FINAL REPORT

Analysis Of The European Crude Tall Oil Industry – Environmental impact, Socio-Economic value & Downstream potential

Short Title: EU CTO – Added Value Study

Dated: 11 May 2016

Fraunhofer
UMSICHT

For:
Mr. Charles Morris
President and COO
Pine Chemicals Association, Inc.
P.O. Box 17136
Fernandina Beach, FL 32035-3136
USA

Oberhausen, 11 May 2016

Fraunhofer
UMSICHT

FINAL REPORT

Analysis Of The European Crude Tall Oil Industry – Environmental impact, Socio-Economic value & Downstream potential

Short Title: EU CTO – Added Value Study

Presented by:

Fraunhofer Institute for
Environmental, Safety and Energy Technology UMSICHT
Director
Prof. Eckhard Weidner

Osterfelder Strasse 3
46047 Oberhausen

Germany

Project team:

Name	Telephone	E-Mail
Venkat K. Rajendran*	+49 208 8598 1417	venkat.rajendran@umsicht.fraunhofer.de
Klaas Breitkreuz	+49 208 8598 1300	klaas.breitkreuz@umsicht.fraunhofer.de
Dr. Axel Kraft	+49 208 8598 1167	axel.kraft@umsicht.fraunhofer.de
Dr. Daniel Maga	+49 208 8598 1191	daniel.maga@umsicht.fraunhofer.de
Mercè Font Brucart	+49 208 8598 1139	merce.font.brucart@umsicht.fraunhofer.de

**Project Manager*

Oberhausen, 11 May 2016

Table of Contents

1 Executive Summary

The European pine chemicals industry has been in existence for over 80 years as a major end user of the by-products resulting from the European paper and pulp industry. Crude Tall Oil (CTO), one of the commercially valuable by-products of the Kraft pulping process, is processed and upgraded by CTO bio-refineries into a wide array of products such as adhesives, coatings, fuel additives, mining and oilfield chemicals, lubricants, rubber emulsifiers, surfactants, paper size chemicals and fuels (as residue). The CTO bio-refineries have key production facilities in Austria, France, Finland and Sweden, with added downstream processing and upgrading operations across Europe.

The present-day CTO refining and upgrading industry serves as an example for resource efficiency through its cascading use of biomass resources, making highest value bio-based chemicals first before utilising final material for biofuels and energetic use. In doing so, the pine chemical industry also contributes to the European Union's 'Circular Economy' goals by using biomass resources in a more sustainable way. Furthermore, the cascading principle applied by the pine chemical industry ensures that economic and social value of this biomass raw material is maximised through several sequences of product upgrading and processing along the downstream value chain.

CTO is bio-based raw material with a constrained annual global volume of around 2 million tonnes and an EU wide availability of approximately 650,000 tonnes. As a by-product of papermaking industry, CTO volumes remain limited by the production volume of the Kraft pulping process, where approximately 35-40 kg of CTO is obtained per tonne of pulp. This reflects that there is a finite volume of CTO available on the world market and any increase in demand for CTO does not lead to an increase in supply. The European crude tall oil industry has for many decades, processed this limited resource in technically complex biorefineries to produce bio-based chemicals and intermediates which are building blocks for a number of industrial chemicals and everyday end-use products.

However, the current Renewable Energy Directive (RED) (Directive 2009/28/EC) "*on the promotion of the use of energy from renewable sources*", as amended by (Directive (EU) 2015/1513), contains a definition for "processing residue" under Article 2. Although CTO falls outside this definition, the point (o) in Part A of Annex IX of the RED incorrectly lists CTO as a "*biomass fraction of wastes and residues from forestry and forest-based industries*" and that when used for production of biofuels, can be double counted (considered to be twice its energy content) against the Member States' 2020 targets for energy in transport set by the RED. The RED is a key legislative act that sets out the legal obligations and national targets for Member States to help the EU reach the 2020 targets, where at least 20% of the total energy demand must be renewable; and at least 10% of Member States' transportation fuels must come from renewable sources.

When implementing RED and in order to meet their respective national renewable energy targets some Member States have put in place state aid schemes to support the production of biofuels and encourage CTO and other raw materials for energetic use rather than for creating bio-based products of higher value. Consequently, there is now an increased demand for CTO that is already fully utilised by the European pine chemical industry in producing bio-based chemicals.

As CTO is a constrained raw material, this study undertook a scientific, quantified and a comprehensive analysis to estimate and compare the **environmental impact**, the **economic added value (EAV)**, and the **social impact** (direct, indirect and induced jobs) of the existing European pine chemical industry refining CTO to bio-based chemicals to that from the competing process route converting CTO into biofuel (renewable diesel). Both cases were based on the assumption that all 650,000 tonnes of the CTO available in the EU were utilised in their respective processing routes.

In conclusion, the key findings of this study are summarised as follows:

- Utilising CTO in the full life cycle of production, use and disposal of industrial and consumer chemicals produces slightly lower amounts of Green House gas (GHG) emissions compared to using the same amount of CTO in the production and consumption of renewable diesel.
- The economic added value generated by the entire pine chemicals industry (CTO refiners and the extended downstream operators along the value chain) is at least 4 times more than the added value generated from the production of renewable diesel. The total economic added value generated by pine chemicals was estimated to be around 1,800 million euros, whereas the renewable diesel would have generated only 300 million euros (for the base year 2015).
- The European pine chemicals industry has a significant social impact in terms of generated employment compared to the renewable diesel production route. The upstream pine chemicals industry alone generated a total employment of 4000 jobs (1000 direct jobs and 3000 indirect jobs); whilst the downstream CTO derived chemicals generated an additional 5,100 jobs, yielding in total about 9,100 jobs. On the contrary, the renewable diesel production route was estimated to generate only 400 jobs in total (100

direct jobs and 300 indirect jobs). Thus, the total employment generated by the pine chemicals industry and its downstream value chain is at least 20 times more than that generated from the production of renewable diesel.

- If all available CTO in the EU (650,000 tonnes per year) were to be converted to biofuels with a theoretical yield of 100%, it would only contribute to a mere additional 0.2% to the total EU transportation fuels consumed in 2014.

In more detail the findings are as follows:

The **environmental impact** was estimated by conducting a life cycle assessment for both cases, where the global warming potential (GWP) was used as the sole indicator. The GWP is represented in terms of the greenhouse gas (GHG) emissions measured in kg CO_2 eq./t CTO. For the production of bio-based chemicals from CTO the calculated GHG emissions amounted to 940 kg CO_2 eq./t CTO and for the production of renewable diesel from CTO the values were 1,218 kg CO_2 eq./t CTO. Therefore, the amount of greenhouse gas emissions associated with the production of renewable diesel is higher than the amount linked to the production of CTO fractions used for industrial and consumer chemical products. This difference is mainly attributed to intensive energy demand for hydrogen production required for CTO hydroprocessing into biofuel.

Additionally, system expansion calculations were made to account for the amount of total saved emissions for both cases. With system expansion calculations, the estimated savings generated from utilising CTO for bio-based chemicals was -2,256 kg CO_2 eq./t CTO and the estimated savings resulting from using CTO for renewable diesel was -2,118 kg CO_2 eq./t CTO. Therefore, it could be concluded that there is no significant difference in comparitive savings potential of GHG emissions resulting from diverting CTO into the production of renewable diesel from its current utilisation in the production of bio-based chemicals.

The **economic added value (EAV)** generated by the existing pine chemical industry by upgrading CTO into valuable products was calculated for within the business-to-business (B2B) limits. This was done by taking into account all major CTO product lines entering various application areas along the downstream value chain for two steps from the primary industry (CTO fractionators). For each of these B2B interactions, typical CTO percentages within respective product lines and the typical product prices along the value chain were identified and determined for the calculations. Additionally, the EAV generated from the conversion of CTO into renewable diesel was calculated on the basis that 100% or all the available 650,000 tonnes of CTO in Europe would be diverted into biofuel production. A most likely processing pathway was employed and assessed, based on data from a real production process for hydroprocessing of fats and oils as well as from published scientific data on hydroprocessing of crude tall oil. In particular this pathway addresses transportation fuels in the so-called middle distillate range - currently diesel and potentially Jet-fuel in the future.The EAV calculations for both the cases were estimated for the base year 2015.

It was found that the existing value chain of the EU pine chemical industry for CTO derived chemicals generates an economic added value of about 1,800 million euros, whereas the 100% diversion of CTO into renewable diesel generates only around 300 million euros. Therefore, the economic added value generated by the pine chemicals industry is at least 4 times and extending upto 6 times more than that generated in the scenario for fuel production, where 100% diversion of the feedstock to fuel production was assumed.

Finally, the **social impact** assessments were made by accounting for the direct, indirect and the induced job effects arising from the economic activity in both the competing process routes. It was estimated that the EU pine chemicals industry generates 1,000 direct jobs directly attributed to the primary industry, whilst an additional 3,000 jobs are generated as a result of inter-industry transactions and exchange of goods and services. Furthermore, an additional 5,100 direct jobs were estimated to be generated by the processing of crude tall oil intermediates and products in the downstream industry. yielding in total about 9,100 jobs. For the process route involving the production of renewable diesel this number yielded a very low figure, where the estimated direct and indirect jobs were 100 and 300 respectively yielding in total only 400 jobs. For the renewable diesel case, it was assumed that no downstream jobs are generated, since the product chain terminates with the production of renewable diesel with no subsequent extension of the value chain. Thus, the total employment generated by the pine chemicals industry and its downstream value chain is at least 20 times more than that generated from the production of renewable diesel.

2 Background

In light of the current Renewable Energy Directive (RED) (Directive 2009/28/EC "*on the promotion of the use of energy from renewable sources*", as amended by (Directive (EU) 2015/1513), Crude Tall Oil (CTO), amongst others is listed under point (o) in Part A of Annex-IX, as feedstock that can be double counted for its contribution towards the Member States' 2020 transport fuel targets.

