrounded" on site by both industries for by-products (Air Liquide, Givaudan, ARD) as well as researchers (AgroParisTech, CEBB) creating new products and opportunities. This approach is not unique globally, with the German Spitzencluster[10] adopting a similar model. According to a Dutch study on creating 'negative emissions', 17 to 19% of the technical potential and more than 30% of the realistic practical potential to create negative emissions in the Netherlands by the year 2050 can be allocated towards the biobased economy (green chemical and green concrete innovation)[11].

Lignocellulosic biomass from wood, grasses, crop residues, forestry waste, (and municipal solid waste) are abundant in Norway and have potential for bioconversion into various value-added biological and chemical products. Biotechnological conversion of lignocellulosic biomass into different industrial products is a cost effective and environmentally sustainable route. Examples of these conversion pathways with examples of end products are shown in appendix 2.

Bio-based value chain innovation is increasingly being emphasised in several jurisdictions and Circa sees great potential for a similar model in Norway, where opportunities to attract downstream manufacturing investment are real and already identified. It can be considered a "Borregaard plus" model, with a strategic aim to attract downstream investment in value adding, not simply extraction and sales at secondary manufacturing level.

Expected outcome

The recommendations made in this submission are particularly effective in achieving the following outcomes: reduced carbon emissions, reduced trade deficit, and new employment in sustainable enterprises that leverage the biomass resource of Norwegian forests.

Reduction of carbon emissions

Norway has set a goal to reduce carbon emissions 55% by 2030 compared to 1990 levels. In 2017, 8.5 per cent of Norway's GHG emissions came from agriculture, corresponding to 4.5 million tonnes of CO_2[12]. Waste biomass contributes to sector emissions, but when properly managed, and with the appropriate bio-based value chain developments it is a feedstock resource for industry.

The forest sector can play a major role in this reduction, and its contribution is immediate. According to FAO (2015 data) 33.1% or about 12,112 ,000ha of Norway is forest and of this 1.3% (160,000 ha) is classified as primary forest, the most biodiverse and carbon-dense form of forest. Norway has around 1,529,000 ha of planted forest. The Norwegian Forest holds around 1,069 million m^3 of growing stock; 55% of the biomass consists of stem wood and bark and nearly 20% of branches, leaves and needles; the remaining 25% is biomass in the stump-root system. The annual growing stock volume (million m^3 over bark) is 7.98 million corresponding to about 3.5 million tonnes of carbon[13]. Using the molar weights this annual increase corresponds to around 13 million metric tonnes of CO_2 or around 30% of Norway's 2015 total CO_2 emissions[14].

10 https://www.clusterplattform.de/CLUSTER/Navigation/EN/NationalLevel/SpitzenclusterWettbewerb/spitzencluster-wettbewerb.html

11 Strengers, B., Eerens, H., Smeets, W., van den Born, G. J., & Ros, J. (2018). Negatieve Emissies. Technisch potentieel, realistisch potentieel en kosten voor Nederland. Achtergrondstudie. Planbureau voor de Leefomgeving.

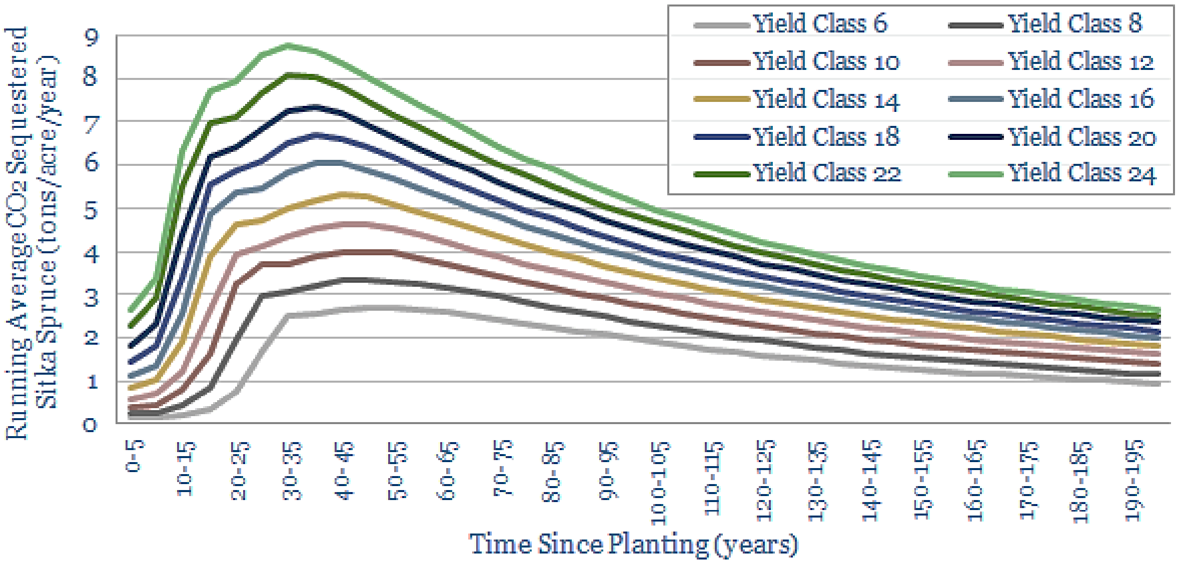
12 https://unfccc.int/documents/215704

13 All data extracted from FAO (2015). Global Forest Resources Assessment 2015. Country Report Norway. FAO

14 https://www.worldometers.info/co2-emissions/norway-co2-emissions/

A tree (exemplified by a sitka spruce) absorbs different amounts of CO_2 over its lifetime as shown in Figure 1. From this figure it is clear that CO_2 absorption is maximised by felling and replanting after 70 to 110 years depending on the soil quality.

Figure 1: CO_2 absorption by age for Sitka Spruce (https://thundersaidenergy.com/2022/01/26/sitka-spruce-top-fact/)



Research and studies[15] show that if forestry is to make the largest possible contribution to reduce CO_2 levels in the atmosphere, the highest possible production of biomass should be the goal. To maximise the benefit, new products and materials based on tree biomass should be developed by an expanded and supplemented forest industry. The flows of biomass-based products and materials should be developed in such a way that product life cycles are extended, and so that reuse and recycling opportunities are increased. The conclusions are that actively managed forests are optimal from a CO_2 absorption perspective given that the harvested cellulose is used in ways that does not release all the CO_2 captured.

The use of wood and wood-based products are associated with lower fossil and process-based emissions when compared to non-wood products[16]. In spite of having a very large potential impact these mitigation effects are much less known and understood by the public[17]. This means that the production system mix and product mix that is applied to wood cellulose matters for the net CO_2 absorption effect. As an example, it has been shown that increasing the use of by-products for textiles and wood–plastic composites in place of kraft pulp and biofuel implies greater overall substitution credits compared to increasing the level of log harvest for construction[18]. For biochemicals based on wood by-products (like

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15 Lundmark, T., Bergh, J., Hofer, P., Lundström, A., Nordin, A., Poudel, B. C., ... & Werner, F. (2014). Potential roles of Swedish forestry in the context of climate change mitigation. Forests, 5(4), 557-578.

Lundmark, T., Poudel, B. C., Stål, G., Nordin, A., & Sonesson, J. (2018). Carbon balance in production forestry in relation to rotation length. Canadian journal of forest research, 48(6), 672-678.

16 Leskinen, P., Cardellini, G., González-García, S., Hurmekoski, E., Sathre, R., Seppälä, J., ... & Verkerk, P. J. (2018). Substitution effects of wood-based products in climate change mitigation. From Science to Policy 7. European Forest Institute. https://doi.org/10.36333/fs07

17 Ranacher, L., Stern, T., & Schwarzbauer, P. (2017). Do wood products protect the climate? Public perception of the forest-based sector's contribution to climate change mitigation. Austrian Journal of Forest Science, 134(3), 281-298.

18 Hurmekoski, E., Myllyviita, T., Seppälä, J., Heinonen, T., Kilpeläinen, A., Pukkala, T., ... & Peltola, H. (2020). Impact of structural changes in wood-using industries on net carbon emissions in Finland. Journal of Industrial Ecology, 24(4), 899-912.

saw dust) this substitution effect can be larger than 45 as compared to the use of cellulose for textiles which is considered to have a very high substitution effect of about 4[19].

It should also be noted that concentrating only on maximising net production of forest biomass may come into conflict with other important goals (biodiversity, hunting, access to berries and mushrooms, recreational forest use, etc.). In practice, the demands of several legitimate stakeholders must be satisfied and balanced against each other.

