From field to Engine: Biobased and biodegradable lubricant- and hydraulic oils

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Innehållsförteckning

Introduction

There has been intensified discussion on how to transition from a fossil-based to a bio-based society—from governments, industries, and academia to individuals. In this net-zero transition, one important approach will be to shift raw material streams, leading to increased production of chemicals and materials from bio-renewable resources. Historically, lignocellulosic biomass was among the first raw materials used to produce commodity chemicals, but it was replaced by fossil-based sources such as coal and oil. Today, the challenge is to reintroduce biomass as one of the main sources for commodity chemicals through the development of cost-effective, scalable, and sustainable processes.

Modern agriculture is highly dependent on machinery for fieldwork, forestry, and livestock management. This equipment requires significant amounts of lubricant- and hydraulic oils, which are usually fossil-based and non-biodegradable. Leakage of these oils from machinery creates various environmental challenges, both in the form of soil and groundwater contamination, as well as negative health effects for humans. Estimates suggest that as much as 7 million liters of various types of mineral oils leak each year from the use of chainsaws in forestry operations, in Sweden only.

This project was aimed at exploring the possibility of developing bio-based, biodegradable alternatives, with a focus on ester-based bio-oils derived from renewable fatty acids. The U.S. National Renewable Energy Laboratory (NREL) identified several key biobased platform chemicals, including methanol, ethanol, acetic acid, and lactic acid, as already commercialized bulk bio-chemicals. Other candidates such as butanol, furfuryl derivatives, levulinic acid, and itaconic acid are also considered highly promising. Among these alternatives the project chose to focus on levulinic acid, itaconic acid and lactic acid. Lactic acid has achieved the greatest commercial success, while levulinic and itaconic acids are emerging as important building blocks for polymeric and lubricant applications.

Lactic acid has successfully been converted from low-value cellulose from forestry industry side streams. Based on this earlier acquired knowledge and literature, the Lantmännen's side streams—such as bran, straw, and other carbohydrate-rich materials—could similarly be converted into lactic acid, creating a circular and sustainable system within the company's operations. According to current literature, itaconic and levulinic acid can be produced from various sugars through fermentation, and the technology to convert sugars or cellulose into biobased alcohols is already well established.

The project, financed by Klimatledande Processindustri, KPI, has been a collaboration between Chalmers Industriteknik, Chalmers University of Technology, Lantmännen/Aspen, Fuchs, one of the world's leading lubricant companies, and BASF, one of the largest chemical companies and a producer of additives that improve and stabilize the properties of lubricants and oils. This constellation represents expertise and commitment along the entire value chain, from raw materials through processing and formulation to end use.

The synthetic work has been focusing on the potential of the chemistry and to build knowledge on the relation between structure and lubricating properties like viscosity and temperature stability while the market analysis and the techno-economical evaluation have concentrated the work on chain-saw oils, being a clear and defined product segment.

1. Background

Humans have used natural fats and oils since prehistoric times. During industrialization in the 19th century, the need for higher-performance lubricants became clear, which led to the large-scale use of vegetable oils such as castor oil and rapeseed oil. With the breakthrough of the petroleum industry in the 20th century, biobased lubricants lost ground to cheaper and more stable fossil alternatives. More recently, however, environmental legislation and increasing demands for sustainable solutions have led to a renaissance for biobased lubricants. Today, a wide range of raw materials are used to produce biobased lubricants, with various vegetable oils (rapeseed, soybean, palm, sunflower, and coconut oil) among the most common. However, it is preferable to use raw materials that do not compete with food or feed production, which is why attention is also directed towards secondary feedstock such as used cooking oil and industrial by-products.

The development of biobased lubricating oils goes hand in hand with the development of biobased fuels, where, for example, biodiesel can be produced by transesterification of vegetable oils (or other fats), in which triglycerides react with alcohol to form fatty acid methyl esters. Unlike biofuels, lubricants are used in machines to

i) control friction by reducing wear
ii) remove heat; and
iii) protect surfaces from corrosion by reducing the risk of metal oxidation

For lubricating oils, properties related to the lubrication profile, e.g., viscosity and thermal stability are essential. Other important parameters, such as interaction with necessary additives like corrosion inhibitors, antioxidants, and antifoaming agents, are often omitted in scientific studies but are required in a final product. Expertise in the field of lubricants and their properties was covered by the involvement of both Fuchs, Aspen and BASF in the project consortium.

To design and prepare the next generation of synthesized biobased lubricants, it is important to build knowledge on the link between properties and the chemical structure, which has been an aim of this project.

1.1 Biobased platform Chemicals

The U.S. National Renewable Energy Laboratory (NREL) identified several key biobased platform chemicals, including methanol, ethanol, acetic acid, and lactic acid, as already commercialized bulk bio-chemicals. Other candidates such as butanol, furfuryl derivatives, levulinic acid, and itaconic acid are also highly promising. Among these, lactic acid has achieved the greatest commercial success, while levulinic and itaconic acids are emerging as important building blocks for polymeric and lubricant applications.

Agricultural residues can be converted into various promising biobased chemicals[1] such as 1,4 dicarboxylic acids (succinic acid, fumaric acid, and malic acid), 2,5-furandicarboxylic acid, 3-hydroxypropionic acid, lactic acid, aspartic acid, glucaric acid, glutamic acid, itaconic acid, levulinic acid, 3-hydroxybutyrolactone, glycerol, sorbitol, and xylitol/arabinitol. These can all be achieved through various chemical or enzymatic processes, most often by hydrolysis (i.e., the breakdown of biomass into carbohydrates) followed by fermentation into biobased chemicals.

Levulinic acid is currently produced mainly via chemical hydrolysis of C6 carbohydrates through acid-catalyzed biomass conversion. Industrial players include GF Biochemicals (Europe), Biofine Developments Northeast (USA), and several Chinese manufacturers such as Langfang Triple Well and Hefei TNJ. Itaconic acid, produced primarily by fermentation with Aspergillus terreus, is also gaining attention. Global capacities for both acids are increasing, driven by the demand for sustainable chemical feedstocks.

Out of these possible platform chemicals, the project selected three alternative acids, levulinic acid, itaconic acid and lactic acid, to proceed with in the synthetic work producing ester-based oils. Figure 1. The selection was based on experience from earlier projects and the availability of the chemicals on the market.