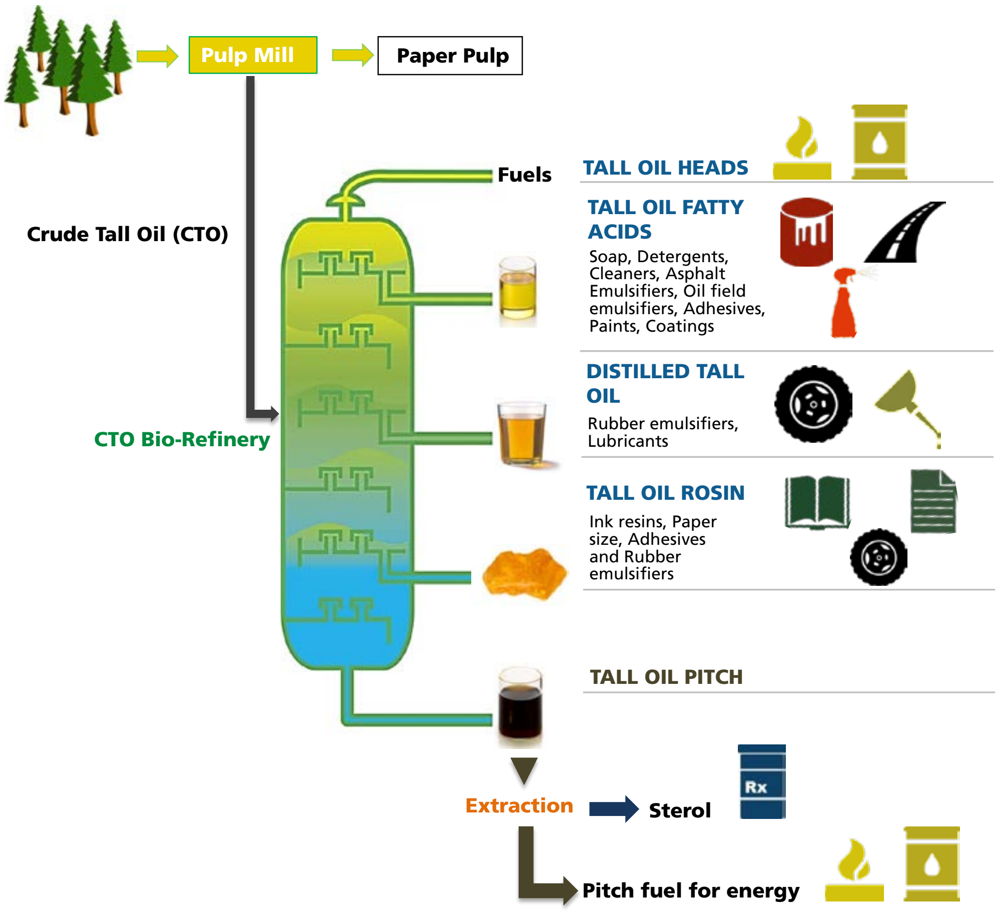
CTO being a constrained raw material that has been in use by the European pine chemical industry for the past 80 years, this research aims to conduct a wide-ranging analysis in making a case for an intelligent utilisation of such scarce feedstocks. CTO is a commercially important by-product of the paper and pulp industry, it is a complex mixture of Tall Oil Fatty Acids (TOFA), Distilled Tall Oil (DTO), Tall Oil Rosins (TOR), Tall Oil Pitch (TOP) and other light ends with the following Chemical Abstract Service (CAS) number: TOFA (CAS no. 61790-12-3); TOR (CAS no. 8050-09-7) and DTO (CAS no. 8002-26-4). Considering the fact that CTO is a key feedstock contributing to the European biochemical industry, this study also aims to comprehend the unintended setback such classification could potentially have on the established European pine chemicals industry when the raw material is diverted to competing energetic use.

CTO is a scarce renewable resource with a global availability of less than 2 million tonnes per annum and EU wide availability limited to about 650,000 tonnes per annum. As a by-product of the papermaking industry, CTO volumes remain limited by the production volume of the Kraft pulp process. To put this in context, in 2014, the total EU biofuel consumption was estimated at 14 Million tonnes (EurObserv'ER-2015). Therefore, just one medium sized refinery or a power station could take up the entire available European CTO feedstock. Furthermore, a simple back-of-the envelope cost-benefit analysis provides a convincing argument that diverting this very limited raw material from its maximum resource use to energetic use for biofuels will make next to little difference in its contribution to the overall EU biofuel share.

Therefore, such imbalanced incentivisation towards energetic use compromises the best practise principle of "Cascading use" (see Figure 3-2, page 15). Hence, through a cascading use (de Besi & McCormick-2015; EEB-2015) of CTO starting from refining and processing of CTO to make highest value bio-based chemicals first before utilising the final residue for biofuels and energetic use will not only address the issue of resource efficiency but also contribute to the European Union's ambitious circular economy goals (COM/2015/0614) where resources are to be used in a more sustainable way. The listing of CTO as "processing residue" and enabling it for double counting, not only provides unfair competitive advantage to the biofuel industry, but also could potentially threaten the existence of an established 80 year old European pine chemical industry which relies on this constrained raw material.

CTO is recovered during the traditional Kraft pulping process for paper making. For decades, the EU pine chemical industry has operated complex bio refineries across Europe to process CTO into a multitude of upgraded high value added products (see Figure 2-1). These are used as building blocks for several market applications used in everyday consumer products.

Figure 2-1:
Cascading use in a pine chemicals bio-refinery (modified from HARRPA-2015)



CTO bio-refineries are capital intensive industries that employ complex and highly innovative technologies and operations to process CTO into its individual components viz., TOFA, TOR, DTO and TOP. These complex operations require highly skilled workforce and supporting staff, generating engineering, R&D, chemistry, technicians, sales & marketing and administration jobs. In Europe the CTO bio-refineries are spread across Austria, Finland, France and Sweden and downstream companies processing and upgrading the primary pine chemicals are located across Europe.

This study takes a scientific, quantified analysis to estimate the environmental impact, economic added value (EAV) and the social impact generated by the existing CTO based industry in contrast to the competing route of converting CTO into biofuel. Therefore, the analysis and estimation of this study comprises of the following:

a) Determination of the environmental impact of the EU pine chemical industry in contrast with other competing processes and substitutional products.

b) The economic added value measured in revenue generated by crude tall oil fractions processed into a wide range of industrial application areas is quantified and compared to that generated in using CTO directly as a biofuel.

c) Finally, the determination of the social impact with specific focus on the generated jobs.

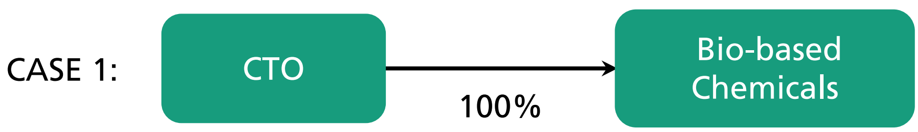
2.1 Scope of Work

The overall goal of the study is to make a reliable analysis in comparing the total added value generated from the resource use of CTO in producing bio-based chemicals to that resulting from producing biofuels.

The scope of the study thus covers a methodological and structural analysis of the European pine chemical industry starting from the segmentation of the CTO intermediates namely, TOFA, DTO, TOR and TOP produced by the CTO refiners. These primary intermediate fractions are then mapped along their respective downstream value chains and segments based on the major product lines and predominant product application areas (see Figure 2-4). A methodological compilation of these product application areas based on their respective market volumes and market revenues is shown in Table 3-2 (see page 20).

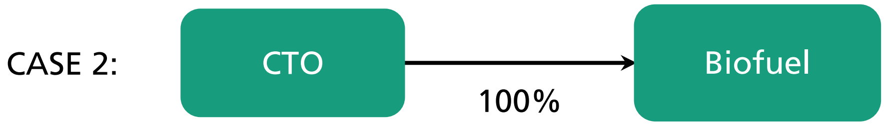
An industry level analysis was performed to estimate the total value generated by the EU pine chemicals industry by estimating the Economic Added Value (EAV) derived from the revenues, the generated social value in terms of direct and indirect jobs, and finally the environmental value of producing crude tall oil based bio-chemicals against its petroleum substitutes. For this case, as shown in Figure 2-2, a process route with 100% utilisation of CTO to Bio-based chemicals was assumed.

Figure 2-2:
Case 1: CTO to bio-based chemicals



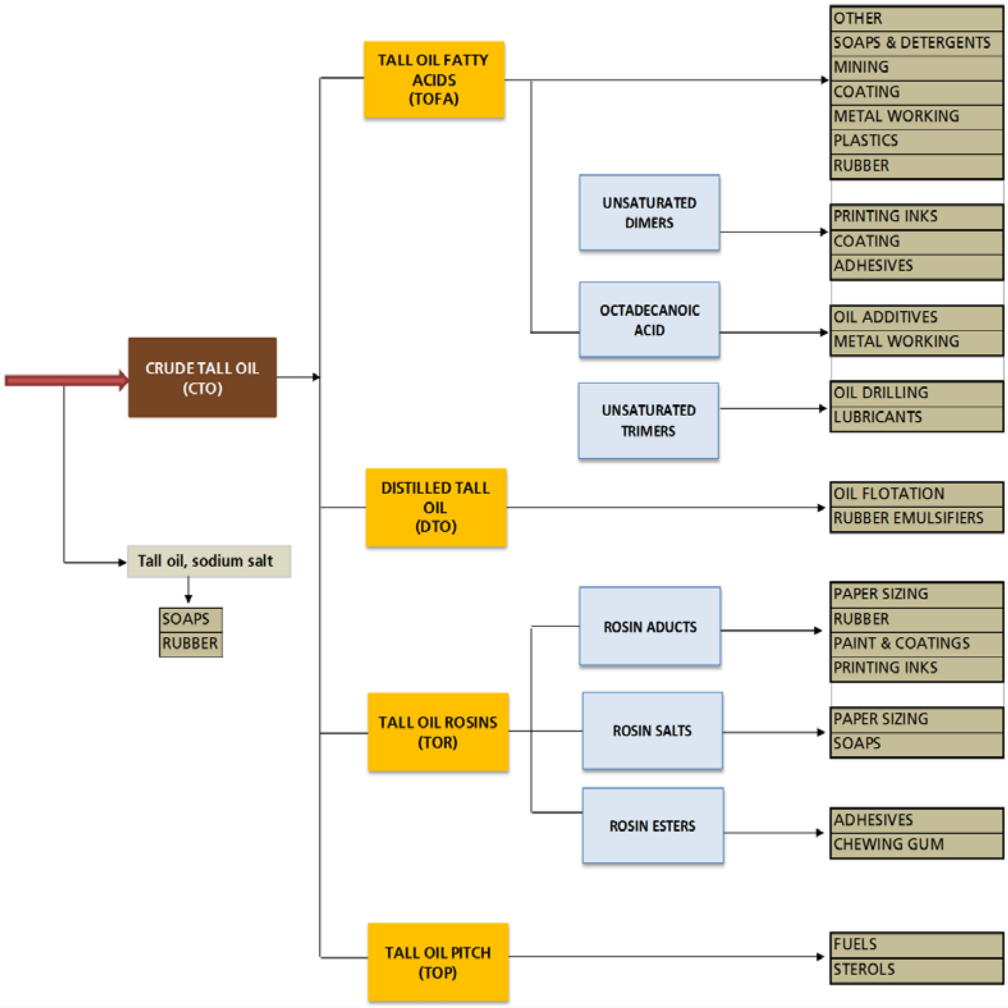
In addition, the study also makes a comprehensive analysis of the value generated by the competing process route for the energetic use of converting CTO to renewable diesel. The economic value, social value, and environmental value generated through the diversion of the feedstock from its current principal usage in the bio-based chemical industry to biofuels industry for the production of renewable diesel was thoroughly assessed. For this case, as shown in Figure 2-3, a process route with 100% utilisation of CTO to Biofuel (renewable diesel) was assumed.