Reduction in trade deficit

High value products derived from domestically generated biomass waste streams that are protected by IP and that require complex production processes can provide a sustainable contribution towards Norway's non-petroleum export.

Green value chains originating in forestry can be developed in four different domains:

- Those that are developed using a mass lens and that include construction elements and construction materials including cross laminated timber, glued-laminated timber, oriented strand board, veneer-based engineered wood products, wood plastic composites etc. These value chains are in a sense more efficient and technology intensive version of traditional forest industry.
- Those that are developed using an energy lens and that include solid biofuels, made from sawmill side-streams towards simple products, like fuel for combined heat and power, pellets, and charcoal. Liquid biofuels, mainly pyrolysis oil for boilers can also be produced and so can gaseous biofuels, including the conversion of syngas to synthetic natural gas.
- Those that are developed using a molecular lens.
- Those that are developed using an atomic lens which includes novel cellulose-based technical (e.g., textiles, transparent paper, etc) and life-science related products (including chemicals).

There are many different types of value-added products that can be produced through a chemical processing route from biomass as illustrated in Table 1. Out of the 534 products in the NACE division 20 (manufacture of chemicals and chemical products), 110 were in 2018 fully or partly bio-based. Out of the 110 bio-based products, 40 % were fully bio-based (e.g. tanning extracts of vegetable origin, sorbitol, tall oil), 24 % products had a bio-based share of at least 10 % (e.g. ethylene glycol, carboxylic acid, adipic acid) and 36 % were products of lower bio-based shares (e.g. acetic acid, methanol, epoxy resins)[20].

Table 1: Examples of biomass originated value added products[21]

Starting material	Product categories	Examples of value-added products
Biomass	Monosaccharides	Glucose, Xylose, Fructose, Mannose, Galactose, Arabinose, Rhamnose
	Oligosaccharides	Fructo-oligo, Galacto-oligo, Isomalto-oligo, Lactosucrose, Xylo-oligo, Manno-oligo
	Biofuels	Bioethanol, Bio-butanol
	Bioactive Compounds	Phenolic acids, Flavonoids, Terpenoids, Carotenoids

19 Kunttu, J. (2020). Wood utilization scenarios and their sustainability impacts in Finland. PhD Dissertation, School of Forest Sciences, The Faculty of Science and Forestry, University of Eastern Finland.

20 Porc, O., Hark, N., Carus, M., Dammer, L., BIC, D. C., & Knapsack, C. (2020). European Bioeconomy in Figures. nova-Institute for Ecology and Innovation.

21 Cho, E. J., Trinh, L. T. P., Song, Y., Lee, Y. G., & Bae, H. J. (2020). Bioconversion of biomass waste into high value chemicals. Bioresource technology, 298, 122386.

	Nanocellulose	Cellulose nanofibers, Cellulose nanocrystals, Bacterial nanocellulose
	Lignin-by-products	Binders, Dispersants, Carbon fibres, Activated carbon, Benzene, Toluene, Xylene

The opportunities are considerable for biochemical manufacture. Markets for Circa's primary products are in excess of 1,000,000 tonnes per year, with a CAGR of 3-4%. These markets cover a wide range of uses – from paints and coatings through to solvents for oil and gas production, pharmaceutical manufacture, membrane manufacture and agrichemicals. Further downstream processing of Circa's products into new polymers and advanced materials is underway by industry and academia. The size of the market – and feedstock requirements along with Industry supply chain demands – require the development of multiple, linked "bio-factories" as supply sources. With the growing demand from industry for closer geolocated supply, the Circa strategy is focussed on building a strong European manufacturing base, close to available bio feedstocks, engineering expertise and supporting research. These attributes are available within the Norwegian economy.

Employment

To simultaneously fulfil the competitive requirement of increased productivity and the political requirement of increased employment a firm needs to increase its global market share faster than it increases its productivity despite it having to operate on the productivity frontier. To examine the value of employment opportunities in the bioeconomy warrants an examination of labour productivity across its sectors. Number of persons employed, value added, and apparent labour productivity by sector of the European bioeconomy is shown in
Table **2**.

Table 2: The European Bioeconomy Sector[22]

Sub-sector	**Number of persons employed**	**Value added (€ million)**	**Labour productivity (€ 1000 / person employed)**
Agriculture	9,273,470	188,519	20
Forestry	517,480	25,301	49
Fishing	166,610	6698	40
Manufacture of food, beverages, and tobacco	4,398,761	215,311	49
Manufacture of bio-based textiles	692,906	21,103	30
Manufacture of wood products and furniture	1,424,540	47,268	33
Manufacture of paper	590,456	41,702	71
Manufacture of bio-based chemicals, plastics pharmaceuticals, rubber (excluding biofuels)	396,712	60,312	152
Manufacture of liquid biofuels	20,506	3216	157
Production of bioelectricity	22,550	4208	187
Total European Bioeconomy	17,503,992	613,637	35

There is no comparable data available for Norway, but it is worth noting that the bioeconomy labour productivity in Sweden, Finland and Denmark is twice as high as the average in the European Union. The increase in the Finnish economy has been very high and has been driven by productivity leaps in

[22] Ronzon, T., Piotrowski, S., Tamosiunas, S., Dammer, L., Carus, M., & M'barek, R. (2020). Developments of economic growth and employment in bioeconomy sectors across the EU. Sustainability, 12(11), 4507.

the manufacturing of bio-based chemicals, pharmaceuticals and plastics, forestry, and the manufacture of paper[23].

The forest-based industry is a perfect illustration of the circular bioeconomy. Side streams such as wood chips, sawdust, and bark from sawmills are used in the pulp & paper industry, in the production of wood-based panels, as inputs for biochemical production, and for energy. Paper as well as solid wood products (and some biochemicals) are recovered after having been used, either being recycled or serving as raw materials in production or for energy generation.

Construction[24] and biochemicals and biofuels[25] are amongst the most promising emerging wood-based product markets[26]. Employment opportunities are a function of market size, market growth and productivity growth.
Table **3** shows the estimated European market size for some biochemicals.

Table 3: Estimates of total EU production and the bio-based share of production[27]

Product category	**EU Biobased production (kt/a)**	**Total EU production (kt/a)**	**EU bio-based production share (%)**	**EU bio-based consumption (kt/a)**	**Estimated global annual market growth in biobased category**	**Average annual Labour productivity improvement 2011-2021[28]**
Platform chemicals	181	60,791	0.3	197	9%[29]	
Solvents	75	5,000	1.5	107	6.6%[30]	
Polymers for plastics	268	60,000	0.4	247	8%[31]	

23 Ronzon, T., Piotrowski, S., Tamosiunas, S., Dammer, L., Carus, M., & M'barek, R. (2020). Developments of economic growth and employment in bioeconomy sectors across the EU. Sustainability, 12(11), 4507.

24 Antikainen, R., Dalhammar, C., Hildén, M., Judl, J., Jääskeläinen, T., Kautto, P., ... & Thidell, Å. (2017). Renewal of forest based manufacturing towards a sustainable circular bioeconomy. Reports of the Finnish Environment Institute 13|2017.

Hildebrandt, J., Hagemann, N., & Thrän, D. (2017). The contribution of wood-based construction materials for leveraging a low carbon building sector in Europe. Sustainable cities and society, 34, 405-418.

Toppinen, A., Röhr, A., Pätäri, S., Lähtinen, K., & Toivonen, R. (2018). The future of wooden multistory construction in the forest bioeconomy–a Delphi study from Finland and Sweden. Journal of Forest Economics, 31, 3-10.

25 Nattrass, L., Biggs, C., Bauen, A., Parisi, C., Rodríguez-Cerezo, E., & Gómez-Barbero, M. (2016). The EU bio-based industry: results from a survey. Institute for Prospective and Technological Studies, Joint Research Centre, European Commission.

Baker, P., Chartier, O., Haffner, R., Heidecke, L., van Hussen, K., Oberč, B. P., ... & Walker, M. (2017). Research and Innovation perspective of the mid-and long-term Potential for Advanced Biofuels in Europe. European Commission, Directorate-General for Research and Innovation.

26 Jonsson, R., Rinaldi, F., Pilli, R., Fiorese, G., Hurmekoski, E., Cazzaniga, N., ... & Camia, A. (2021). Boosting the EU forest-based bioeconomy: Market, climate, and employment impacts. Technological Forecasting and Social Change, 163, 120478.