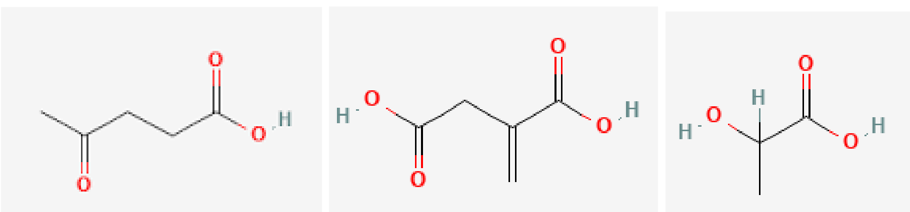


Figure 1. Levulinic acid, Itaconic acid and Lactic acid

Most of the promising chemicals have more than one reactive group, i.e an alcohol, OH-group, or a carboxylic group, COOH, which opens the door to formation of more than one ester. Esters are formed when a hydroxyl group reacts with a carboxylic group, Figure 2.

[1] Biddy et al.,"Chemicals from Biomass: A Market Assessment of Bioproducts with Near-Term Potential", *National Renewable Energy Laboratory*, **2016**, https://www.nrel.gov/docs/fy16osti/65509.pdf

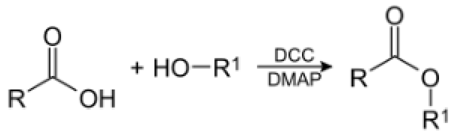


Figure 2. Formation of and ester

With these possibilities for structural modification, there is potential to use short-chain bio-based alcohols or fatty acids to build viscous fatty acid esters that can be used as lubricants.

Longer unsaturated fatty acids, such as those found in for example olive oil, a combination of several fatty acids, Figure 3, have good lubricating properties. However, the unsaturation in the structures, double bonds, allow them to crosslink at the molecular level, leading to higher melting points, aggregation, and thus poorer lubricating properties compared to their saturated analogues. There is also a risk of oxidation, leading to carbonyl groups, that impacts the properties.

CH3-(CH2)7-CH=CH-(CH2)7-COOH,

CH3-(CH2)4-CH=CH-CH2-CH=CH-(CH2)7-COOH

CH3-CH2-CH=CH-CH2-CH=CH-CH2-CH=CH-(CH2)7-COOH

Figure 3. Three of the dominating fatty aids in olive oil, oleic acid, linoleic acid and alpha-linoleic acid.

2. Experimental Work and Esterification Studies

2.1 Experimental Overview

A series of biobased carboxylic acids – levulinic acid, lactic acid, and itaconic acid – were selected as model compounds for ester synthesis aimed at developing potential bio-based lubricants. The project was divided into different phases, including literature study, reaction condition optimization, ester synthesis, rheological evaluation, and final reflections. In the sub sections that follow it is first explained, in general terms, how the literature was searched, described in 2.2., Thereafter, section 2.3 describes briefly how the reactions conditions were tuned to find reaction conditions that gave descent yield, at least 85%. 2.3.1 describes the synthesis of diester of lactic acid, and 2.3.2 the reactions performed on Itaconic acid or the anhydride. 2.3.3 describes the reactions on Levulinic acid, and lastly 2.3.4 describes the reactions on di-tri and tetra-alcohols.

2.2 Literature Study and Reaction Strategy

An extensive literature review was conducted via SciFinder and Web of Science to determine suitable esterification parameters. Initial searches on WebofScience on esterification of lactic, levulinic and itaconic acid and their production/synthesis were converted to maps with correlations. The text and author network maps for Lactic acid are shown below as an example.

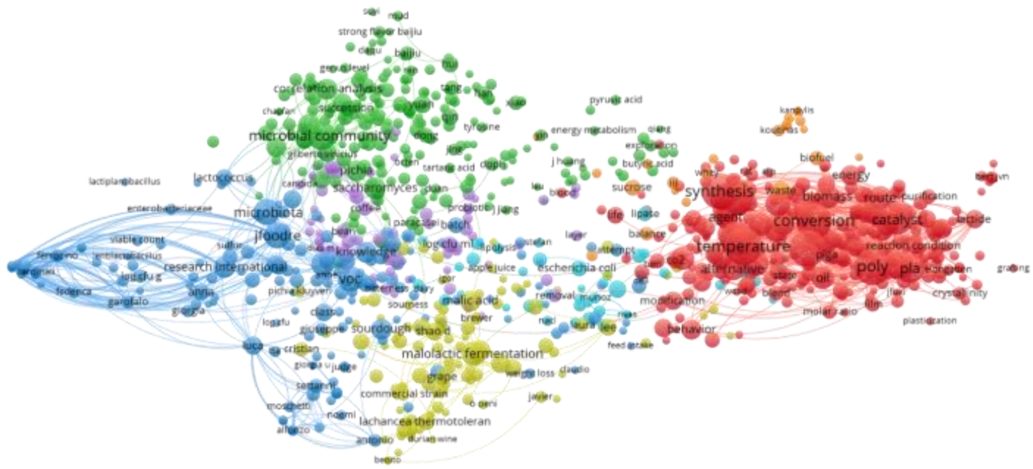


Figure 4: A correlation map based on key words from WebofScience search on lactic acid