Figure 2-3:
Case 2: CTO to renewable diesel



For both cases the added value estimates were calculated for the base year 2015. For the chemical products the adjusted prices were done using the Eurostat producer price index (PPI) for the manufacture of chemicals and chemical products, while for fuels the EU commodity prices were taken.

Figure 2-4:
Crude Tall Oil processing: inter-mediates, products and markets (modified from PCA-2003)



2.2 Overall methodology

This study takes a three-fold approach to realise the scope in analysing the impact of the utilisation of the constrained raw material, crude tall oil into two processing routes – (a) for bio-based chemicals and (b) for renewable diesel by:

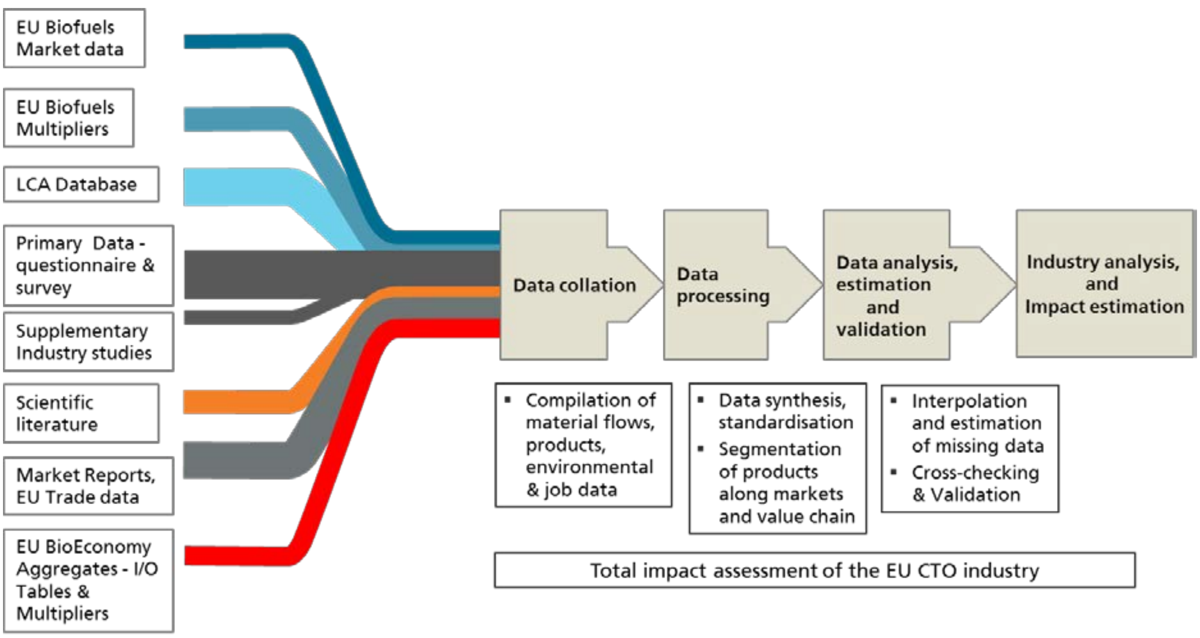
i) Capturing the environmental impact through comparative distribution of greenhouse gas emissions including system expansion study and investigating respective product substitutional effects for both processing routes.

ii) Estimating the economic added value (EAV) generated by the existing European pine chemical industry in comparison to the renewable diesel route on the generated economic added value.

iii) Determining the social impact resulting from both processing routes measured in terms of direct, indirect and induced jobs as well as contrasting the socio-economic potential and job displacement/loss thereof resulting from the scenarios from a competitive standpoint.

Figure 2-5 below outlines the research methodology and the spectrum of primary and secondary data used in conducting this study.

Figure 2-5:
Research Methodology



The primary research involved collecting information from questionnaires sent to companies engaged in the pine chemicals industry. This provided direct information on the market size, growth patterns, competitive landscape etc. The secondary research involved additional sources including industry studies, market reports (Frost & Sullivan, research and markets), pricing reports (e.g. ICIS, Argus media, Indexmundi), industry presentations, governmental publications, scientific papers and official trade statistics (e.g. Eurostat, Comtrade). Data from these sources was used to develop a model which estimated the economic added value and total Job impacts for both cases. All prices have been adjusted to the base year 2015 with the Eurostat producer price index (PPI) for the manufacture of chemicals and chemical products.

2.3 Assumptions

All analysis and estimations derived from this study were made in the context of the European market, to be specific EU-27 in particular. The overall assumptions made in this study are listed below.

- Only the EU wide available CTO of 650,000 tonnes is considered in this study, any other quantities imported into the EU market is excluded from the analysis.
- Market size and market estimates for each CTO intermediate fractions (TOFA, DTO, TOR and TOP) were based on the primary and secondary data which provided production volumes, sales volumes and sales revenues.
- All prices considered in calculating revenues from the CTO fractions as well as the upgraded CTO fractions were obtained through several primary and secondary quotes (prices in Euros).
- All prices considered in calculating revenues from the upgraded CTO fractions ending in the final application area were obtained from bulk commodity prices (prices in Euros).
- All prices for the calculation of the Economic Added Value (EAV) have been extrapolated to 2015 as a base year using Eurostat the producer price indices (PPI) for the manufacture of Chemicals and chemical products.
- The calculated EAV is limited to transactions within the B2B sector. Additional added value is generated within the B2C section, wherein typical multipliers ranging from 3 to 50 (e.g. for printing inks) for certain end-use products can be expected.
- All mass balances within the EAV calculation are consistent to the ones used in the LCA (Life Cycle Assessment) for this study.

- The generated data on the number of direct jobs for both the biochemical use as well as the biofuels use were estimated through primary research on publicly available resources.
- The generated data on the number of indirect jobs for both bio-based chemical use as well as biofuel use were estimated using the widely accepted CEFIC multiplier (CEFIC-2016) for the chemical industry in Europe.
- The generated data on the number of induced jobs for both bio-based chemical use as well as biofuel use were estimated using the Eurostat biochemical industry (Eurostat-2014) multiplier effect on job creation per million euros of respective industry revenues.
- For the LCA, only the global warming potential was used as an environmental impact indicator, but it was considered to be appropriate for the scale of the study, as emissions of greenhouse gases have a global effect and their measurement is internationally standardized.
- In the LCA, for Case 1, the following substitutional reference compounds were used: (a) TOR substituted by gum rosin, alkylsuccinic acid, C5 hydrocarbon resins, and acrylic resin; (b) TOFA by soybean oil; and (c) DTO by petroleum sulfonates. For Case 2, it was assumed that renewable diesel replaces fossil diesel. For both cases, it was considered that the TOP fraction can be substituted by heavy oil.
- In the LCA, for Case 2, it was assumed that the fraction of CTO that undergoes hydroprocessing is depitched CTO, which was obtained from the separation of the TOP fraction from CTO in a previous distillation step. Accordingly, experimental results obtained for hydroprocessed, depitched CTO (Anthonykutty et al.-2013) were used to determine the mass balance.

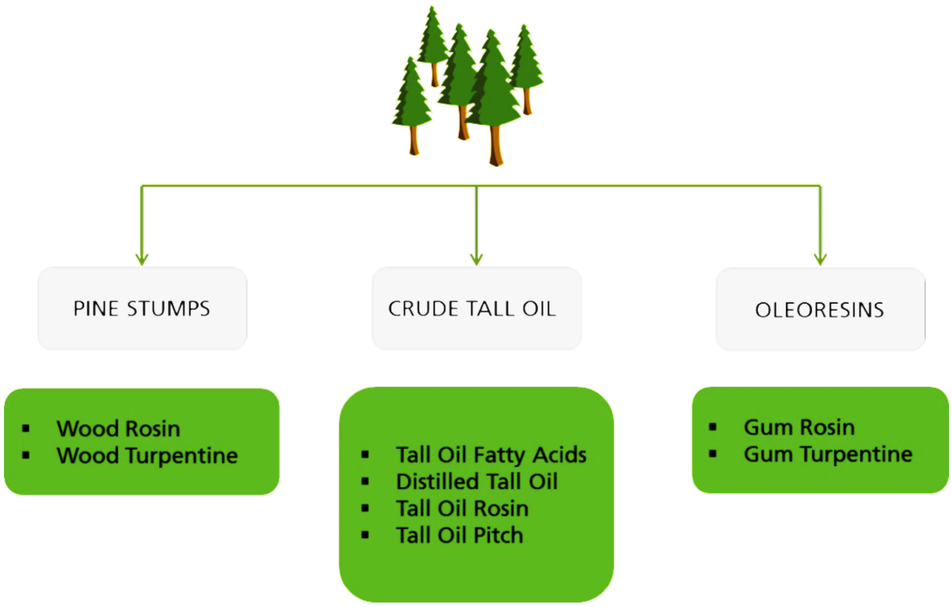
3 European Pine Chemical Industry

Pine chemicals can be categorised as one of the earliest segments of the European chemical industry, where tapping pine trees for gums and using primitive forms of pine tars and pitch date back to historical times. Pine chemicals today play an important role contributing to the EU bioeconomy with upscale jobs and a multitude of consumer products. These products are by and large derived from three pathways as shown in Figure 3-1, namely:

- Recovering by-products from the Kraft process for paper making
- tapping living trees for oleoresins
- extracting wood rosins from aged pine stumps

The scope of this study is limited to pine chemicals recovered in the sulphate or Kraft pulping process.