27 Spekreijse, J., Lammens, T., Parisi, C., Ronzon, T., Vis, M. (2019). Insights into the European market of bio-based chemicals. Analysis based on ten key product categories. EUR 29581 EN. Publications Office of the European Union

28 UK data sourced from https://www.ons.gov.uk/economy/economicoutputandproductivity/productivitymeasures/datasets/labourproductivitybyindustrydivision

29 https://www.mordorintelligence.com/industry-reports/bio-based-platform-chemicals-market#:~:text=The%20market%20for%20bio%2Dbased,on%20conventional%20petroleum%2Dbased%20products.

30 https://www.marketsandmarkets.com/Market-Reports/solvent-market-1325.html?gclid=CjwKCAjwuYWSBhByEiwAKd_n_hLRDiFp-Xt_2PGRVe_PQRVUFulzSWhsqbd90pMYLtAWe2UsRfXXCRoC9moQAvD_BwE

31 https://www.bioplasticsmagazine.com/en/news/meldungen/20210201-Growth-rate-for-bio-based-polymers-far-above-overall-polymer-market-growth.php#:~:text=In%202020%2C%20the%20total%20production,expected%20to%20continue%20until%202025.

Product category	EU Biobased production (kt/a)	Total EU production (kt/a)	EU bio-based production share (%)	EU bio-based consumption (kt/a)	Estimated global annual market growth in biobased category	Average annual Labour productivity improvement 2011-2021[28]
Paints, coatings, inks and dyes (estimated numbers)	1,002	10,340	12.5	1,293	4%[32]	
Surfactants	1,500	3,000	50	1,800	3.5%[33]	
Cosmetics and personal care products (estimated numbers)	558	1,263	44	558	4.9%[34]	
Adhesives (estimated numbers)	237	2,680	9.0	320	11.3%[35]	
Lubricants (estimated numbers)	237	6,764	3.5	220	4.8%[36]	
Plasticisers (estimated numbers)	67	1,300	9.0	117	3.5%[37]	
Man-made fibers	600	4,500	13	630	12.5%[38]	
Total	4,725	155,639	3.0	5,489	9%	Manufacture of chemicals and chemical products: 8.9%. Manufacture of pharmaceutical products and pharmaceutical preparations:10.8%

Looking at
Table **3** we can conclude that labour productivity improvements are on average lower than forecasted market growth leading to an increase in employment in the bioeconomy. This conclusion is underpinned by a US study that show one new job created in the bioeconomy for every $235,000 contribution to GDP. In the biochemicals sector this figure is one new job generated for $218 thousand in business

32 https://www.mordorintelligence.com/industry-reports/dyes-and-pigments-market

33 https://www.globenewswire.com/news-release/2022/02/08/2381124/0/en/Global-Surfactants-Market-and-Specialty-Surfactants-Market-Size-Share-Value-2022-Analysis-By-Latest-Industry-Developments-New-Investment-Scenario-Business-Challenges-Major-Key-Insi.html

34 https://www.blueweaveconsulting.com/report/bio-based-cosmetics-and-personal-care-ingredients-market

35 https://www.globenewswire.com/news-release/2022/01/07/2363023/0/en/Bio-Adhesives-Market-to-Hit-16-07-Billion-by-2028-Bio-Adhesives-Industry-CAGR-of-11-3-between-2021-2028-Exclusive-Insight-Report-by-Vantage-Market-Research.html

36 https://www.fortunebusinessinsights.com/bio-lubricants-market-104654#:~:text=The%20global%20bio%20lubricants%20market,are%20used%20to%20formulate%20them.

37 https://www.expertmarketresearch.com/reports/plasticisers-market

38 Estimated based on several different market research reports covering different subdomains

turnover[39] and in a European study the equivalent is one new job generated for a turnover of €200,000 in the biochemical sector[40].

Achieving this economic growth will require aligned activities between the public and the private sector. Appendix 4 outlines the tools available to implement industry policy, and they will need to be applied across four domains: firstly, increased availability and reduced cost of capital for scale-up and capital investment; secondly, regulation and procurement that drives demand and accelerates the scale-up process for new products; thirdly an effective cluster and location policy that ensures the benefit of agglomeration economics and economic geography (this can be assessed using economic complexity analysis); and fourthly, capability development. This latter challenge is well illustrated by the Swedish chemical industry needing to recruit up to 8000 postgraduates until 2030 while the Swedish education system only educates a total of about 2000 postgraduates annually across all subject areas[41]. Norway graduated 1634 doctoral students during 2020 across all subjects[42].

Recommendations for Bionova

Bionova has been established to ensure increased value creation and jobs related to the use of biomass in Norway and it will contribute to the forest industry increasing the processing of biomass in Norway. Both the challenge and opportunity are considerable, presenting the potential to drive the transition to a low carbon economy and deliver socio-economic and environmental co-benefits. However, to meet 2030 carbon targets, the Government cannot rely on either untested technologies or companies. There is not enough time for another technology cycle to unfold in the time frame up until 2030 (see appendix 3).

For innovative SMEs building businesses with this technology, the cost of capital is normally very high since their financing conditions differ from the financing of large, established corporations. As opposed to large corporations, with SMEs capital structure has an influence on the financing costs and in an early phase of an SME's lifecycle, the average cost of capital rises when equity capital is substituted by debt[43].

Government funding is critical in domains where novelty and risk limit access to funding from the market or when the combined socio-economic and environmental returns have a very large share of social returns or when the market is immature or non-existent and the market must be created through a combination of public procurement and funding of production facilities. Since these activities frequently involve SMEs who are also both capital poor and with limiting borrowing or equity raising capacity the provision of capital is of importance.

It has also been observed that early adopter customers of novel technologies require a collaborative innovation environment to realise the full potential of its products and apply them in industrial processes, with the support of specialised research bodies and industry experts. For Circa there is a known and readily available Norwegian value chain to engage with – from project finance to forest owners, logistics, offtake customers – with EU demand for the balance of output.

In addition to the above capital and capability issues, Circa understands that customers cannot readily quantify the value the transition to safer and sustainable chemicals can create, such as reduced EHS risk and growth into new markets with sustainable products.

[39] Rogers, J. N., Stokes, B., Dunn, J., Cai, H., Wu, M., Haq, Z., & Baumes, H. (2017). An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy. Biofuels, Bioproducts and Biorefining, 11(1), 110-128.

[40] Porc, O., Hark, N., Carus, M., Dammer, L., BIC, D. C., & Knapsack, C. (2020). European Bioeconomy in Figures. nova-Institute for Ecology and Innovation.

[41] IKEM. (2022). Fler forskarutbildade önskas. https://www.ikem.se/globalassets/huvudsajt/dokumentfiler/fragor-vi-driver/kompetensforsorjning-dokument/kompetensforsorjning_kortrapport_slutversion.pdf

[42] https://www.statista.com/statistics/1123758/number-of-doctorate-graduates-in-norway-by-gender/#:~:text=In%202020%2C%201%2C634%20doctorate%20students%20(PhD's)%20graduated%20in%20Norway.

[43] Koch, L. T., Kuhn, W., Gruenhagen, M., & Hisrich, R. D. (2010). The 'irrelevance of irrelevance'in entrepreneurial finance: modeling the cost of capital in start-ups beyond Modigliani–Miller. Strategic Change, 19(1-2), 29-43.

Circa recommends the following measures for Bionova to consider in order to foster this value chain:

- **Technology-push measures** that enable the supply of technology by providing financial support to subsidise the costs of plant development. This should cover activities not currently supported by the Research Council of Norway.
- **Demand-pull measures** that pursue the acceleration of technological change by providing incentives for early adopters. Co-funding the cost of adapting industrial processes could grows the market for bio-based substitutes for petroleum-based products. This support should be coordinated with other funding and regulatory bodies.
- **Capacity building measures** that support new value chain development, building new capability, fostering learning networks that advance adoption, and maturing of bio-based product innovations. This is a core domain for Bionova and should be coordinated with activities and support provided by SIVA (Norsk Katapult), Innovasjon Norges and the Cluster Program.
- **Support for measurement of outcomes** so that impact can be assessed and promoted to other industries / jurisdictions. This should include a customer benefits realisation study and social outcomes measurement so that the resulting impact can be quantified, demonstrating ROI and leading other organisations and jurisdictions to adopt what Norway has modelled.

Appendix 1: Circa Group AS – company overview

Founded in 2006, Circa is a renewable chemicals company with the scalable technology to produce unique and highly valuable bio-based chemicals. Our Furacell™ production process takes forest waste biomass and produces levoglucosenone (LGO), char, and water. The proprietary technology was developed in 2009 and fine-tuned over ten years across five pilot plants. In the last three years, over 1,000 trials have been distributed globally to universities and industry.