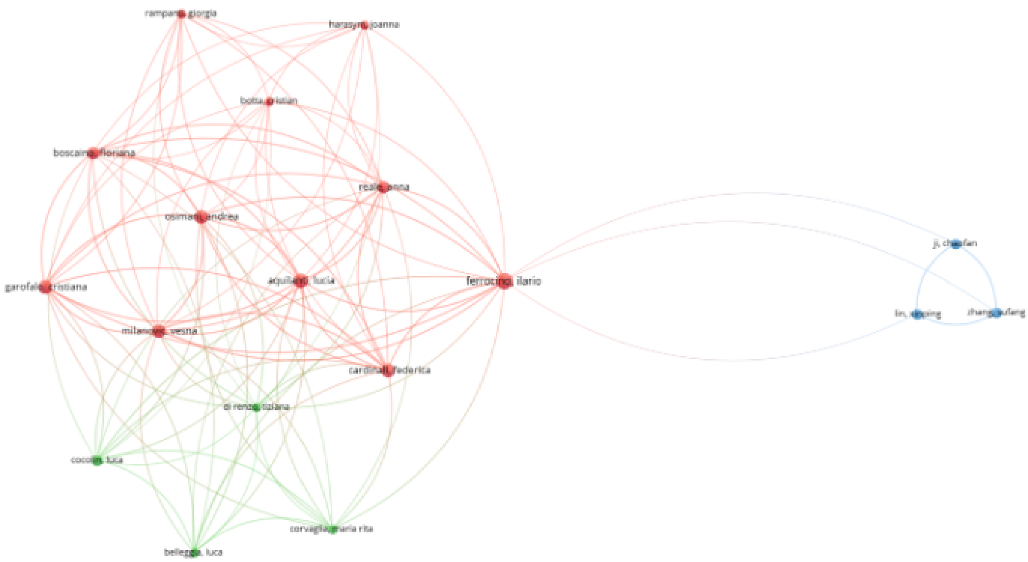


Figure 5. Author network made from WebofScience search.[2]

The maps were primarily used to get a brief overview of researchers and appropriate keywords for more detailed searches in SciFinder.

SciFinder search on esterification gave 1557 synthetic methods, 727 experimental procedure, 335 synthetic methods on gram+ scale, and 144 reactions with a reported yield of 90-100%. From the publications retrieved in SciFinder the 5 most common reagents used for esterification of lactic acid are listed below, Table 1.

[2] The maps are primarily shown to give the reader an understanding on the data mining process used to find relevant reaction conditions and information on the use of the chemicals. It is not intended to be readable. The raw data file can be sent upon request.

Reagent	Number of articles including the reagent
Hydrochloric acid	95
p-Toluene sulfonic acid	43
Triphenylphosphine	36
Ammonium chloride	34
Di-isopropyl azodicarboxylate	27

Table 1. Reagents for esterfication

From the WebofScience and SciFinder searches, and reading of some of the articles found, two synthetic routes were identified:

i. direct esterification of acid and alcohol with an acid catalyst, and
ii. conversion of the acid to an acyl chloride followed by esterification.

The first route was chosen due to its scalability and simplicity. Para-Toluenesulfonic acid (p-TSA) was used as the catalyst.

2.3 Screening reaction conditions.

As many of the published methods are based on esterification with low-boiling alcohols, used in excess relative the carboxylic acid[3,4,5]. An initial screening was conducted with 10-fold, 5-fold and 1-fold (equal amounts of acid and alcohol) and the temperature was varied from 60-90 °C, for several hours. More specifically, four reactions were run in parallel, using one of the carboxylic acids and four different alcohols (methanol, ethanol, butanol and octanol) and aliquots were taken out every hour. The product was isolated, and NMR was performed on the samples. From the results it was decided to run the reactions for 2-4 hours at 70- 90 °C. It must be clearly stated that this was not intended to optimize the reaction, it was done to find robust reaction conditions that give a yield of 85 % or higher.

Scheme 1: Simplified reaction process for esterification
Acid + Alcohol + [p-TSA] -> product, (minor, almost undetectable side products)
1:1 ratio Acid:Alcohol + 0.01 moleq p-TSA, heating 70-90 °C, 2-4 hours, non-optimized-but improved.

[3] Kumar, R.; Mahajani, S. M. Esterification of Lactic Acid with n-Butanol by Reactive Distillation. Ind. Eng. Chem. Res. 2007, 46 (21), 6873-6882. DOI: 10.1021/ie061274j.
[4] Benedict, D. J.; Parulekar, S. J.; Tsai, S.-P. Esterification of Lactic Acid and Ethanol with/without Pervaporation. *Ind. Eng. Chem. Res.* **2003**, *42* (11), 2282-2291. DOI: 10.1021/ie020850i.
[5] Dusselier, M.; Van Wouwe, P.; Dewaele, A.; Makshina, E.; Sels, B. F. Lactic acid as a platform chemical in the biobased economy: the role of chemocatalysis. *Energy & Environmental Science* **2013**, *6* (5), 1415-1442, 10.1039/C3EE00069A. DOI: 10.1039/C3EE00069A.

2.3.1 Esterification of Lactic acid and formed ester

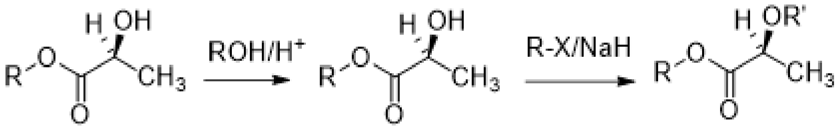


Figure 6. α presentation of the esterification of lactic acid and the diester thereof.

Commonly "lactic ester" refers to the monoester with esterification of the carboxylic acid function of lactic acid. However, it could also refer to the ester where the alcohol of lactic acid has been converted to an ester. The diester was never intended to be made within this project, financed by KPI. However, during the project, financed by KPI, a question raised whether it was possible to make the diester of lactic acid in reasonable yield and cost. After a literature search in SciFinder it was decided to not include the synthesis of the lactate diesters due to harsh reaction conditions, with sodium hydride as reagent, inert atmosphere requirements, Tetrahydrofuran or Dimethyl sulfoxide as solvent and assumed high cost.