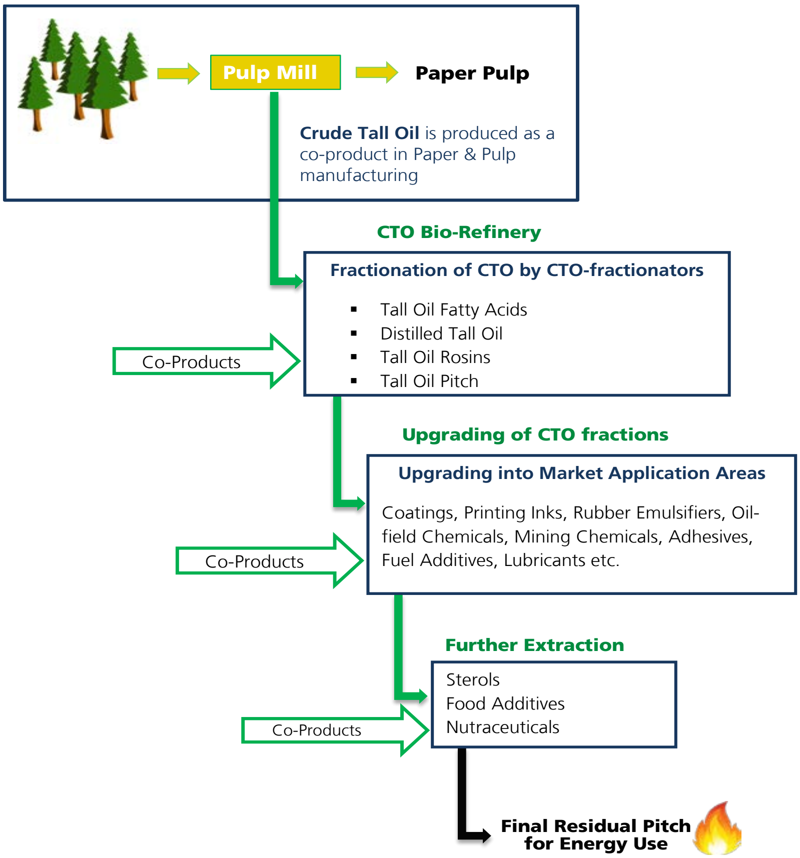
Figure 3-1: Pine chemicals pathways (modified from, ACC-2011)



Since CTO is a by-product of the pulp making process, its supply is constrained to the Kraft pulp production, in fact CTO is imported into the European Union from other parts of the world to provide adequate supplies for the EU pine chemical industry. The European crude tall oil industry relies on this constrained renewable resource to produce bio-based chemicals and intermediates. Bio-refineries spread across the geographical area of Europe process these biomass raw materials into pure fractions (TOFA, DTO, TOR and TOP) which are building blocks for a number of industrial chemicals. These fractions are further subjected to several sequences of upgrading before ending up in a final product. In doing so, this relatively small industry provides added value of several folds throughout its value chain.

The CTO refining and upgrading industry in Europe also serves as an example for resource efficiency through its cascading use of biomass resources. The principle of cascading use ensures resource efficiency, efficient land use as well as effectiveness of material usage (EEB, 2015). The cascading practise in the pine chemical industry as shown in Figure 3-2 ensures that products of higher value are produced from CTO, thus prolonging the value chain and maximizing the economic and social value of this important bio-based raw material.

Figure 3-2:
Cascading use of CTO in Pine Chemicals



The cascading use principle prioritises and ascertains that through each process step the resulting by-product or residue is converted into a product of higher value. This continues until such a point where no further value could be extracted, at which time the resulting final residue is used as a fuel for energy use. Furthermore, burning or incineration of a raw material for energy use before extracting its highest value is not only contrary to EU targets and policy plan on circular economy, but such a practice also halts legitimate options to provide bio-based alternatives to petroleum derived products, as is currently achieved by the existing pine chemicals industry.

3.1 Composition of Crude Tall Oil (CTO)

Crude tall oil like any other bio-based raw material has varying composition based on several factors such as the type of the pine trees, geographical location etc.

Due to the complex nature of the feedstock and the lack of a more detailed available data on a widely accepted composition, the scientific studies published by VTT (Anthonykutty et al.-2013) for hydrotreating and hydro-cracking of "depitched" rosin rich fractions called DTO (renamed as Tall Oil Distillate in this study) has been employed as a design basis for the purposes of modelling the biofuel process.

The reason for using the depitched fraction as a basis was to make a fair and balanced analysis on the environmental foot-print for cases 1 and 2. It was assumed that for both cases Tall oil Pitch (TOP) will be sold "as is" and not be processed further. Therefore, any value generated from TOP for either case is simply equated to the price of the Lower Heating Value (LHV) of pitch fuel.

The composition of the crude tall oil fraction used as a reference feed for Case2 is shown in the following Table 3-1. Therefore, for all LCA calculations the composition of Tall Oil Distillate will be assumed as the basis.

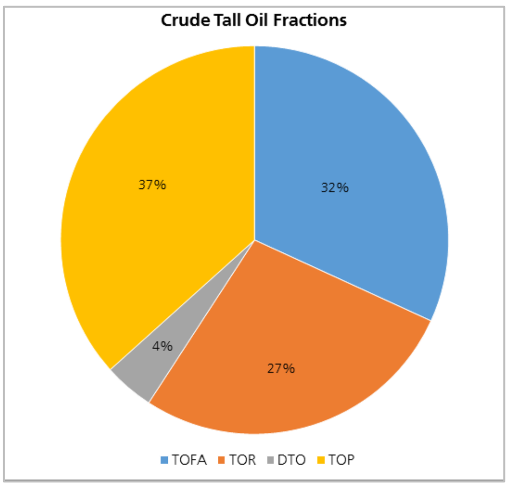
Table 3-1: Detailed composition of Tall Oil Distillate.

ELEMENTAL COMPOSITION	FRACTION
Carbon	77,4
Hydrogen	11,1
Sulphur	0,05
Oxygen	11,5
TOTAL free fatty acids (FFA)	**71,3**
Palmitic acid	0,2
Margaric acid	0,3
Stearic acid	0,7
Oleic acid	15,3
11-octadecenoic acid	0,5
5,9-octadecadienoic acid	0,3
Conjugated octadecadienoic acid	8,3
Linoleic acid	24,3
Pinolenic acid	4,4
Linolenic acid	0,6

ELEMENTAL COMPOSITION	FRACTION
Conj. octadecatrienoic acid	1,8
Arachidic acid	0,4
5,11,14-eicosatrienoic acid	7,6
Behenic acid	0,6
other fatty acids	6
TOTAL resin acids	**23**
8,15-isopimaradien-18-oic acid	0,5
Pimaric acid	4,8
Sandaracopimaric acid	0,3
Diabietic acid	0,5
Palustric acid	2,2
Isopimaric acid	1,1
13-B-7,9(11)-abietic acid	0,4
8,12-abietic acid	0,3
Abietic acid	7,7
Dehydroabietic acid	3,6
Neoabietic acid	0,4
Other resin acids	1,3

For the socio-economic calculations in Case 1 corresponding to the conversion into bio-based products, the following intermediate fraction shown in Figure 3-3 is considered. This composition is a typical profile of EU based CTO fractions and is estimated from an aggregated combination of primary and secondary data.

Figure 3-3:
EU CTO intermediates fraction



3.2 Crude Tall Oil – Drivers and Constraints

Crude Tall oil, a by-product of the paper and pulp industry, is used in a multitude of applications highlighted before, but is constrained by its resource availability. Historically the CTO bio-refining industry has largely been raw material limited, thus operating production volumes are close to name plate capacity. It is estimated that there is a global availability of about 2 million tonnes of CTO available for use in chemical product applications. European CTO production is about 650,000 tonnes. Therefore, any new alternative use for CTO at the level of 100,000 tonnes or more will have a significant impact on the existing EU CTO bio refining industry. In this case the diversion of (CTO) from the established pine chemicals industry to a new industry (biofuels) will certainly drive up raw material prices.

This potential spike in raw material price resulting from the increased demand for the constrained raw material by the two competing industries will make the economic prospects for biofuel manufacturers less attractive or even unfeasible to operate without large EU subsidies. In the case of the existing pine chemical industry, the downward trend in operating margins resulting from such a feedstock diversion could well be tolerated for a short term period of perhaps a few years as it is common knowledge that chemical industries in general operate on higher gross margins compared to a typical fuel industry which operates on higher volumes.

However, it must also be noted that the immediate impact of any such diversion could lead to a potential loss in associated employment, and will potentially place invested capital in CTO biorefineries at risk as the chemical refining processes will have to be scaled back to match the available raw material. Employment effects for such scenarios are investigated in section 6.5.

Demand for CTO based end-use products is derived from a large number of market applications including - paints/coatings, adhesives, food additives, chewing gum, soaps & detergents, synthetic rubber, lubricants, fuel additives, inks, paper sizing chemicals, oilfield and mining chemicals. Many of the pine chemical products are also highly competitive in terms of environmental foot-print in comparison to their respective petrochemical based alternatives (Cashman et al. -2015). The market attractiveness analysis presented in section 3.4.1 highlights the overall market demand and attractiveness of the above mentioned application areas with respect to CTO derived pine chemicals as well as market revenues and future trends. As such the pine chemicals industry helps to promote the goals of the regulations and policies set by the European Union to increase its share of bio-based chemicals. It is estimated that the market share of bio-based products will amount to 40 billion euros by 2020 (Biochem-2010).

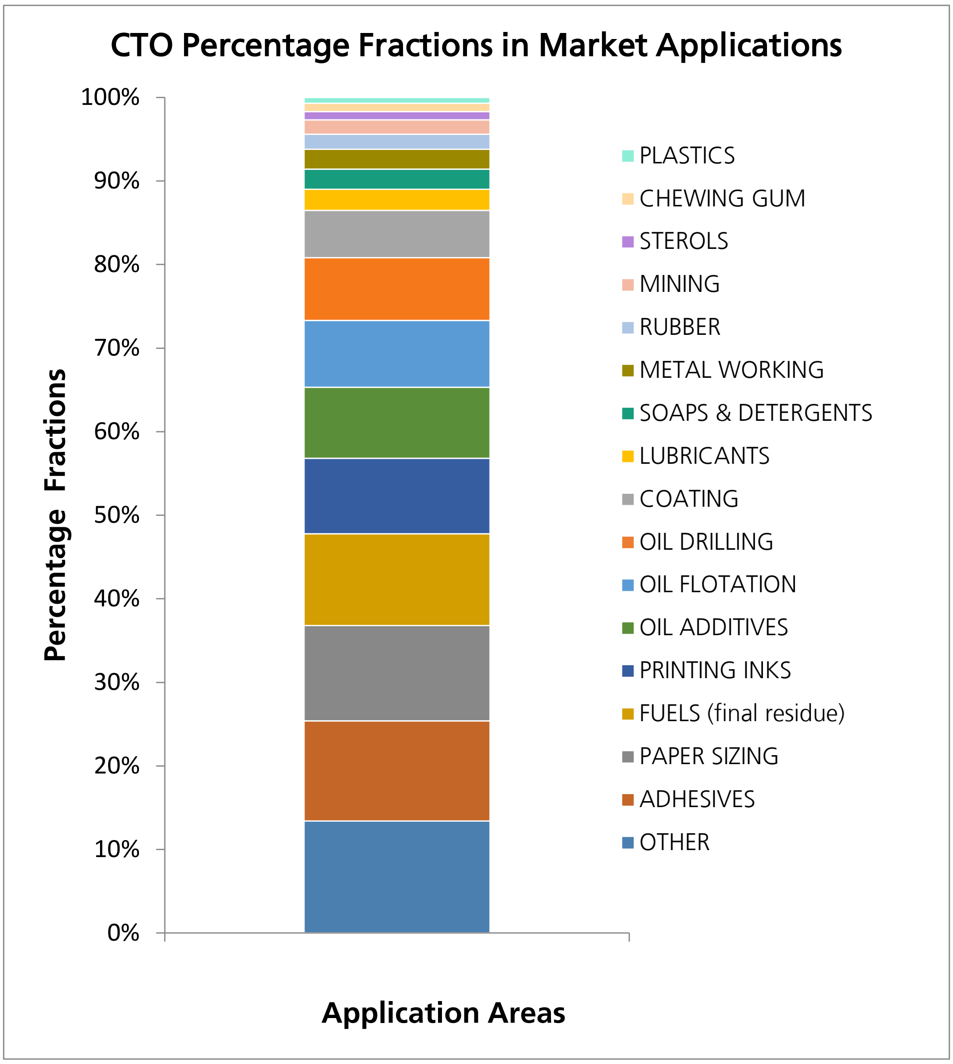
3.3 Mapping the Crude Tall Oil value chain

3.3.1 Market segment analysis

Mapping the CTO market was based on the main CTO fractions (TOFA, DTO, TOR and TOP) and their corresponding product application areas, which were clustered together and evaluated. The proposed clustering was based on production volume and market value. All relevant inputs corresponding to the material flows within a CTO-refinery were obtained from the primary data. The market volumes, market size and growth rate were estimated and/or obtained from secondary sources.