Circa has won the support of the French Government, the EU Horizon 2020 research and innovation programme and the Bio-based Industries Consortium to fund the design, commissioning and operation of the EUR 50 million ReSolute plant. We lead the ReSolute consortium, which brings together 11 key actors from 6 European countries. Our partners represent the entire value chain, from feedstock to market uptake.

The ReSolute project will result in Circa's first industrial scale plant and confirms a downstream value chain for the adoption of Cyrene™. The plant will scale-up the current Cyrene™ production process to 1,000 metric tons of output per year. This is the first in a series of plants on a roadmap that will see Circa build 80,000 tonnes of capacity by 2030.

Today Circa works with global businesses who are committed to transitioning from fossil-based chemicals, including the solvents used in their industrial processes. The market for these solvents is mostly served by unsustainable and toxic fossil-based solvents. Governments and industries worldwide are seeking substitutes to these chemicals which are harmful to human health and the environment. Cyrene™ is widely acknowledged as one of the very few viable, low-toxicity and sustainable alternatives, with probably the broadest use profile.

Circa Group AS is incorporated in Norway with its head office in Oslo and listed on Euronext Growth with the code CIRCA.

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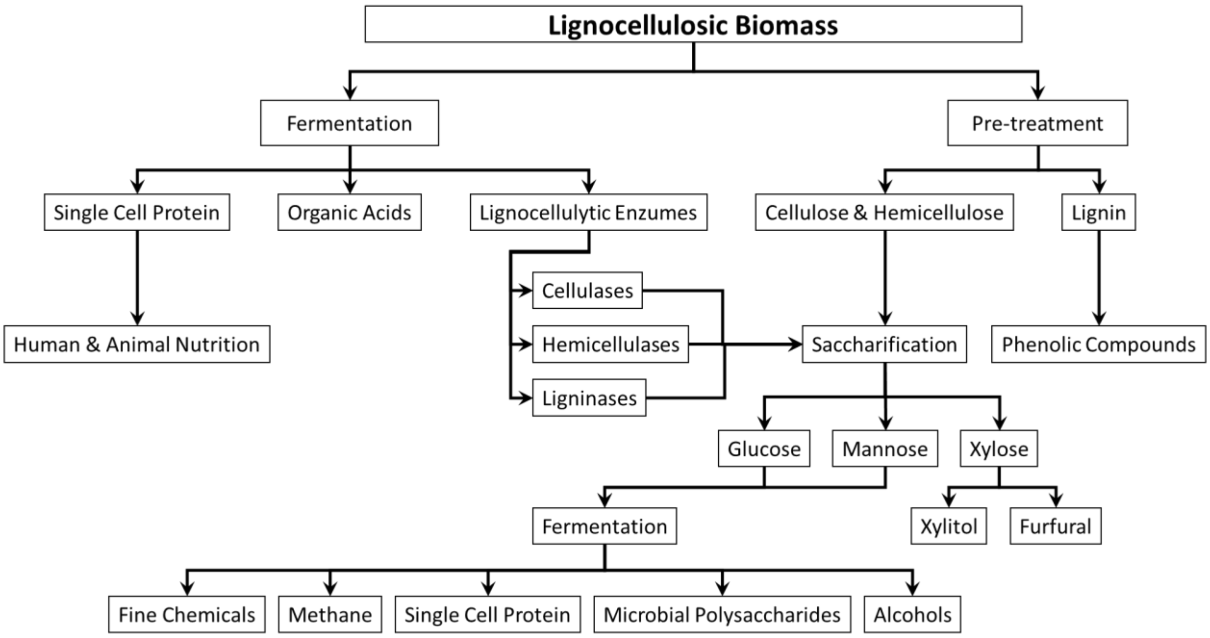
Appendix 2: Lignocellulosic biomass valorisation

Lignocellulosic biomass from wood, grasses, crop residues, forestry waste, (and municipal solid waste) are particularly abundant in nature and have a potential for bioconversion into various value-added biological and chemical products. Biotechnological conversion of lignocellulosic biomass in various industrial products is a cost effective and environmentally sustainable route. Examples of these conversion pathways with examples of end products are shown in
Figure **2**.

Figure 2: Lignocellulosic conversion pathways for high value products[44]



It is important to note that not all these pathways generate end-products that are cost competitive on the world market. For some of these pathways there is also a need to achieve stable qualities at high volumes which may require further development of the production system. Present production technologies used in these pathways are summarised in Table 4 and Table 5.

Table 4: Examples of lignocellulose pre-treatment technologies

Production step	**Technology**	**What it does**
Pre-treatment. Pre-treatment of lignocellulose refers to	Milling	Size reduction, breaks down the structure of lignocellulosic materials, crystallinity decrease of cellulose[45]

[44] Mussatto, S.I. and Teixeira, J.A. (2010) Lignocellulose as Raw Material in Fermentation Processes. In: Mendez-Vilas, A., Ed., Current Research, Technology and Education, Topics in Applied Microbiology and Microbial Biotechnology, Formatex Research Center, Badajoz, 897-907.

Zhao, X., Zhang, L. and Liu, D. (2012) Biomass Recalcitrance Part I: The Chemical Compositions and Physical Structures Affecting the Enzymatic Hydrolysis of Lignocellulose. Biofuels, Bioproducts and Biorefining, 6, 465-482.

[45] da Silva, A. S. A., Inoue, H., Endo, T., Yano, S., & Bon, E. P. (2010). Milling pretreatment of sugarcane bagasse and straw for enzymatic hydrolysis and ethanol fermentation. Bioresource technology, 101(19), 7402-7409.

the destruction of the high crystallinity structure of lignocellulose by certain technical means, which makes it easy to be further degraded and utilized. Pre-treatment can destroy the wrapping of lignin and hemicellulose on cellulose, remove lignin, degrade hemicellulose, change the crystal structure of cellulose, increase the accessible inner surface area and loose degree of cellulose, increase the reaction area between enzyme and substrate, and significantly increase the subsequent enzymatic hydrolysis efficiency and sugar yield.	Pyrolysis	Rapid degradation of cellulose into H_2, CO, and carbon residues at temperatures above 300——C[46]
	Microwave	Structural disruption of lignocellulose, thus increases the enzymatic susceptibility[47]
	Ultrasound	Treats lignocellulosic raw materials through ultrasonic cavitation, which generates stress in the fiber voids and causes microcrystalline dislocations, thereby increasing the specific surface area of the cellulose materials, increasing the amorphous area, and reducing the cellulose crystallinity[48]
	Chemical (acid-alkaline) Normally either strong acid-strong base (dilute sulfuric acid-sodium hydroxide) or weak acid-weak base (formic acid-ammonia)	Acid and alkaline pre-treatment under high temperature disrupts hemicellulose and lignin fraction[49]
	Green solvent (N-Methylmorpholine N-oxide or NMO)	At high concentrations of NMO, not only the hydrogen bonds between the cellulose chains are completely broken, but the van der Waals forces between the cellulose chains are also weakened, and the cellulose crystallinity is significantly reduced. Moreover, NMO can also be recycled through biodegradation, is green and environmentally friendly, and has mild processing conditions and high efficiency.
	Steam explosion or ammonia explosion	Thermochemical process, hemicellulose disruption by the addition of heat in the form of pressurized steam[50] It leads to the destruction of the internal spatial structure of lignocellulose, it is not only reduces the crystallinity of cellulose, but also reduces the enveloping effect of hemicellulose on cellulose.[51]
	CO_2 blasting	Here the degradation of hemicellulose is accomplished by carbonic acid, and there is no by-product that inhibits subsequent fermentation in the treated lignocellulosic raw material.
	Oxidative delignification	Lignin is degraded by the enzyme peroxidase in the presence of H_2O_2[52]

46 Kumar, P., Barrett, D. M., Delwiche, M. J., & Stroeve, P. (2009). Methods for pretreatment of lignocellulosic biomass for efficient hydrolysis and biofuel production. Industrial & engineering chemistry research, 48(8), 3713-3729.

47 Lu, X., Xi, B., Zhang, Y., & Angelidaki, I. (2011). Microwave pretreatment of rape straw for bioethanol production: focus on energy efficiency. Bioresource technology, 102(17), 7937-7940.

48 Zeng, G., He, S., Li, Y., Sun, D., Li, H., Wen, X., & Wang, J. (2021). Pretreatment technology of lignocellulose. In E3S Web of Conferences (Vol. 271). EDP Sciences.