2.3.2 Esterification of Itaconic acid

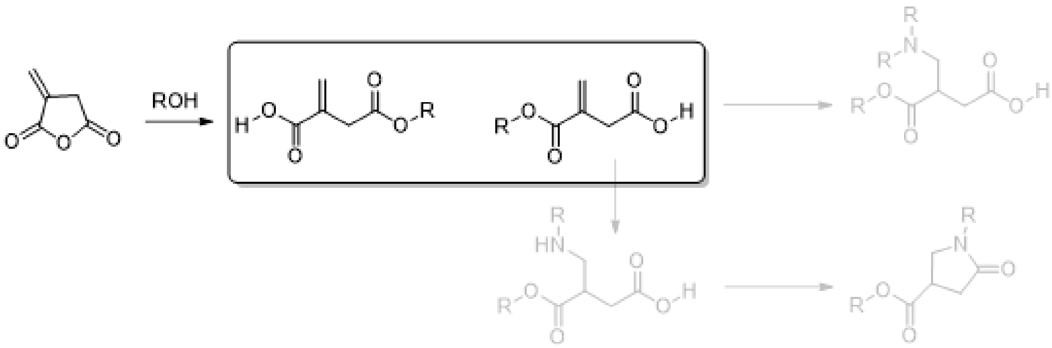
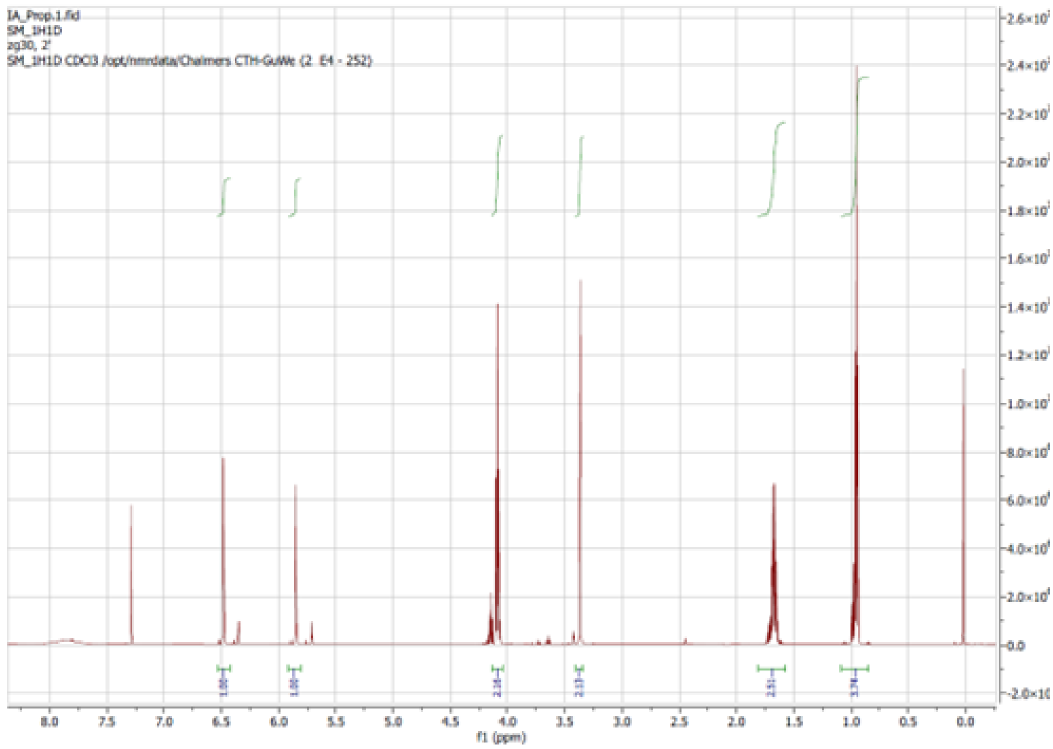
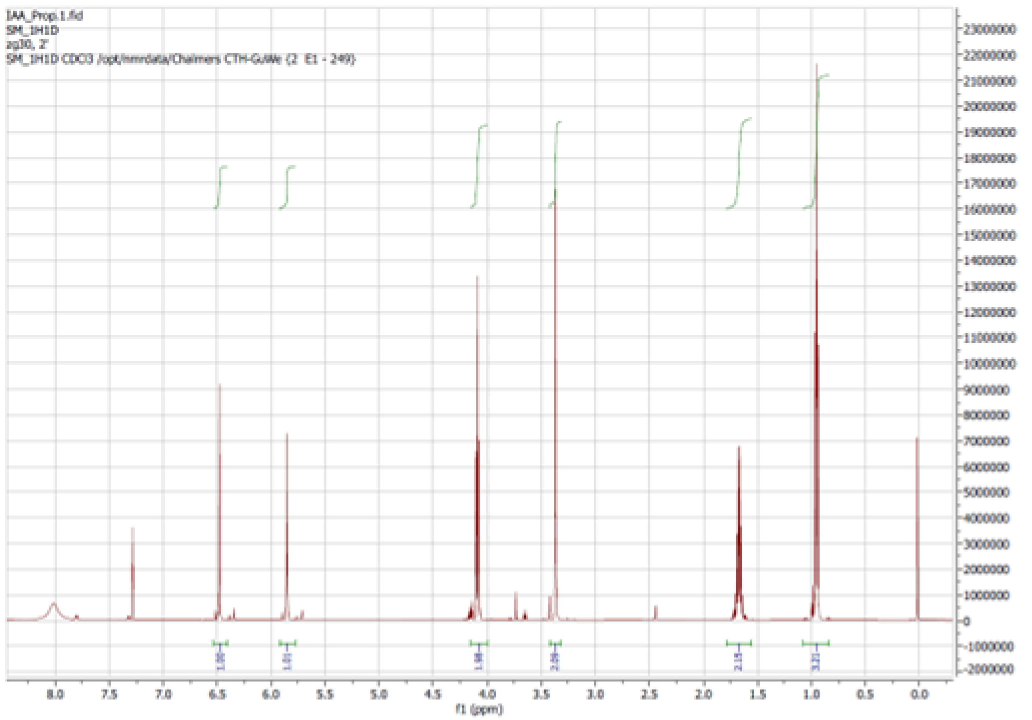


Figure 7. Schematic presentation of esterification of Itaconic anhydride and the possible further reactions that might be done on the formed monoester.

In most NMR spectra the scale has the highest scale value to the left and the lowest value on the scale to the right. This may look strange and wrong. But since in NMR the chemical shift axis (ppm) usually shows higher numbers on the left (downfield) and lower numbers on the right (upfield). This isn't arbitrary — it follows how chemical shift is defined and how the first NMR instruments display data, and almost how all NMR instruments produce spectra and how they are presented in academic literature.



Spectra 1. NMR for the Ethyl itaconate with Itaconic anhydride as starting material,



Spectra 2 NMR for the Ethyl itaconate with Itaconic acid as starting material.