The primary CTO fractions are utilised within several product application areas. Figure 3-4 below shows the percentage compositions of CTO fractions in the overall market application areas globally.

Figure 3-4: Global CTO Percentage fractions in market application areas (PCA-2003)



Since the application areas for crude tall oil based products are very diverse, this study streamlines them into the following segments based on the outlined logic shown in Table 3-2.

Table 3-2: Market mapping and segmentation of CTO into application areas

CTO Fractions	Application Areas
Tall Oil Fatty Acids	Fuel Additives
	Lubricants
	Alkyds/coatings
	Mining chemicals
	Oilfield chemicals
Tall Oil Rosins	Paper sizing chemicals
	Adhesives
	Printing Inks
	Rubber
Distilled Tall Oil Heads	Alkyds/coatings
	Rubber
Tall Oil Pitch	Heating value

The value of Tall oil pitch (TOP) was taken into account based on its LHV (lower heating value). For Distilled Tall oil (DTO), Tall oil Rosins (TOR) and Tall oil fatty acids (TOFA), data gathered from the primary and secondary research were utilised.

3.4 Current trends and future potential

Established downstream industries in Europe that purchase and process CTO based intermediate chemicals provide a stable and significant market for CTO biorefineries and companies that upgrade pine chemical products for use in specific applications. These industries include inks, adhesives, paints and coatings, papermaking, and many others.

European Rosin consumption, including both Tall Oil Rosin and Gum rosin, amount to 325,000 tonnes. While printing inks and adhesives are the major markets for end-user products, TOR is also used in rubber emulsifiers, rosin soaps, paper sizing and other applications.

Demand for Tall oil fatty acids in Europe is driven by its use in alkyd resins which are consumed in plastics and paints and coatings, or converted into dimer acids which are used in various applications such as specialty inks, coatings and adhesives. Other uses for TOFA include lubricants, soaps &

detergents and fuel additives. The overall demand for TOFA in Europe for the year 2014 stood at 170,000 tonnes.

Furthermore, the rising demand for bio-based lubricants, solvents and surfactants as alternative to petroleum derived products, widens the market opportunities for pine chemicals in mining and floatation chemicals and lubricants. These markets, with policy incentives that would support bio based chemicals, could provide a great potential to substitute conventional fossil-based products.

3.4.1 Market attractiveness – CTO application areas

Figure 3-5 shows the market attractiveness of the various application areas that use pine chemicals derived products and intermediates.

The EU bio-lubricants market comprising of hydraulic fluids, lubricants for chain saws, and mould release oils etc. is expected to grow annually at 3.6% reaching 420,000 tonnes in 2020 (ERRMA-2010; Innnocenti-2010). Likewise the bio-solvent industry is expected to reach 1.1 million tonnes by 2020 with a growth rate of 4.8% per annum (Biochem-2010).The bio-surfactants industry driven by concerns of toxicity and biodegradability of fossil oil based chemicals presents an opportunity for bio-based pine chemical products. This market shows an annual growth rate of 3.5% with a potential to reach 2.6 million tonnes in 2020. It is further estimated that bio-based products would generate about 93,700 direct jobs in Europe by 2020 (Biochem-2010) which would be complimented by an additional 280,000 indirect jobs.

According to the Technical Committee of Petroleum Additive manufacturers in Europe (ATC), a sector group of CEFIC, the entire fuel additives and lubricants market in EU-27 in 2013 was 2.6 million tonnes, generating 4,100 jobs, of which the fuel additives was over 200,000 tonnes generating a value of 500 million euros per annum (ATC-2013).

The adhesives and sealants market in 2014 generated more than 13 billion euros, accounting for 2% of the entire EU chemical industry. This industry also provides direct employment to more than 41,000 people. The EU adhesives market represents about 35% of the global adhesives and sealants sales. In Europe around 450 adhesives and sealant manufacturers operate across 700 sites. According to the Association of the European Adhesive & Sealant Industry (FEICA), the industry produces more than 2.3 million tonnes of adhesives sealants in Europe each year (FEICA-2015) this numbers are anticipated to grow at 4.7% from 2015 to 2020.

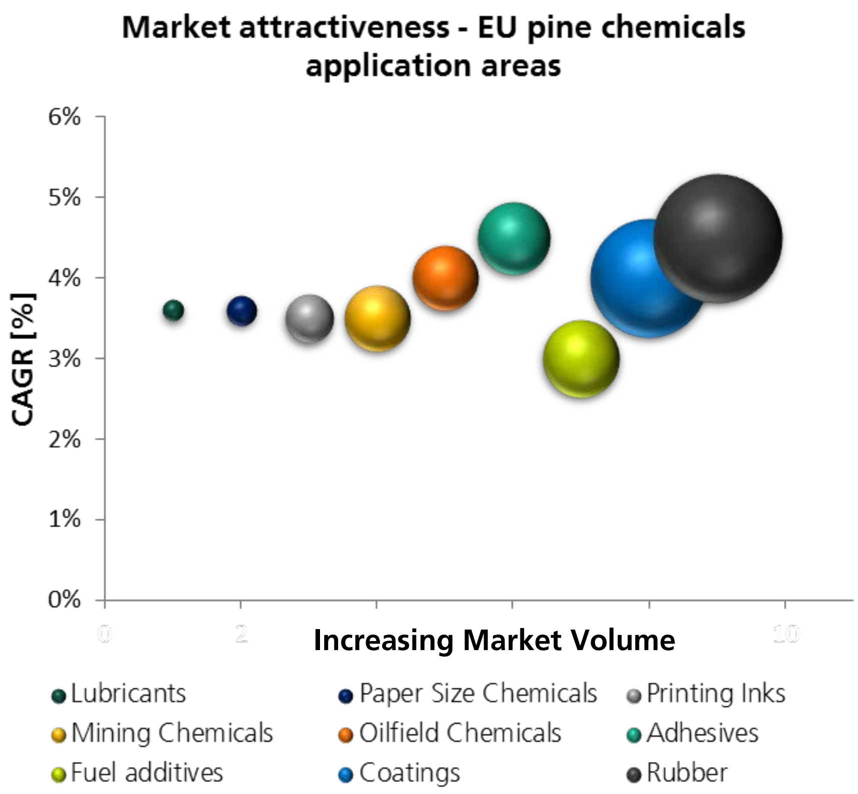
In 2014, the European Rubber and Tyre manufacturing industry (ETRMA-2015) produced around 7.4 million tonnes of rubber and tyre goods in 7,800 manufacturing facilities employing around 350,000 people across the industry. The rubber goods in particular generated operating revenue of 47 billion euros in 2014.

Printing Ink is a niche market in Europe, with about 100 manufacturers producing 1 million tonnes of inks and employing 13,000 people directly. According to the European Printing Ink Association (EuPIA- 2015) the industry generated revenue of 3.5 billion euros, moreover the economic added value of this small industry has a high multiplier in value along its supply chain. It was estimated that the revenues generated by all printed packaging industry in Europe exceeded 150 billion euros in 2015.

The European coatings industry in 2015, according to CEPE (CEPE-2015) produced 6.08 million tonnes of paints and coatings, providing direct employment to 120,000 people and generated revenue of 17 billion euros.

Finally, the paper size chemicals market in Europe was estimated to produce 390,000 tonnes of paper size chemicals with generated revenue of 1.85 billion euros (Eurostat-2014).

Figure 3-5:
Market attractiveness analysis of EU pine chemicals application areas



4 Biofuels Reference Process

In the last several years, fats and oils based diesel, so-called green or renewable diesel, is estimated to be commercially on a scale of 2 million tonnes annually. NESTE (Neste Oil-2014), the largest producer of biodiesel in Europe, currently operates three large-scale facilities located in Porvoo (Finland), Rotterdam (The Netherlands) and Singapore. This produced diesel fuel is a fungible, low-carbon, low-emission, paraffinic biofuel. Compared to petroleum diesel it contains no aromatic compounds or sulphur, resulting in improved performance characteristics and lower emissions. The increased performance is expressed in significantly higher Cetane number and good cold-flow properties measured via the so-called cold filter plugging point (CFPP). A so-called blend-wall with fossil diesel, in the range of 50% paraffinic fuels by weight, is typically encountered due to the inherently low density of paraffinic fuel.

Renewable Jet-fuel can be made by the same process employing identical catalytic steps and unit operations operated at different process conditions and recycling ratios. Jet-fuel has been made available in semi-commercial quantities and has been tested by several airlines like Lufthansa and KLM since 2009. In 2016 Oslo will become the first hub flying routinely with bio jet-fuel made from fats and oil. When making jet-fuel, naphtha is made as a by-product in significant amounts. The overall distribution between jet-fuel, diesel and naphtha determines the total value of the product mixture to a great extent. For details the interested reader is referred to the "Alternative Fuels Report" published by IATA every year.

Another company running a similar process at demonstration scale in the European Union is UOP/ENI. In addition UPM and Haldor Topsoe are known to have recently implemented processes in Finland and Sweden utilising CTO as a feedstock. Furthermore, there are a handful of companies in the United States running similar processes on commercial or demonstration scale as well. Several major oil companies have tested the so-called co-processing of fats and oils with fossil diesel. However, such co-processing is currently not eligible for fulfilling the blending mandates in the European Union.

An overview on the processing of fats and oils as well as Crude Tall Oil via "hydroprocessing" to paraffinic fuels is described in the following paragraphs.

The commercial process of making renewable diesel is comprised of several unit operations performing physical and catalytic hydroprocessing steps. The overall processes comprises 3 different steps, each step depending on the feedstock blend, the desired fuel yield and properties as well as cost-performance characteristics of the renewable diesel fuel product. A premium product is typically characterized by a high Cetane number and a low CFPP typical for winter diesel or even artic winter diesel. It almost impossible to back calculate from a fuel analysis, even from a renewable diesel made from a single feedstock alone, the way of processing in terms of energy requirements, yields, conversion costs or the type of feedstock employed.