49 Fang, Z. (Ed.). (2013). Pretreatment techniques for biofuels and biorefineries. Springer.

50 Agbor, V. B., Cicek, N., Sparling, R., Berlin, A., & Levin, D. B. (2011). Biomass pretreatment: fundamentals toward application. Biotechnology advances, 29(6), 675-685.

51 Zeng, G., He, S., Li, Y., Sun, D., Li, H., Wen, X., & Wang, J. (2021). Pretreatment technology of lignocellulose. In E3S Web of Conferences (Vol. 271). EDP Sciences.

52 Sun, Y., & Cheng, J. (2002). Hydrolysis of lignocellulosic materials for ethanol production: a review. Bioresource technology, 83(1), 1-11.

	Ozonolysis	Lignin is oxidized[53]
	Organosolv	Reaction with organic solvents, with or without addition of a catalyst. Partial hydrolysis of lignin lignin-carbohydrate complex
	Wet oxidation	Reaction occurs in the presence of oxygen or catalysed air, aimed to disintegrate lignin and hemicellulose linkage[54]
	Ionic liquids	Ionic liquids act at low severity, break down noncovalent interactions in lignocellulosic biomass[55]
	Supercritical fluids	Based on certain fluids, whose temperature and pressure are above critical values under supercritical conditions, easily penetrate into the biomass tissue, increasing the efficiency of cellulose accessibility to cellulase enzymes[56]
	Biological	Biological pretreatment is the modification of the chemical composition and/or structure of lignocellulosic materials by using microorganisms[57] or enzymes[58]
	Plasma	Uses electric energy to form highly active ionized gas to destroy the complex structure of lignocellulose. It can be divided into air (nitrogen), ozone and argon plasma pre-treatment methods[59] This method is simple to operate, green and pollution-free, and can also improve the efficiency of subsequent enzyme treatment.

It is worth noting that no single pre-treatment technology will deliver maximum economic returns in all locations and in addition some of these technologies have low maturity (low Technology Readiness Level). Regional variations in feedstock availability (both in nature and quantity), chemical and equipment costs, and opportunities for inter-industry interaction render the search for such a technology unproductive. Instead, it is critical to simulate the specific pre-treatment processes in the regional context in which they are being considered.

Process simulation identifies the key parameters of a given biomass pre-treatment that have an impact (positive or negative) on the economic feasibility of the process. Such parameters include mass flow balances, composition of each process stream, energy analysis, solvent recovery, by-product isolation and yield, and operation conditions, and these parameters cannot be accurately assessed using laboratory-scale pre-treatment experiments.[60] This is a domain where there is a need for cooperation and the use of public agencies and policies e.g. a collaboration between industry and between DIGICAT

53 García-Cubero, M. T., Coca, M., Bolado, S., & González-Benito, G. (2010). Chemical oxidation with ozone as pre-treatment of lignocellulosic materials for bioethanol production. Chemical Engineering Transactions, 21.

54 Carvalheiro, F., Duarte, L. C., & Gírio, F. M. (2008). Hemicellulose biorefineries: a review on biomass pretreatments. Journal of Scientific and Industrial Research, 67(11), 849-864.

55 Zhuo, K., Du, Q., Bai, G., Wang, C., Chen, Y., & Wang, J. (2015). Hydrolysis of cellulose catalyzed by novel acidic ionic liquids. Carbohydrate polymers, 115, 49-53.

56 Serna, L. D., Alzate, C. O., & Alzate, C. C. (2016). Supercritical fluids as a green technology for the pretreatment of lignocellulosic biomass. Bioresource technology, 199, 113-120.

57 Wan, C., & Li, Y. (2012). Fungal pretreatment of lignocellulosic biomass. Biotechnology advances, 30(6), 1447-1457.

Zhang, Z., Shah, A. M., Mohamed, H., Tsiklauri, N., & Song, Y. (2021). Isolation and Screening of Microorganisms for the Effective Pretreatment of Lignocellulosic Agricultural Wastes. BioMed Research International, 2021.

58 Wang, S., Gao, W., Chen, K., Xiang, Z., Zeng, J., Wang, B., & Xu, J. (2018). Deconstruction of cellulosic fibers to fibrils based on enzymatic pretreatment. Bioresource technology, 267, 426-430.

59 Zeng, G., He, S., Li, Y., Sun, D., Li, H., Wen, X., & Wang, J. (2021). Pre-treatment technology of lignocellulose. In E3S Web of Conferences (Vol. 271). EDP Sciences.

60 González, M., Tejado, Á., Peña, C., & Labidi, J. (2008). Organosolv pulping process simulations. Industrial & engineering chemistry research, 47(6), 1903-1909.

(Norsk Katapult) and any new green value chain oriented katapult (see below). There are also applied research opportunities in finding more new green pre-treatment solvents and expanding large-scale production using these.

During some of the chemical pre-treatment undesirable inhibitory compounds for the fermentation process (furans: furfural and 5-hydroxymethylfurfural; phenolics; weak acids: acetic acid, levulinic acid, formic acid; extractives from the raw materials: acid resins, tannic acids, and terpene acids; iron; chromium; nickel; and copper) may form.[61] This requires an additional production step called detoxification. Some of the technologies used are listed in Table 5.

Table 5: Examples of lignocellulose detoxification technologies

Production step	Technology	What it does
Detoxification.	Evaporation	Simple method of physical detoxification, since the high temperature of hydrolyzate reduces the concentration of inhibitors, volatile compounds, such as acetic acid, furfural, and vanillin[62]
	Membrane extraction	Membranes applied in pre-treatment have surface functional groups attached to their internal pores, which can separate inhibitors[63]
	Ion-exchange resin	Ion-exchange resin helps to remove lignin derivatives and inhibitors, such as acetic and furfural acid. Resins can be regenerated and reused[64]
	Neutralisation	Leads to the removal of phenolics and furfural compounds, due to precipitation at different pH[65]
	Solvent extraction	Removal of inhibitors, such as acetic acid, furfural, vanillin, 4-hydroxybenzoic acid, phenolic, and low molecular weight compounds[66]
	Biological	Use of specific enzymes or microorganisms that act to modify the composition of inhibitory compounds[67]
	Overliming	Use of calcium oxide in the pH raising of hemicellulosic hydrolyzate, followed by reduction, precipitates some toxic components due to the instability of some compounds at pH changes[68]

[61] Palmqvist, E., & Hahn-Hägerdal, B. (2000). Fermentation of lignocellulosic hydrolysates. I: inhibition and detoxification. Bioresource technology, 74(1), 17-24.

Palmqvist, E., & Hahn-Hägerdal, B. (2000). Fermentation of lignocellulosic hydrolysates. II: inhibitors and mechanisms of inhibition. Bioresource technology, 74(1), 25-33.

[62] Anish, R., & Rao, M. (2009). Bioethanol from lignocellulosic biomass part III hydrolysis and fermentation. Handbook of plant-based biofuels, 159-173.

[63] Chandel, A. K., da Silva, S. S., & Singh, O. V. (2011). Detoxification of lignocellulosic hydrolysates for improved bioethanol production. Biofuel production-recent developments and prospects, 10, 225.

[64] Nilvebrant, N. O., Reimann, A., Larsson, S., & Jönsson, L. J. (2001). Detoxification of lignocellulose hydrolysates with ion-exchange resins. Applied biochemistry and biotechnology, 91(1), 35-49.

[65] Canilha, L., Chandel, A. K., Suzane dos Santos Milessi, T., Antunes, F. A. F., Luiz da Costa Freitas, W., das Graças Almeida Felipe, M., & da Silva, S. S. (2012). Bioconversion of sugarcane biomass into ethanol: an overview about composition, pretreatment methods, detoxification of hydrolysates, enzymatic saccharification, and ethanol fermentation. Journal of Biomedicine and Biotechnology, 2012.

[66] Cantarella, M., Cantarella, L., Gallifuoco, A., Spera, A., & Alfani, F. (2004). Comparison of different detoxification methods for steam-exploded poplar wood as a substrate for the bioproduction of ethanol in SHF and SSF. Process Biochemistry, 39(11), 1533-1542.

[67] Anish, R., & Rao, M. (2009). Bioethanol from lignocellulosic biomass part III hydrolysis and fermentation. Handbook of plant-based biofuels, 159-173.

[68] Antunes, F. A. F., Chandel, A. K., Milessi, T. S. S., Santos, J. C., Rosa, C. A., & Da Silva, S. S. (2014). Bioethanol production from sugarcane bagasse by a novel Brazilian pentose fermenting yeast Scheffersomyces shehatae UFMG-HM 52.2: evaluation of fermentation medium. International Journal of Chemical Engineering, 2014.