The strong signals in the spectra correspond to the ester of Itaconate, the smaller signals at approx. 3.4-3.8, 4.2, 5.7 and 6.3 ppm are from unreacted Itaconic acid. The small signals at 2.45, 7.3 and 7.77 ppm are from p-Toluenesulfonic acid. The broadening of the strong signals at 1.65 and 4.1 ppm, more clearly seen in Spectra 1 is from residues of Ethanol.

The esters were prepared according to the text below.

Itaconic anhydride or Itaconic acid 1g in EtOH 10 ml and a catalytic amount of p-TSA was heated at 50 °C for 16 hours. Excess alcohol was removed under reduced pressure, and the product was dried under a vacuum without any further filtration or purification to obtain the pure white crystal. Since both the anhydride and alcohol gave similar yield and quality of product, Itaconic acid was used in all further studies since it only cost 1/10 of the price of Itaconic anhydride.

Aza-Michael Reactions'

The Aza-Michael reaction was done to investigate if it was possible to include an amine functionality into the itaconic derivatives. The argument for this was two-fold,

i) it is known in that amines can act as corrosion inhibitors
ii) removal of the α, β-unsaturation to minimize unwanted degradation, by reaction of the unsaturation. Unfortunately, the reaction gave no product

The reaction was also investigated by reacting of 1.4-dimethyl Itaconate with hexylamine in EtOH. From literature data, the initial reaction was done by reacting the two components at RT over/night. The next day, the mixture was heated at 120 °C for 20 minutes in a microwave reactor. NMR of the material shows ring-closed material. NMR-data omitted in the text

2.3.3 Esterification of Levulinic Acid

Levulinic acid reacted with various alcohols under acidic conditions using p-TSA as catalyst. The general procedure involved heating levulinic acid (8.6 mmol) with alcohol at 90°C for 2 hours. For the reactions with MeOH and EtOH 5ml of alcohol was used whereas for the reactions with 1-octanol and 2-octanol 10 mmol of alcohol was used.

After reaction, the mixture was cooled, and for MeOH and EtOH, excess alcohol was removed by rotary evaporation. NMR analyses confirmed the presence of the desired esters with no side products other than residual catalyst traces. For the reactions with 1- and 2-octanol product and a small residue of the octanol was detected in the NMR spectra.

All synthesized levulinate esters were obtained as liquids at room temperature, confirming successful esterification. Melting point data for levulinic acid (33–35°C) and the liquid nature of all products support the completion of the reaction.

2.3.4 Multifunctional Alcohols and Polyesters

As the ester synthesized so far in the project, financed by KPI, had low viscosity, determined from their flow behavior in round bottom flask, it was decided to investigate if esters from multifunctional alcohol could increase the viscosity. Thus, the di-, tri-, and tetra-alcohols 1,8-octanediol, triethylene glycol, glycerol, and pentaerythritol were added to the study. All of them reacted with both levulinic and itaconic acids using the same catalytic system, p-TSA. All reactions produced viscous oils with higher viscosity than the monoesters. However, in the case of itaconic acid, crystallization was observed during rheological testing, which led to discontinuation of that serie.

2.4 Summary of esterification

All reactions seem to have worked successfully.
The alcohol used in initial screening were 1-Octanol, 2-octanol, Undecanol, Citronellol, 2-ethyl-hexanol, 3-pentanol, Cyclohexanol, and Diethylenglycolmonomethylether. The reaction process was to add Acid, Alcohol and catalytic amount of p-TSA, the reagents, acid and alcohol were in a 1:1 ration and approx. 0.01 mol equivalents of p-TSA were used and the mixtures were heated to heated 70-90 ^{o}C, 2-4 hours. All the reactions gave products in 85% yield or higher yield, based on NMR data.

Physical properties of the prepared esters.
Itaconic esters with C1, C2, C6, C8 carbon chains gave solid products, whereas esters with C3-C5 carbon chain gave a gel/liquid like appearance.

Itaconic esters with 1-octyl and 2-octyl groups show very good surfactant properties water and organic solvent becomes a suspension (milky). All prepared Levulinic and Lactic esters gave liquid products.

2.5 Rheological Evaluation

The synthesized esters were characterized for their rheological behavior using an Anton Paar rheometer equipped with a plate-to-plate geometry. The viscosity was plotted against the shear rate, graph xx below. In the graph below are the Levulinic esters of glycerol, triethylene glycol and erythritol plotted, dotted lines. As reference, there are three average lines for typical hydraulic, gear and engine oil included. From the graph levulinic erythritol, blue dotted line, has similar viscosity profile, consistent with gear oils at 23 ^{o}C. whereas levulinic glycerol, green dotted line, showed a viscosity profile like hydraulic oils at 23 ^{o}C. Itaconic esters, however, crystallized during testing, which limited further evaluation. It shall be noted that all esters showed excellent purity in NMR with yields exceeding 95%.

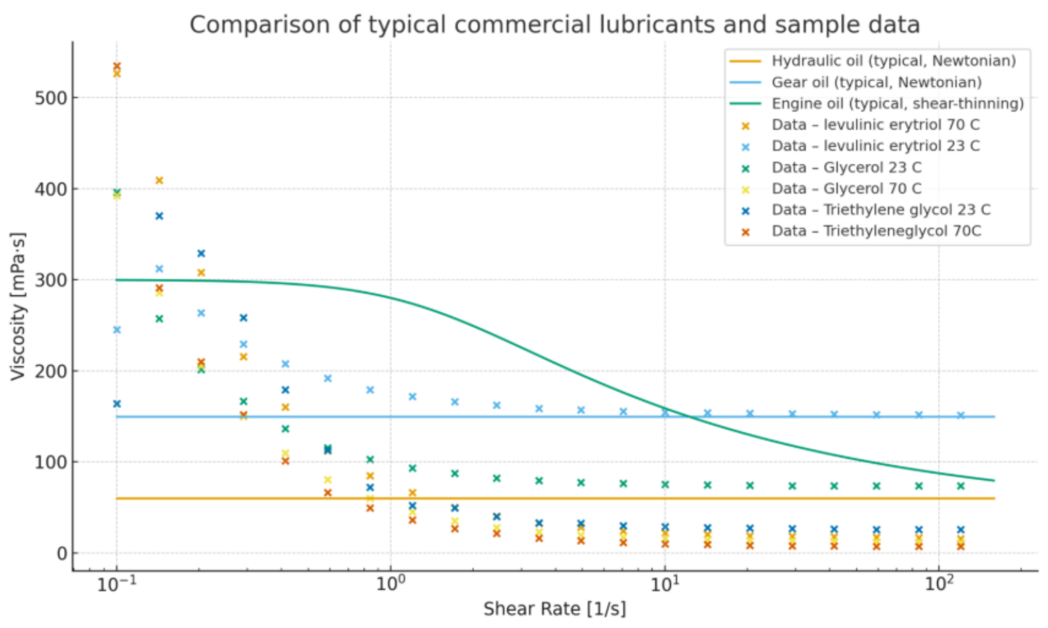


Figure 8. Viscosity vs. shear rate for esters of levulinic acid.