4.1 Technology overview: Hydroprocessing of fats and oils to diesel fuels

4.1.1 Pre-treatment of feedstock

Pre-treatment of feedstock includes removal of impurities and catalyst poisons. Vegetable oils used in biofuels typically are food grade, but must be pre-treated to prepare them for hydroprocessing. This pre-treatment typically comprises of three separate steps. The pre-treated product is either called RBD (refined bleached deodorized) or NBD, where 'N' stand for chemical de-acidification with caustic. The energy intensity, use of utilities like steam, electricity and chemicals for the pre-treatment depends strongly on the type of vegetable oil feedstock. The main determining factors for the pre-treatment process are the degree of free fatty acids as well as the content of nitrogen, sulphur, phosphorus and inorganic salts (cationic and anionic alike). For CTO considerably more pre-treatment is required relative to a normal fats and oil feedstock, resulting in yield losses and additional cost.

4.1.2 Conversion via Hydrotreatment and Hydroisomerisation / Hydrocracking

Hydroprocessing typically comprises a sequence of hydrotreatment and hydroisomerisation (HIS) or on occasion hydrocracking. Hydrocracking is not well defined per se but comprises hydrotreatment and hydroisomerisation in one step. Since the selectivity to diesel usually suffers and the catalysts employed are typically expensive short hydrocracking alone is not preferred. The hydrotreatment step results in total oxygen removal and removal of any unsaturation in the carbon chain. The carbon chain isomerization step leads to a mixture of fully saturated linear and branched paraffins. Hydrotreatment typically requires one to four kilograms of hydrogen per 100 kg feedstock not accounting for hydrogen losses during recycling. Hydroisomerisation does not consume significant amounts of hydrogen.

Depending on different distribution of carbon chain lengths in fats and oils encountered, which ranges from 8 to 22 carbon atoms, each feedstock requires an individual degree of HIS to reach similar product properties. Since hydrotreatment mostly delivers solid products containing only straight chain hydrocarbons the HIS-processing step and the degree of its severity is of paramount importance for meeting the different regional requirements for summer and winter diesel according to the European norm for diesel (EN590). The severity of hydroisomerisation can be expressed in terms of conversion of straight hydrocarbons chains to branched ones as well as the number and position of branching points. The higher the conversion of straight hydrocarbon chains the higher loss towards hydrocarbon by-products boiling in the naphtha range. If the freezing points of jet fuel (also a diesel fuel) of minus 50°C were to be reached the naphtha yield can be as high as 50%. The production of winter diesel for central Europe (CFPP -20°C) typically does not yield more 10-20% naphtha and for summer diesel (CFPP 0°C) the loss towards naphtha may even be close to 0%. A further point to consider is that the Cetane number of the individual hydrocarbon molecules ranges from 0 for a 12-carbon containing symmetrical methyl-branched paraffin (freezing point -70°C) up to 100 for 22-carbon containing unbranched paraffin (freezing point +35°C). The European norm for diesel requires a Cetane number 51 independent of the season.

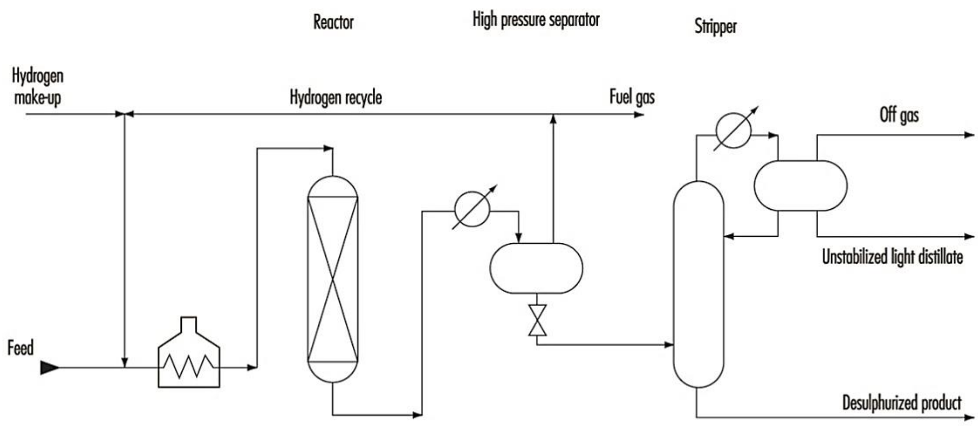
The selectivity to diesel in general decreases with increasing reaction temperature during hydrotreament and hydroisomerisation as well while the selectivity towards naphtha increases involving cracking. If this process is wanted or even required to crack solid multi-cyclic alkane structures in the feedstock, which can't be transformed to liquid ones by a hydroprocessing step, it is called hydrocracking. Hydrocracking is also known as hydrodewaxing (Hydrodeoxygenation). The latter is the case for CTO due to its tricyclic resin acid and sterol content implying several condensed hydrocarbon ring structures which are present in the feedstock. Also the carbon chain lengths encountered in tall oil reach up to 28 carbon atoms (Palanisamy et al.-2014) compared to 22 in plant and animal oils. Therefore, it can be stated that processing CTO into renewable diesel is much more challenging and costly compared to state-of-the-art for Hydrotreatment of fats and oils. Refined tall oil fatty acid (TOFA), however, can be processed identically to all other fats and oils and will result in diesel with a high Cetane number significantly exceeding the European requirement of 51. The opposite is true for a CTO fraction containing mainly (>90%) rosin acids, where 51 can't be reached at commercially meaningful liquid diesel yields of 70-80% even when hydrocracking is employed. (Coll et al.-2001)

4.1.3 Production of hydrogen and recycling of intermediates and energy integration

Production of hydrogen is performed by steam reforming of natural gas in combination with recycling hydrogen recovered from mixtures of hydrocarbons. The by-products of hydrotreatment, i.e. water and carbon dioxide, are removed by phase separation and absorption with amines. To a certain extent recovery of light gases at high and low pressure is also performed. Depending on the complexity of the purification process significant amount of hydrogen is lost and thus substantially increases the production costs and subsequently the carbon footprint. Hydrotreating reactions are highly exothermic; hence the excess heat is used to heat up the incoming feed reducing the requirement for external energy.

A simplified flow sheet for hydro-processing of crude diesel as well as fats and oils to renewable diesel is shown in Figure 4-1. The steam reformer as well as the water and carbon dioxide removal are not shown for simplicity.

Figure 4-1: Simplified flow sheet for hydro-processing of fats and oils to renewable diesel (more than one reactor and distillation column are typical) (Sotelo-Boyas et al.-2012)



As a reference process and a reference mass balance data published by Neste Oil (NESTE Oil-2012) for processing of tallow fat in its Singapore plant have been used as shown in Table 4-1.

Table 4-1: Industrial reference system mass / energy balance for NExBTL-Diesel (Neste Oil 2012)

Mass Balance NExBTL® Singapore 01.09.2011 to 31.08.2012	
	Tonne per tonne
Pre-treatment Total Feed	1.21
NExBTL®	1.18
Hydrogen to NExBTL® Unit	0.038
NExBTL® Unit production yields	
NExBTL® Product	1
Bio Naptha Product	0.0052
HP Propane rich off gas	0.0505
LP Propane rich off gas	0.0096

The simplified mass balance of the renewable diesel process for tallow is as follows:

1.18 kg C57H102O6 + 0.035 kg H2 →1 kg RD +0.05 kg CO_2 +0.1 kg H2O +0.06 kg C3H8

Whereas a feedstock containing only free fatty acids does not yield any by-product hydrocarbons, processing of a fats and oil feedstock results in propane as a by-product. The amount of propane is directly proportional to the amount of glycerol in the feedstock. Typically glycerol is integrated into the fat and oil feedstock as triglyceride, which stands for the tri-ester of glycerol with three fatty acids. Since all crude tall oil fractions are essentially free of triglycerides, it was considered that no propane is produced as a by-product in the hydroprocessing of CTO.

The hydrogen and feedstock amounts required per kg of diesel have been developed for the case of using crude tall oil as a feedstock. Realistic values for adaptation have been taken from published data by VTT (Anthonykutty et al.-2013). Also the data for pre-treatment have been adjusted to the chosen CTO case.

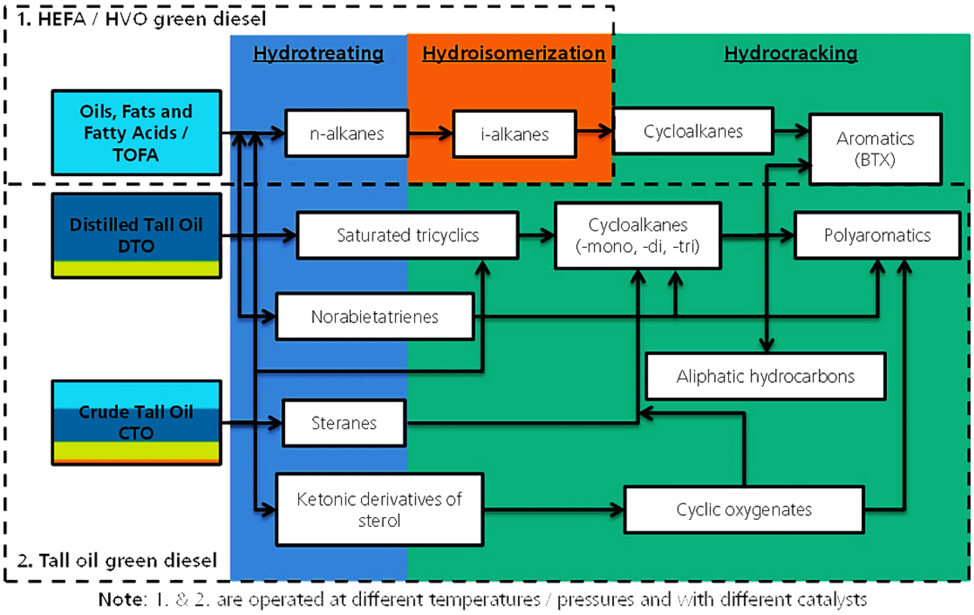
4.1.4 Hydroprocessing of crude tall oil to renewable diesel

As explained above, all fats and oil containing feedstocks are converted by a combination of hydrotreating and hydroisomerisation (HIS) to a mixture of linear and branched alkanes. However, this standard process can't be employed when cyclic molecules coming from rosin acids and sterols like in crude tall oil are present.

Hydrotreating as usual at temperatures around 300°C leads to a (solid) hydrocarbon mixture containing significant amounts of interconnected saturated cyclic ring structures containing 3 to 4 rings. Those structures are known to have very low Cetane values, display high melting points and can't be further upgraded by hydroisomerisation at all.