	Active charcoal	Low cost and efficient detoxification method for the removal of inhibitory compounds. Removes phenolic compounds[69]

After the pre-treatment process and detoxification (when required), microorganisms suitable for each type of carbohydrate conversion into bioproducts can be used to produce specific value-added products. Some of these value-added products have no petrochemical alternative (e.g. Xylitol) whereas others can substitute for petrochemical products in existence. A list of the top value-added chemicals from biomass can be found in the publications:

- Werpy, T., & Petersen, G. (2004). Top value added chemicals from biomass: volume I--results of screening for potential candidates from sugars and synthesis gas (No. DOE/GO-102004-1992). National Renewable Energy Lab., Golden, CO (US).
- Holladay, J. E., White, J. F., Bozell, J. J., & Johnson, D. (2007). Top value-added chemicals from biomass-Volume II—Results of screening for potential candidates from biorefinery lignin (No. PNNL-16983). Pacific Northwest National Lab.(PNNL), Richland, WA (United States).

Potentially promising replacement chemicals should be in demand from a large or growing industry sector, difficult to obtain using fossil-based strategies (i.e., have high production cost), thus favouring replacement. Furthermore, in the context of bio-production, replacement chemicals should be relatively easy to obtain from biomass (i.e., have low production cost).

Replacement chemicals with one or more of the following characteristics are likely to have higher demand: (1) relatively few carbon atoms, oxygen atoms, or few functional groups and (2) contain alkenyl, hydroxyl, phenyl, or carboxyl groups. Chemicals with >18 carbon atoms, >4 oxygen atoms, >4 functional groups, or >2 distinct functional groups are likely to have small demand. Replacement chemicals with one or more of the following characteristics are likely to be expensive to obtain from fossil fuel feedstocks: (1) >6 carbon atoms but without phenyl groups, (2) 4–5 carbon atoms, and (3) carboxyl groups. Replacement chemicals that are suitable for bio-production typically have a large $[24 + 2(H/C) + 32(O/C)]/[60 + 15(H/C) - 30(O/C)]$ ratio , where C, H, and O represent the numbers of carbon, hydrogen, and oxygen atoms, respectively, in the molecular formula.[70]

The substitution of existing, frequently petroleum-based, chemicals with biomass-based chemicals may require modification of the production processes in which these chemicals are used with the associated capital investments and other adaptation costs.

Both Cellulose and lignin-based products could achieve market success if some of the barriers are overcome, the most important ones being:[71]

- Capital and funding for both pilot scale and full-scale plants.
- Availability of biomass in sufficient quantity and quality in environment with competing uses and demand for the raw material.
- The establishment of new green value chains based on interdisciplinary and cross-sectoral communication and cooperation.
- Innovation in this domain requires access to facilities and equipment (infrastructure) with high cost.

69 Mussatto, S. I., & Roberto, I. (2001). Hydrolysate detoxification with activated charcoal for xylitol production by Candida guilliermondii. Biotechnology letters, 23(20), 1681-1684.

70 Wu, W., & Maravelias, C. T. (2019). Identifying the characteristics of promising renewable replacement chemicals. Iscience, 15, 136-146.

71 Graichen, F. H., Grigsby, W. J., Hill, S. J., Raymond, L. G., Sanglard, M., Smith, D. A., ... & Warnes, J. M. (2017). Yes, we can make money out of lignin and other bio-based resources. Industrial crops and products, 106, 74-85.

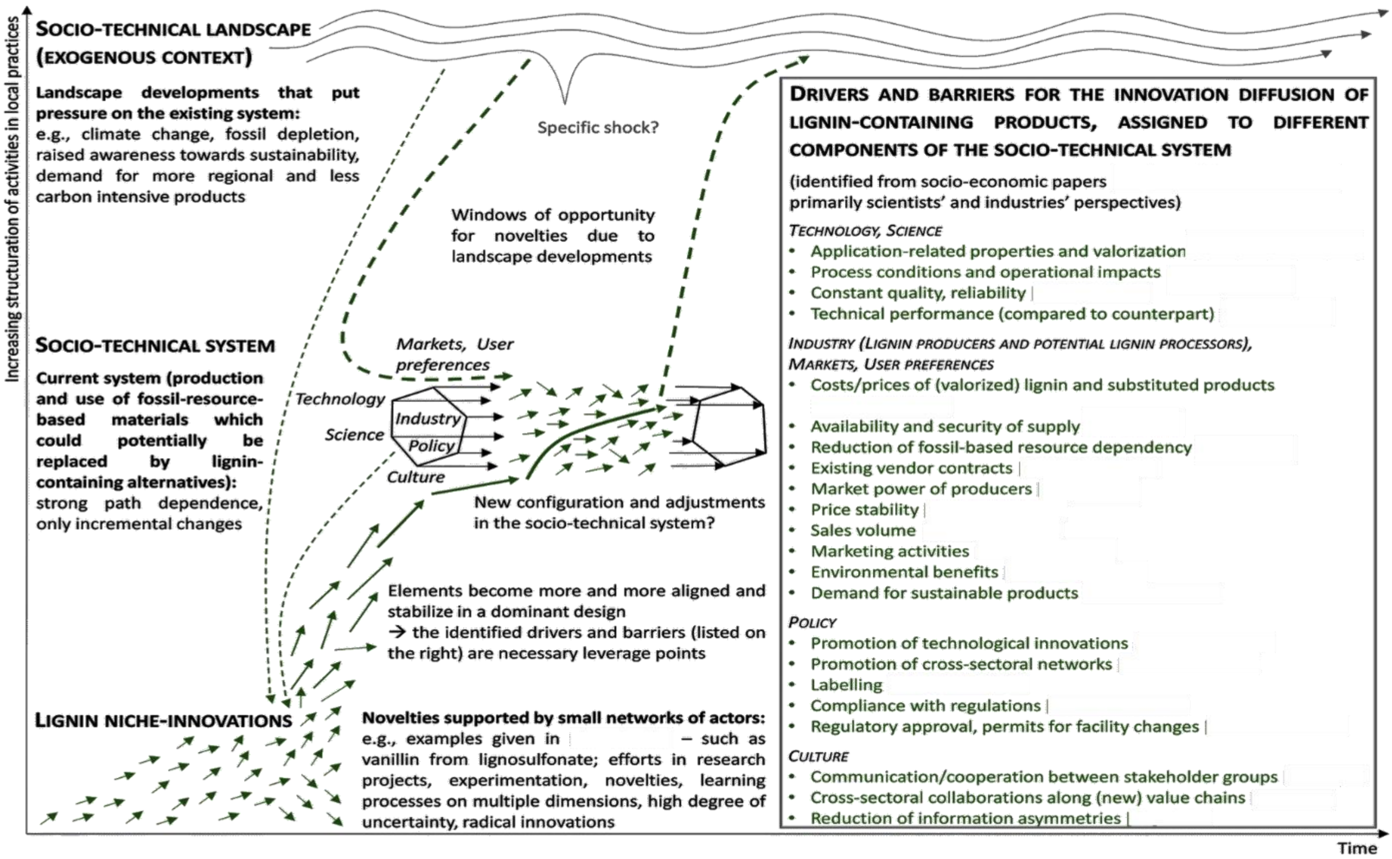
Ahlqvist, T., Dufva, M., Kettle, J., Vanderhoek, N., Valovirta, V., Loikkanen, T., & Roos, G. (2015, November). Foresight for building a regional cluster platform: cellulosic fibre value chain technology roadmap in green triangle region, South Australia. Paper presented at the 5th International Conference on Future-Oriented Technology Analysis (FTA) – Engage today to Shape Tomorrow, Brussels, Belgium.

Dufva, M., Ahlqvist, T., Kettle, J., Vanderhoek, N., Valovirta, V., Loikkanen, T., & Roos, G. (2013, December). Future pathways for radical transformation of an industry sector. Paper presented at 6th ISPIM Innovation Symposium – Innovation in the Asian Century, Melbourne, Australia.

- Regulatory measures are efficient in driving innovation and adoption (market creation) but must pe predictable, transparent, and understood by stakeholders and must also be part of an integrated industry policy approach.

A good summary of barriers and drivers of these value chains are provided by Wenger et al.[72] and shown in Figure 3. This figure is valid also for other green value chains of a similar type.