3. Market Analysis of Chainsaw Oil

The market analysis was conducted using the NABC method, a structured framework designed to evaluate the value of a project idea. To gather insights, separate interviews were carried out with the project partners: Fuchs, Aspen, Lantmännen, and BASF.

The NABC approach focuses on four key dimensions: **Need, Approach, Benefits, and Competition (or Alternatives)**.

- **Need** involves identifying and defining the customer's or market's most pressing challenges - *What problems are being solved, and why is this need both important and urgent?*
- **Approach** describes the proposed solution and how it addresses the identified need - *What makes this approach unique or innovative?*
- **Benefits** highlight the measurable improvements and value the solution delivers - *What tangible gains will customers experience, and how does the solution compare to existing alternatives?*
- **Competition (or Alternatives)** examines other solutions in the market and evaluates why the proposed approach is more viable or advantageous.

By applying this method, the analysis provides a structured understanding of the project's potential impact and differentiators.

Need

Chainsaw oil is used outdoors and drains directly into the soil, creating a clear need for sustainable, CO_2-neutral, and low-toxicity products. There is a growing demand in public procurement for bio-based and biodegradable oils. Although bio-based alternatives such as refined rapeseed oil exist, the market is still dominated by mineral oils (approximately 90%). Bio-based options are prone to oxidation and corrosion unless additives are used, which increases costs. While low cost remains essential, there is a growing willingness to pay for sustainability. Collaboration with additive suppliers is necessary to develop more sustainable formulations, and scalability requires access to high-volume waste streams.

Approach

The project focuses on using unused side streams as raw materials, aiming to create circular flows and optimize the entire production chain. The formulation is designed to be flexible to accommodate variations in raw materials. There is potential for future expansion into forest-based side streams and marine resources from the blue bioeconomy, such as algae. The goal is to utilize the entire crop in a closed-loop system from agriculture to end user. Candidate raw materials include itaconic and levulinic acids derived from cellulose and straw, as well as other side streams like oat hulls, wheat bran, hemicellulose, and fuel oil containing fatty acids.

Benefits

The solution supports companies' net-zero strategies and climate goals by offering a non-toxic and resource-efficient product with reduced environmental impact. Its sustainability profile can provide market differentiation and facilitate certifications. A diverse raw material base enhances flexibility and supply security. The potential for large-scale base chemical production can help lower costs and reduce fossil dependency. By utilizing side streams, the solution avoids competition with food production. Biodegradability is critical, as oil enters nature during use. Chainsaw oil is a niche product with high consumption, making sustainability efforts particularly impactful. There is also a first-to-market advantage through the use of waste-based raw materials. Improved biodegradability of the final product is a key benefit, although price and customer trust in new products remain ongoing challenges.

Competition

Other eco-friendly alternatives to chainsaw oil exist beyond the proposed chemistry. Expanding the raw material base is advantageous, as alternative oils may meet specifications and offer flexibility when availability changes. Rapeseed-based oils perform adequately and are relatively low-cost. Fossil-based oils remain cheaper and often outperform due to synthetic components. However, upcoming regulations requiring increased bio-based content will challenge fossil-based options and reshape the competitive landscape. Utilizing side streams helps reduce conflicts with food production and brings additional benefits.

4. Techno-economical evaluation

The majority of the commercial lubricants are synthetic mineral-based oils. The reason is that they can easily be tailored for various applications or according to customer specifications. However, the interest in biobased alternatives is growing, and the market share is estimated to grow quite extensively over the coming years. Some of the more prominent reasons for the transition to biobased alternatives are, according to both Aspen and Fuchs, companies ambition to reduce their carbon footprint, reduced toxicity of products, and achieving a biodegradable product.

The European market for chain saw oil constitutes about 30% of the global market, with a value of ~400 million USD. It can be assumed that Sweden, with its large forest industry, is a major consumer of these products, but without exact numbers a modest assumption, 2-3%, is appropriate, giving a market value of about 8-12 million USD or 80-120 million SEK.

The current biobased alternatives, rapeseed or canola[6], are generally more limited regarding application considering that they have a narrower performance profile if not modified. To overcome these deficiencies, this project has been focusing on synthesizing ester-based oils from biobased raw materials, with the aim to build knowledge on the importance of the molecular structure for the property profile to enable a future transition to biobased chainsaw oils. The acids in focus are among those pinpointed as being the most interesting biobased platform chemicals for the future chemical industry, i.e. itaconic acid, levulinic acid and lactic acid which have all been combined with different biobased alcohols in order to determine the connection between structure and functionality.

However, for future success with these lubricant alternatives, it is vital not only to understand the technical potential but also the economic side of the new products as the price will be an important factor when introducing alternatives to the market. The experience says that the “willingness-to-pay” for a product with less climate impact is not without restriction and higher prices has been the bottleneck for many biobased alternatives being inherently more expensive.

As the current project is in an early stage, TRL 2, the full cost and yield in an industrial production situation is not possible to foresee. The best option is to compare today’s products available on the market, both fossil- and bio-based, with possible new products based on cost of the raw materials included.

A minor comparison of chain-saw oils, available on the Swedish market, is presented in Table 2. The information has been collected from various web pages and is neither an exhaustive investigation nor exact, but merely an example for comparison. The oils are identified as fossil based but some are biodegradable. Table 3 is created in the same way but with focus on oils claimed to be biobased alternatives only.