Hence higher temperatures are required during hydrotreatment to induce hydrocracking of rings to smaller linear and branched alkanes and to monocyclic rings also called cycloalkanes or naphthenes. The overall process is much more complex and produces hitherto unknown hydrocarbons compared to fats and oils. This is illustrated in the following sketch (Figure 4-2) showing the dependency of products formed from different crude tall oil fractions as function of temperature during the hydrotreatment process step compared to fats and oils.

Figure 4-2:
Proposed reactivity for the formation of major products from crude tall oil feeds in hydro-treating Adapted and modified from (Anthonykutty et al.-2015)



It has been estimated from published data of VTT (Anthonykutty et al.-2013) for hydrotreating of rosin rich fractions that a processing temperature around 400°C induces enough cracking to yield a diesel product with reasonable quality that can be blended with fossil diesel up to 10%. So a rather positive scenario in terms of liquid diesel yield has been chosen compared to a scenario for a higher blend ratio implying higher yield losses.

Although UPM and Haldor Topsoe are known to have recently implemented processes in Finland and Sweden utilising CTO as a feedstock, no details are disclosed in patents and public literature on the exact yields of diesel and by-products (Nousiainen et al.-2012). Also Cetane numbers of the products are not disclosed. The only information that can be retrieved from a patent of UPM is that a diesel fuel may be made by a combination of a hydrotreating and hydrodewaxing catalyst mixture at 70 bars, an average temperature of around 370°C and a WHSV of 0.69. One example is given where a diesel with cold flow properties not suited for winter diesel was made. Three fractions containing gases (C1 to C4), light hydrocarbons (C5 to C9) and a middle distillate (C10 to C28), representing the diesel fraction, are obtained. The feed is composed of not specified crude tall oil, which has been purified by depitching before being fed to the reactor.

5 Life Cycle Assessment and Methodology

5.1 Goal and scope

The life cycle assessment comprises a definition of the goal and scope, inventory analysis, impact assessment and interpretation according to the ISO 14040:2006 standard (DIN EN ISO14040). In this first section, the goal, the systems under study, their boundaries and further assumptions are described. In section 5.2 the data collected for the systems are described, and in section 5.3 the results derived from the impact assessment are shown and discussed.

The following two scenarios are investigated:

- The use of crude tall oil (CTO) to produce tall oil fractions for chemicals (Case 1, see chapter 2.1), which refers to the use of CTO to obtain TOR, TOFA, DTO, and TOP. For the life cycle assessment, it was assumed that the production of TOR, TOFA and DTO replaces the production of existing products in the European market such as hydrocarbon resins, vegetable oils, and petroleum sulfonates. In addition, production and combustion of TOP replaces the production and combustion of heavy oil.
- The use of CTO to produce renewable diesel (Case 2, see chapter 2.1), which comprises the removal of the TOP fraction from CTO in a first step to obtain depitched CTO, and the conversion of depitched CTO into renewable diesel by hydroprocessing. For the life cycle assessment, it was assumed that production and combustion of renewable diesel and TOP replaces the production and combustion of fossil diesel and heavy oil respectively.

These two scenarios were selected since they are representative of the applications of CTO for the production of bio-based chemicals and biofuels.

5.1.1 Goal

The main goal of this part of the study is to compare the relative changes in GHG emissions as a result of using CTO to produce renewable diesel (Case 2) against its current use in producing bio-based chemicals (Case 1). The balance of greenhouse gas emissions associated with each case also includes the saved greenhouse gas emissions from the production of existing products in the European market that can be replaced by CTO-derived products, and the saved greenhouse gas emissions from the production and combustion of substituted fossil fuels.

5.1.2 Functional unit

In this part of the study a life cycle assessment is conducted for both Case 1 and Case 2. The functional unit considered for both cases is "1 tonne of CTO" used as raw material for chemicals or for renewable diesel production. The selection of this functional unit allows the comparison of different end-use applications of CTO. In both cases the TOP fraction is first removed from the CTO and considered to be used as fuel.

5.1.3 Systems under study

In this section the systems under study are briefly described. Production of CTO encompasses (1) the cultivation of pine trees, their harvesting and felling; (2) the pulping process, where black liquor soap is recovered; (3) the recovery of soap from black liquor and its conversion to CTO through acidulation, that is, the transformation of the soap into free fatty and rosin acids by reaction with sulfuric acid (Norlin-2000).

Use of crude tall oil to produce tall oil fractions for chemical applications

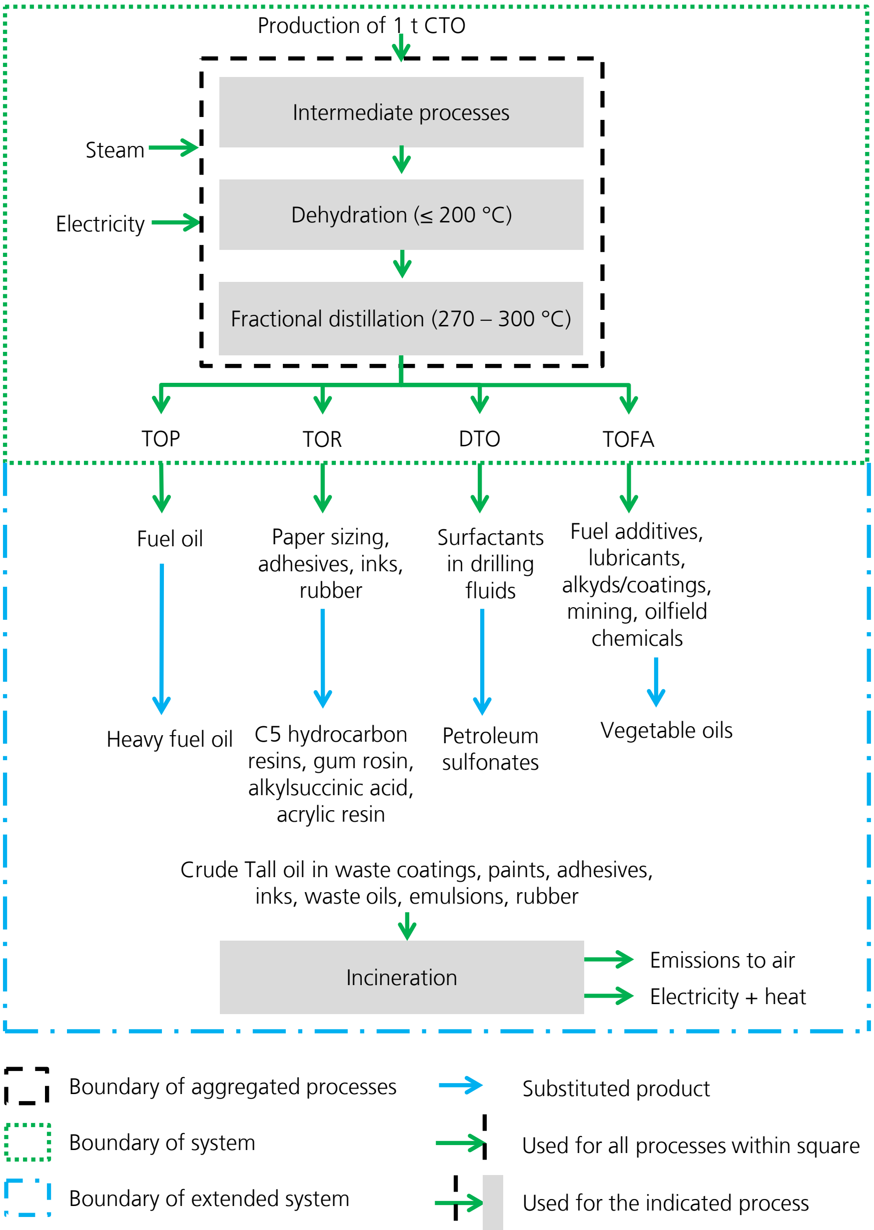
Figure 5-1 shows the flow diagram and the boundaries of the system for the analysis of the use of crude tall oil to produce tall oil fractions (Case 1). CTO is first dehydrated in an evaporator under vacuum (3 – 6 kPa, up to 200 °C), and then is separated by fractional distillation under vacuum (130 – 1300 Pa, 270 – 330 °C): in a first fractionating tower TOP is separated, and in a second column TOR, DTO, TOFA are separated (Norlin-2000).

TOR, DTO and TOFA fractions may represent about 63% (m/m) of the distilled product. Because of their content of fatty and resin acids, these fractions are important compounds used to produce a wide range of chemical products. TOFA has applications in fuel additives, lubricants, alkyds, mining operations (used as collector for the flotation of minerals) and oilfield chemicals. TOR has applications in adhesives, paper size, inks, and rubber. DTO may be used in surfactants to form drilling fluids used in the metal processing industry. In comparison with the fractions rich in fatty and resin acids, TOP is composed of neutral compounds, especially sterols, and normally is used as fuel.

In all these applications, crude tall oil fractions can substitute other products currently present in the market. As explained in section 5.1.5, the balance of greenhouse gas emissions associated with Case 1 is expanded by including the amount of greenhouse gas emissions linked to the production of a range of potentially substituted products by tall-oil fractions.

At the end of their life cycle, waste chemicals need to be managed. A detailed analysis of their management is out of the scope of the current study. Despite this fact, it was assumed that a common treatment operation for most waste containing CTO-derived chemicals is pre-treatment followed by incineration with energy recovery. Those waste fractions that may follow this route are waste derived from the manufacture and use of products such as coatings, adhesives and inks, rubber, as well as oil waste and oil emulsions from metallurgy industries (EC, JRC-2006). Only the impact associated with the amount of crude tall oil in these waste categories is considered. Waste derived from mining operations (i.e., flotation tailings) as well as waste derived from the extraction of hydrocarbons undergo other management pathways or end up in the environment during the use stage (EC, JRC-2009). The effect of these fractions are not included in the studied system.

Figure 5-1:
Flow chart for Case 1:
To simplify the scheme, only air emissions produced in processes shown in a grey square are indicated.



Use of CTO to produce renewable diesel

Figure 5-2 shows the flow diagram and the boundaries of the system for the analysis of the use of crude tall oil for the production of renewable diesel (Case 2). A more detailed description of this process is found in section 4. First CTO undergoes a distillation step in which TOP is separated. Then the depitched crude tall oil (also called "tall oil distillate" or "depitched CTO", see section 3.1) is hydrotreated (hydrodeoxygenated). Hydrotreating reactions are exothermic. At a temperature in the range of 325 °C – 375 °C with a supposedly sulfided hydrotreating NiMo catalyst these reactions include hydrogenation of double bonds and deoxygenation (removal of oxygen) of fatty and resin acids (Anthonykutty et al.-2013; Mikulec et al.-2012). At these temperatures and up to 400 °C deoxygenation of fatty and resin acids is believed to occur mainly through hydrodecarbonylation, hydrodeoxygenation and decarboxylation reactions (Anthonykutty et al.-2013; Anthonykutty et al.-2015):

$$RCOOH + H_2 \rightarrow RH + CO + H_2O \quad (1)$$

$$RCOOH + 3\ H_2 \rightarrow RCH_3 + 2\ H_2O \quad (2)$$

$$RCOOH \rightarrow RH + CO_2 \quad (3)$$

At temperatures higher than 375 °C the hydrocarbons without oxygen (mainly composed of alkanes derived from the deoxygenation of fatty acids, but also nonaromatic cyclic compounds obtained from the deoxygenation of resin acids) are cracked (they are broken apart into smaller molecules) and isomerized to yield a product mix that is lighter, with lower melting points, and branched (Anthonykutty et al.-2013). Cracking may produce compounds that are too small to be efficiently used in diesel. This fraction of lighter molecules will mainly produce naphtha (lighter alkanes) during subsequent fractionation (Figure 5-2).