Figure 3: Sociotechnical transition pathways with drivers and barriers for the innovation diffusion of biomass originating products



For those pathways that are both available at scale and can generate products at competitive prices and with high margin, and where the necessary modifications of user processes are low[73] there is a great potential to build longer high added value export-oriented value chains in Norway based on domestic raw materials.

[72] Wenger, J., Haas, V., & Stern, T. (2020). Why can we make anything from lignin except money? Towards a broader economic perspective in lignin research. Current Forestry Reports, 6(4), 294-308.

[73] Low here means either low in absolute terms or low after any subsidies received to offset the adaptation and modification cost

Appendix 3: Technology funding

Within the Norwegian system there is already agencies that fund Research on TRL and MRL levels 1 to Level 4 (see Figure 4 and Table 6). So Bionova does not need to provide additional funding here. For both large and small companies there is a lack of funding available for Levels 5-6 and for SMEs also for level 7-8 so these are the domains where Bionova should focus its efforts.

The importance of providing grants on the higher TRL levels to SMEs is illustrated by the US Department of energy. They have provided grants for biorefinery and biochemical production in the range of $5-10 million for scaling and validating cellulosic technology for commercialization at demonstration-scale facilities and for the development of improved enzyme systems to be used in converting biomass into clean, renewable chemicals[74]. To this can be added some insights from both DoD and DoE in the US as to the time and cost it takes to move from TRL 1 to TRL 9. The numbers are averages with very high variation but provides some indications (Table 7).

Figure 4: Outline of Technology Readiness Levels (TRL) and Manufacturing Readiness Levels (MRL)[75]

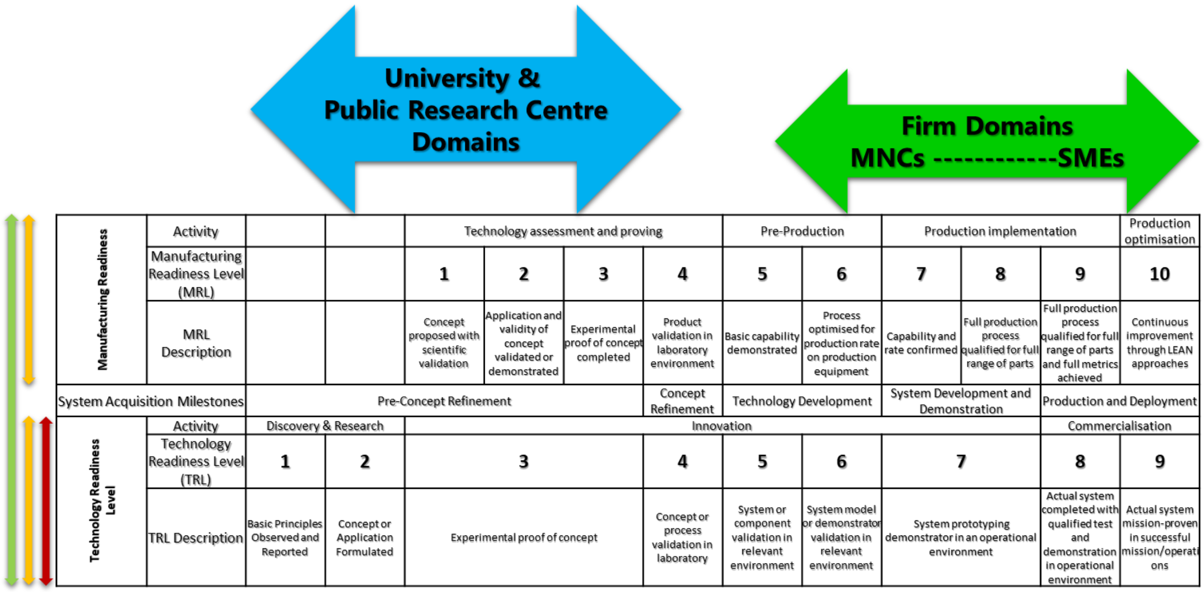


Table 6: TRL scale for the chemical industry[76]

TRL	1	2	3	4	5	6	7	8	9
Label	Idea	Concept	Proof of Concept	Preliminary process development	Detailed process development	Pilot trials	Demonstration and fullscale engineering	Commissioning	Production

74 VERENIUM Corp. Form 10K downloaded from https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.169.9289&rep=rep1&type=pdf

75 Roos, G. & Pike, S. (2011). The Relationship between University Research and Firm Innovation. Chapter 3 in Evans, E., Burritt, R., & Guthrie, J. (eds.). (2011). Bridging the gap between academic accounting research and professional practice. The Institute of Chartered Accountants in Australia & Centre for Accounting, Governance and Sustainability. University of South Australia. pp. 31-50

Roos, G. (2014). Manufacturing in a High Cost Environment – Basis for success on the firm level. Chapter 13 in Roos, G., & Kennedy, N. (eds.). (2014). Global Perspectives on Achieving Success in High and Low Cost Operating Environments. Hershey, PA: IGI Global. doi:10.4018/978-1-4666-5828-8. pp 393-480

76 Buchner, G. A., Stepputat, K. J., Zimmermann, A. W., & Schomäcker, R. (2019). Specifying Technology Readiness Levels (TRL) for the Chemical Industry. Industrial & Engineering Chemical Research, 58(17), 6957-6969.

TRL	1	2	3	4	5	6	7	8	9
Description	Opportunities identified, basic research translated into possible applications (e.g. by brain-storming, literature study)	Technology concept and/or application formulated, patent research conducted	Applied laboratory research started, functional principle / reaction (mechanism) proven, predicted reaction observed (qualitatively)	Concept validated in laboratory environment, scaleup preparation started, shortcut process models foun	Process models found, property data analysed, simulation of process and pilot plant using bench scale information	Pilot plant constructed and operated with low rate production, products approved in final application, detailed process models found	Parameter and performance of pilot plant optimized, (optional) demo plant constructed and operating, equipment specification including components that are type conferrable to fullscale production	Products and processes integrated in organisational structure (hardware and software), full-scale plant constructed	Full-scale plant audited (site acceptance test), turn-key plant, production operated over the full range of expected conditions in industrial scale and environment, performance guarantee enforceable
Tangible work result from the project	Idea / rough concept / vision / strategy paper	Technology concept formulated, list of solutions, future R&D activities planned	Proof of concept (in laboratory)	Documentation of reproduced and predictable (quantitative) experiment results, multiple alternative process concepts evaluated	Parameter and property data, few alternative process concepts evaluated in detail	Working pilot plant	Optimised pilot plant, (optional) working demo plant, sample production, finalized and qualified system and building plan	Finalised and qualified system and building plan	Full-scale plant tested and working
Project Workplace	Office (sheets of paper (physical or digital), whiteboard or similar)	Office (sheets of paper (physical or digital), whiteboard or similar)	Laboratory	Laboratory	Laboratory / mini plant	Pilot plant, technical centre	Pilot plant, technical centre, (optional) demo plant (Potentially incorporated in production site)	Production site	Production site

Table 7: Time and cost to migrate across the TRL scale[77]

From TRL	To TRL	Average duration in months	Cost increase multiple
1	2	62	1.4
2	3	81	1.6
3	4	57	1.4
4	5	17	1.1
5	6	29	1.2
6	7	39	1.2
7	8	23	1.1
8	9	11	1.1
Total		257	6.0