In conclusion, from this short summary there seems to be only a small difference in price between the mineral-based and biobased alternatives. Lower prices are offered when larger quantities are purchased, for example buying 1litre package can cost 150 SEK/litre while the same quality in a 20-litre package can cost 90 SEK/litre instead.

[6] Canola is an abbreviation for Canadian Oil Low Acid, but is rapeseed oil

Rapeseed is an abundant crop in Europe, and the refined oil has good lubricating properties, is biodegradable, and suitable as chain saw oil. To improve the performance under cold or warm conditions, additives of other biobased oils or synthetic esters are common. Refining of the rapeseed oil is done to remove various impurities and to increase shelf life. The process can be done either under warm or cold conditions. There are major suppliers of technical qualities in Austria, Netherlands, Poland, Ukraine and Germany and the price for bulk purchases is typically in the range of 10-14 SEK/liter.

Supplier	Country of origin	Product name	SEK/litre	Comments
STIHL	Germany	SynthPlus, BioPlus	109 SEK 129 SEK	One of the global leaders; SynthPlus is partly synthetic, while BioPlus is a fully biodegradable product
HUSQVARNA	Sweden	Mineral Chain Oil, X-Guard BIO	77 SEK 79 SEK	Dominates Nordic markets; wide range of mineral and bio-oils.
OREGON	USA (Blount Inc.)	Oregon Bio Chain Oil, Oregon Chain Oil	99 SEK	Known for chain bars and chains; offers both mineral and bio-oils.
ASPEN	Sweden	Aspen Bio Chain Oil	149 SEK	Specialized in clean fuels and environmentally friendly lubricants.
MAKITA/DOLMAR	Japan/Germany	Chain Oil (Mineral)	150-192 SEK	Offers branded oils mainly for own tools, often mineral-based.
ECHO (YAMABIKO)	Japan	Echo Premium Bar and Chain Oil	140 SEK	Competes globally with Stihl and Husqvarna; less dominant in Europe.
AGROL (LANTMÄNNEN)	Sweden	Kedjeolja Mineral / Bio	89-109 SEK	Strong presence in agriculture and forestry sectors.
MPM OIL COMPANY	Netherlands	MPM Chain Saw Bio	149 SEK	Offers ISO-VG classified biodegradable oils.

Table 2. Examples of price for fossil chain-saw oils, on the market[7]

Supplier	Country of origin	Product name	SEK/litre	Comments
PANOLIN	Switzerland	Fully synthetic, biodegradable	180 SEK	Used in professional forestry and sensitive areas.
FUCHS	Germany	Plantogear Bio Chain Oils		Known for industrial-grade biodegradable lubricants.
BIO-KETTENÖL (CARL BECHEM)	Germany	High-performance bio oils		Focus on environmental safety and forestry compliance.
RATIOPARTS	Germany	ChainBIO (rapeseed)	99 SEK	Offers KWF-certified rape seed chain oils.
UNIVAR/SVITH	Sweden	Univar Chain Saw Oil		Premium mineral and bio-oils used in pro forestry.

Table 3. Examples of price for fossil chain-saw oils, on the market[7]

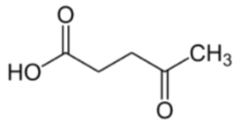
[7] Information collected from various webpages like, Kelkoo, BAUHAUS, Jula, Granngården, Reservdelar , PANOLIN, Univar Solutions and others

4.1 Raw materials

4.1.1 Biobased acids

In the project three biobased acids, levulinic, itaconic and lactic, were selected for further investigation, below a short description of each of the acid is provided alongside suppliers, market volumes and price indications.

Levulinic acid

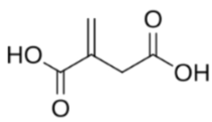


Levulinic acid can be produced by acid treatment of starch or the C6-carbohydrates in lignocellulosic biomass via the hydration of HMF, an intermediate in this reaction. A side product of this reaction is formic acid which is produced in equimolar amounts (33, 155). It is also possible to obtain levulinic acid from the five carbon carbohydrates in hemicellulose (e.g. xylose, arabinose) by addition of a reduction step (via furfuryl alcohol) subsequent to the acid treatment. Levulinic acid contains two reactive functional groups that allow a great number of synthetic transformations.

It is manufactured in industrial quantities and the global capacity 2025 was estimated to reach 22 000 tons[8]. Industrial players include GF Biochemicals[9], who took over the patent portfolio of Segetis in 2016, and is now commercializing levulinic ketals for a variety of applications. Other suppliers include Biofine Developments Northeast[10], supplier of biobased chemicals and fuels, and Langfang Triple Well[11] and Hefei TNJ[12], both suppliers of biobased chemicals for various applications. The expansion in production is mainly seen in Asia.

The price varies, depending on the cost of the incoming raw materials and the quality of the product, and can fluctuate from $0,4-~$1/kg.

Itaconic acid



Itaconic acid is mainly produced via a fermentation turning glucose derived from plant-based sources like corn starch, which is common in the US, China and Brazil, or from starch from wheat or potatoes, which is the more common source in Europe. Most of the activities increasing production are concentrated to China.

Just like levulinic acid, itaconic acid is gaining an increased attention as a biobased platform chemical. In a similar way to levulinic acid it has more than one reactive functional group.

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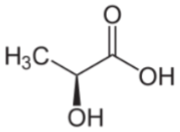
[8] Levulinic Acid Market - Size, Share & Analysis 2025-2030
[9] GFBiochemicals
[10] BDNE Inc.
[11] LangFang Hawk T&D
[12] TNJ Chemical Industry Co.,Ltd.

The global production is about 40 000 tons/y, but with the expansion plans, particularly in China, it is projected to reach volumes between 52 000 tons/y up to 170 000 tons/y already 2025[13]. Suppliers of itaconic acid are for example Itaconix[14], Cambridge Isotope Laboratories[15], SAE Manufacturing[16] and Catalynt[17].

Current price for itaconic acid, ~1,2-$2,1/kg[18], is volatile and depends strongly on the geographical site.

Lactic acid



Lactic acid is a bulk chemical with a global production capacity of over 1,4 million tons[19]. Lactic acid has a long history of applications in various applications like the food and beverage sector, in the pharmaceutical and chemical industries and as the starting material for the biobased polymer PLA.