77 Calculated from public project information available from DoD and DoE

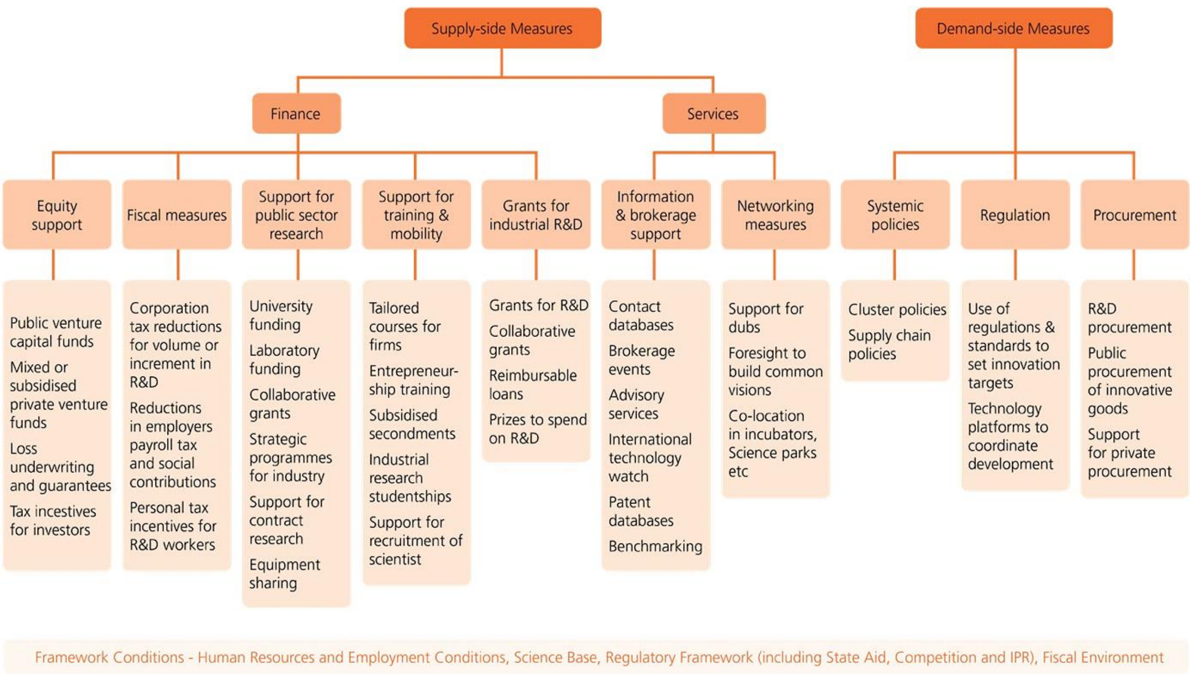
Appendix 4: Tools in the industry policy portfolio

Industry policy tools can be used to overcome barriers and achieve outcomes and objectives and most fall under the following headings:

- Cluster and ecosystem policies.
- Enactment of laws.
- Enforcement policies.
- Grants and other incentives.
- Level to which maintenance is carried out.
- Prioritisation and balancing of proactive and corrective maintenance.
- Procurement policies.
- Provision of infrastructure.
- Provision of neutral and factually correct information.
- Public guidelines and guidance.
- Public promotions and influencing of attitudes and behaviours.
- Public regulations, standards, and rules.
- Public sanctions.
- Public service levels
- Taxation and other fee structures.

The available tools for the industry, innovation and research domain are summarised by Georghiou[78] and illustrated in Figure 5 and summarised by Kaiser & Kripp and shown in Table 8.

Figure 5: Industry Policy Tools[79]



78 Georghiou, L. (2007). Demanding innovation: Lead markets, public procurement and innovation. NESTA Provocation 02. NESTA.

79 Roos, G. (2012). Manufacturing into the Future. Adelaide Thinker in Residence 2010 - 2011, Adelaide Thinkers in Residence, Government of South Australia, Adelaide, Australia.

Table 8: Demand-side policy tools by category (Kaiser & Kripp, 2010) [80]

Category	Policy tools
Public Procurement	• Public sector as a first user and pioneer in purchasing, piloting and using innovations. • Public procurement policies. • Pre-commercial procurement. • Standards to create stimulus for innovative products and processes.
Regulation	• Coherent regulation by coordinating standardisation and labelling. • Regulatory measures directed towards steering innovation. • Labelling for consumer and user information. • Norms on usage to create demand for novelties.
Policies supporting private demand	• Consumer awareness and competence building (e.g. digital skills). • Foresight activities to identify social and economic trends. • Research on societal challenges (e.g. the ageing population or climate change).
Financing and tax incentive policies	• Financing of R&D and innovation projects. • Tax incentives and tax subsidies to create demand for innovations.
Systemic policies	• Systemic coordinated demand-side innovation policies coordinating and combining several demand-driven policy instruments. • Public-private partnership for exploration activities as well as product or process specification and development.

Each of these tools play a different role and are differently important at different stages of a sector's development. The fundamental difference between supply-side and demand-side policy tools is that supply-side policy tools tend to drive activity and tend to be preferred by policy makers grounded in the neo-classical economic view which limits interventions to a reactive response to identified "market failures". Demand-side policy tools tend to drive outcomes and tend to be preferred by policy makers grounded in schools of economic thought that argue a more active industry policy.

The European Commission[81] found that 48% of interviewed firms indicated that demand-side policies (excluding public procurement) have positively affected their innovation activities and only 33% claimed the same for supply-side policies. Demand and supply side policies were considered as equally important for innovation activity by 23% of the firms. Demand-side policies influenced the innovation significantly in the high-tech sector (54%) and in the large enterprise segment (61%). Furthermore, companies in innovation-follower countries (55%) and innovation-leader countries (52%) were positively affected by demand-side policies. In addition, demand-side policies supported an increase of the expenditures on innovation by firms (29%) in comparison to only 12% for supply-side measures[82].

If we summarise this, we can see that demand-side policy tools (excluding procurement) are between 50% and 100% more effective as drivers of innovation (and thereby change) than supply-side policy tools. Public procurement represents 12% of gross domestic product (GDP) and 29% of total government expenditures on average across OECD countries, a clear sign of its potential to support broader policy objectives, including the fostering of innovation and change[83].

80 Kaiser, R., & Kripp, M. (2010, June). Demand-orientation in national systems of innovation: a critical review of current European innovation policy concepts. In DRUID Summer Conference on "Opening Up Innovation: Strategy, Organization and Technology" at Imperial College London Business School.

81 European Commission. (2009) Innobarometer 2009. Analytical Report. Brussels.

82 Kaiser, R., & Kripp, M. (2010, June). Demand-orientation in national systems of innovation: a critical review of current European innovation policy concepts. In DRUID Summer Conference on "Opening Up Innovation: Strategy, Organization and Technology" at Imperial College London Business School.

83 OECD. (2017). Public Procurement for Innovation: Good Practices and Strategies. OECD Public Governance Reviews. OECD Publishing

Since early 2000s the EU has put in place recommendations, frameworks and legislation to facilitate the use of public procurement as a demand side policy tool.[84] Econometric studies show that public procurement is an effective tool for industrial policy to stimulate innovative activities, to shape the transformation of production systems and to foster industrial renewal.[85] Specifically procurement where the contracting authorities act as a launch customer for innovative goods and services that are not yet available on a large-scale commercial basis is highly effective but also particularly important for SMEs. By providing stable and predictable sources of demand, such contracts allow them to make plans for the future including expanding investments in new technologies, capital equipment, and human resources.[86]

The challenge for SMEs as relates to public procurement is that they frequently are unaware of the opportunity[87], lack access to legal expertise, administrative capacity and the relationships to communicate with and influence the issuer before finalising the request for tender[88]. In addition, there are external barriers for SMEs to participate in public tenders like high administrative costs, large and long-lasting contracts, and onerous qualification criteria[89]. There are also subjective barriers like the risk aversion of agencies that result in selection criteria that preferences larger firms experienced as public providers[90].

Despite having a long tradition of implementing public procurement that drives innovation and in spite of adhering to the EU legislation there has been found no evidence that Norway has adopted specific policy measures to increase small businesses' participation in public tenders[91].

84 See e.g.: Directive 2004/18/EC; European Commission. (2007, December). Pre-commercial Procurement: Driving Innovation to Ensure Sustainable High Quality Public Services in Europe; European Commission. (2010, October). Europe 2020 Flagship Initiative – Innovation Union; Directive 2014/24/EU; Directive 2014/25/EU; European Commission. (2014). Public Procurement as a Driver of Innovation in SMEs and Public Services, Guidebook Series "How to Support SME Policy from Structural Funds";

85 Crespi, F., & Guarascio, D. (2019). The demand-pull effect of public procurement on innovation and industrial renewal. Industrial and Corporate Change, 28(4), 793-815.

86 Flynn, A., & Davis, P. (2017). Explaining SME participation and success in public procurement using a capability-based model of tendering. Journal of Public Procurement, 17(3), 337–372.

87 Nicholas, C., & Fruhmann, M. (2014). Small and medium-sized enterprises policies in public procurement: Time for a rethink? 1. Journal of Public Procurement.

88 Flynn, A., & Davis, P. (2017). Explaining SME participation and success in public procurement using a capability-based model of tendering. Journal of Public Procurement.

89 Cases are known where the insurance costs that are required are higher than the contract value

90 Uyarra, E., Edler, J., Garcia-Estevez, J., Georghiou, L., & Yeow, J. (2014). Barriers to innovation through public procurement: A supplier perspective. Technovation, 34(10), 631-645.

91 Divella, M., & Sterlacchini, A. (2020). Public procurement for innovation: firm-level evidence from Italy and Norway. Industrial and Corporate Change, 29(6), 1505-1520.