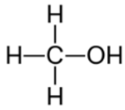
Corbion[20] is the world leader in lactic acid production and is actively exploiting their technology base through its joint-venture Total-Corbion. The company recently announced the opening of their 75,000 tons/year plant in Thailand. Other companies active in PLA include Galactic[21], Futerro[22] and Henan Jindan[23] in China.

Price levels for bulk are in the region of $2-$13/kg[24, 25]. The variation depends strongly on quantity ordered and quality of the lactic acid.

4.1.2 Biobased alcohol

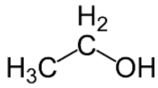
Alcohols used in the synthesis work were methanol, ethanol, 1,8-octanediol, triethylene glycol, glycerol, pentaerythritol, 1-octanol, 2-octanol, undecanol, citronellol, 2-ethyl-hexanol, 3-pentanol, cyclohexanol, and diethylenglycol monomethylether. Global production and price levels have only been investigated for a limited number of the alcohols used in the project.

[13] JÚLIO C. DE CARVALHO*, et. Al, Biobased itaconic acid market and research trends - is it really a promising chemical?, Chimica Oggi - Chemistry Today - vol. 36(4) July/August 2018
[14] Itaconix: Pioneering Sustainability in Consumer Products | Itaconix
[15] Cambridge Isotope Laboratories, Inc. – Stable Isotopes
[16] SAE Manufacturing
[17] Catalynt
[18] Itaconic Acid Prices, Chart, News, Analysis and Demand
[19] Lactic Acid Market Size, Share, Growth & Forecast 2035
[20] Preserving what matters | Corbion
[21] Home | Galactic Manufacturer of Lactic acid
[22] Futerro PLA leader in the bioplastics market | Futerro
[23] Henan Jindan lactic acid Technology Co., Ltd.
[24] Univar Solutions
[25] Global Lactic acid Price | Tridge



Methanol

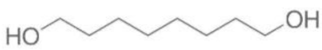
The smallest and simplest alcohol. The main application is in the chemical industry as an intermediate in processes but also as fuel in the transportation sector. The global methanol production is estimated to be 250 million litres[26]. Price levels vary with geography from $0,3/kg in China to ~$0,8/kg in the US[27].



Ethanol

Ethanol is produced in abundant volumes, 2025 it was estimated to be 118 billion liters globally[28]. Ethanol has versatile applications, replacing fossil fuels in the transportation sector, solvent or cleaning agent in industrial applications and intermediate in chemical processes and much more. The main feedstock is corn.

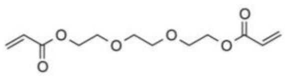
Bulk prices stretch from $0,65/l in the US to $2,9/l in Spain[29].



1,8-octandiol

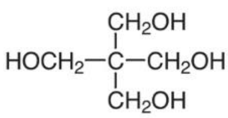
1,8-octandiol is used in the cosmetic industry as an emollient and humectant but also as a monomer in polyesters and polyurethanes.

No information on global production nor on bulk prices could be found.



Triethylene glycol

Used in the industry as disinfectant and dehydration, dehumidification systems. Global production, 2022 was estimated to 880 000 tons[30]. Price indication in 2024 varies from $1,2/kg in the US to $1,6/kg in Germany[31].



Pentaerythritol

Pentaerythritol is commonly used as an intermediate in the chemical industry. In 2022 the global production was estimated to 625 000 tons[32].The price in 2024 varied from $1,4/kg in Saudi Arabia to $2,16/kg in the US.[33]

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[26] f3
[27] Methanol Price|Methanol Institute|methanolorg.wpenginepowered.com
[28] Bioethanol Market Size, Share & Competitive Landscape 2030
[29] Ethanol prices around the world, 24-Nov-2025 | GlobalPetrolPrices.com
[30] Triethylene glycol
[31] Triethylene Glycol (TEG) Prices, News, Chart and Demand
32 New message from Taylor
33 Pentaerythritol (PENT) Prices, News, Analysis and Demand

Without considering the chemistry in detail, it seems reasonable to assume that the suggested biobased esters could be cost competitive with refined rapeseed oils, but it will be very dependent on the chemistry, energy, time etc. which is still unknown factors.

For example, the raw material cost for a product based on levulinic acid and triethylene glycol would be somewhere in the range of ~$2-$3 depending on the qualities of the ingredients and the process. This can be compared with the market price for refined rapeseed oil at approximately ~$1,4/kg[34]

5. Conclusions

There are favorable conditions for using bio-based platform chemicals for the synthesis of esters for lubricant applications. The purpose of the project has been to carry out preliminary study/screening in which various esters have been synthesized based on itaconic acid, lactic acid, and levulinic acid together with bio-based alcohols, and evaluated based on relevant properties for lubricant and hydraulic oil applications.

The vision has been to utilize chemicals that to our best knowledge can be produced from side streams from the agricultural industry (e.g., from Lantmännens operations). By utilizing side streams for the production of a new product, a functional substitute for the fossil-based oils of today, we have not only increased the value of the stream but also contributed to a more circular system.

The Techno-economical evaluation also shows that there is a good economic potential for these biobased alternatives.

This work confirms that levulinic, lactic, and itaconic acids can be used as bio-based building blocks for ester lubricants. The synthesized esters showed high yields and purity but relatively low viscosities. Optimization of alcohol chain length and multifunctionality, combined with potential post-functionalization, can lead to improved lubricant properties. The scalability of these synthetic routes supports their potential for industrial bio-lubricant applications.

The project demonstrated the feasibility of scalable synthesis of biobased esters suitable for lubricant applications. However, the viscosity profiles did not meet the desired specifications. Future improvements could include:

- Using longer-chain or branched alcohols to increase hydrophobic interactions.
- Employing alternative multifunctional alcohols.
- Exploring functionalization of itaconic esters via the alkene group to achieve higher viscosity.

[34] Rapeseed Oil Prices, Trends, Chart, News, Index and Market Demand

- Further pilot-scale synthesis (0.5–5 kg) was identified as a challenge due to limited equipment availability. Additionally, these biobased esters could potentially serve as additive components in existing lubricant formulations.
- More in-depth analysis of the process and the impact on the price levels
- Field test of the oils
- Investigation of the biodegradability