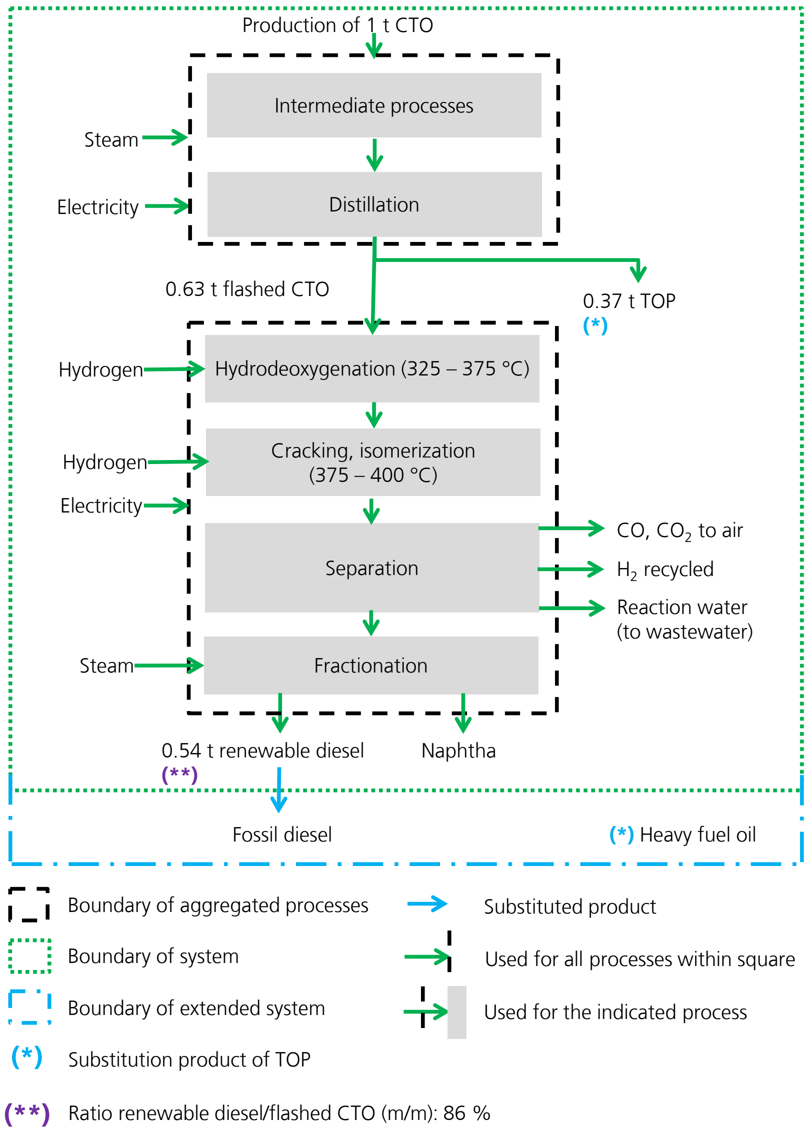
After hydroprocessing, the gas-liquid reaction mixture is directed to a separator. The hydrogen is recycled back to the reactor, where make-up hydrogen is introduced (Stumborg et al.-1996). After separation of the water phase, the organic phase is distilled to yield renewable diesel and naphtha.

A simplified overall reaction is:

$$CTO + H_2 \rightarrow \text{Renewable diesel} + \text{gases } (CO_2, CO) + H_2O + \text{naphtha} \quad (4)$$

In the same way as for Case 1, the balance of greenhouse gas emissions associated with Case 2 is expanded by including the saved greenhouse gas emissions from the production and combustion of substituted fuels (fossil diesel and heavy oil) (see section 5.1.5).

Figure 5-2:
Flow chart for Case 2:
To simplify the scheme, only air emissions produced in processes shown in a grey square are indicated.



5.1.4 Life cycle impact assessment indicator: global warming potential

One single impact assessment indicator was considered: the global warming potential (GWP), that is, the emissions of greenhouse gases (e.g., carbon dioxide, nitrous oxide, methane, halocarbons) that occur during any of the processes included within the system boundaries. To aggregate all the emissions in carbon dioxide equivalent mass units, GWP values given by (IPCC-2007a) for a time period of 100 years were used. GWP values express the relative radiative forcing of a certain greenhouse gas with respect to that associated to carbon dioxide.

A goal of this part of the study is to estimate the impact associated with the use of CTO for the production of tall oil fractions for chemical applications and for the production of renewable diesel. As shown in Figure 5-1and Figure 5-2, the main resources used for the processing of CTO to tall oil fractions for chemicals and to renewable diesel respectively (boundaries of the systems defined in the strict sense in Figure 5 1 and Figure 5 2) are energy related flows (steam and electricity) and also hydrogen for the hydroprocessing of CTO to renewable diesel. Combustion of fuels (primary energy sources) to produce these secondary energy sources can be associated with several potential environmental impacts, such as the emission of greenhouse gases, emission of precursors of tropospheric ozone (e.g., nitrogen oxides, volatile organic compounds) and emission of toxic compounds (e.g., benzene, toluene, xylenes, nitrogen dioxide). Therefore, the selection of the GWP as indicator was considered appropriate to estimate the impact associated with the use of CTO for the production of crude tall oil fractions and for the production of renewable diesel. Other potential impacts were assumed to be also connected to the use of energy.

During the use stage, combustion of biofuels also involves the emission of greenhouse gases, precursors of tropospheric ozone and toxic compounds, while the main potential impacts linked to the use of chemicals may be toxic effects. Emission of volatile organic compounds from chemicals presumably occurs from the solvents added to produce the final chemical products, while the crude tall oil fractions compose the solid part of the final chemical products (Section 5.1.5). However, these impacts are out of the scope of the current study.

The saved greenhouse gas emissions calculated when considering the expanded systems reflect potential savings obtained by replacing non-renewable energy during the production and processing of CTO (to tall oil fractions for chemicals or to renewable diesel), as well as savings obtained by replacing non-renewable energy when using biofuels and when recovering energy from incineration of waste chemicals.

5.1.5 Choice of reference system

A LCA is applied for both scenarios, where system expansion is used to deal with the fact that they are multifunctional processes, that is, CTO is used as a raw material for multiple products. Therefore, the balance of greenhouse gas emissions associated with each case also includes an estimation of the saved greenhouse gas emissions from the production of existing products in the

European market that can be replaced by CTO-derived products, and the saved greenhouse gas emissions from the production and combustion of substituted fossil fuels.

Replacement of chemical products

Table 5-1 shows the CTO fractions that may be used as intermediate chemicals, their corresponding applications, main substituted products, and specific greenhouse gas emissions associated with the production of substituted products. Data on main substituted products were taken from the study by Cashman et al. (2015). For these crude tall oil fractions, it was assumed that 1 mass unit of each CTO application replaces 1 mass unit of alternative product (Cashman et al.-2015). Data on the market share of each application, used to calculate the amount of avoided greenhouse gas emissions, are not shown due to confidentiality reasons.

Table 5-1: Crude Tall oil fractions, their applications, main substituted products in the European market, and specific greenhouse gas emissions. Data on substituted products from Cashman et al. (2015); data on the market share of each application are not disclosed due to confidentiality requirements.

Crude Tall oil fraction	Amount (kg product/t CTO)	Applications	Substituted products	Specific GHG emissions (kg CO_2 eq./t sub. prod.)	Reference GHG emissions
TOR	270	Paper size	Gum rosin, alkylsuccinic acid	2410	Franklin Associates (2013)
		Adhesives	C5 hydro-carbon resins	2940	Franklin Associates (2013)
		Inks	Acrylic resin	4538	ecoinvent dataset: "GLO: market for acrylic binder, without water, in 34% solution state"
		Rubber	C5 hydro-carbon resins	2940	Franklin Associates (2013)
		Others	No data available	3207 (average)	
TOFA	320	Fuel additives	Vegetable oils (soybean oil)	1830	ecoinvent dataset: "RER: soya oil, at plant"
		Lubricants			
		Alkyds / Coatings			
		Mining			

Crude Tall oil fraction	Amount (kg product/t CTO)	Applications	Substituted products	Specific GHG emissions (kg CO_2 eq./t sub. prod.)	Reference GHG emissions
		Oilfield chemicals			
		Others	No data available	1830	
DTO	40	Surfactants in drilling fluids	Petroleum sulfonates	1903	Defever and Polastro (2010)

The amount of greenhouse gas emissions associated with the production of alternative products is 1523 kg CO_2 eq./t CTO (see Table 5-4). This amount was calculated based on the following equation:

$$\sum_i \text{mass CTO fraction} \times \text{market share for application j} \times \text{mass replacement ratio} \times \text{GHG for substituted product i} \quad (5)$$

As shown in Table 5-2, TOP may be a substitute for heavy oil. The specific greenhouse gas emissions for heavy oil were calculated based on the lower heating values shown in

Table 5-3.

Table 5-2: TOP, its applications, main substituted products in the European market, and specific greenhouse gas emissions.

Crude Tall oil fraction	Amount (kg product/t CTO)	Applications	Substituted products	Specific GHG emissions (g CO_2 eq./MJ sub. prod.)	Ref. GHG emissions
TOP	370	Fuel	Heavy oil	89.1	GaBi dataset: "EU 27 process steam from heavy oil, 90 % efficiency"

Table 5-3: Lower heating values for fuels considered in the current study

Fuel	Lower heating value (MJ/kg)	References
TOP	40.6	Tanaka et al. (1980)
Heavy oil	40	European Parliament and Council of the European Union (2006)
Renewable diesel	44	European Parliament and Council of the European Union (2009), Kalnes et al.

Fuel	Lower heating value (MJ/kg)	References
		(2016), Neste Oil (2012)
Fossil diesel	43	European Parliament and Council of the European Union (2009)

The amount of greenhouse gas emissions related to the production and combustion of heavy oil is 1338 kg CO_2 eq./t CTO (see Table 5-4).

Table 5-4: Amount of greenhouse gas emissions attributed to the production of substituted chemicals, and greenhouse gas emissions associated with the production and combustion of heavy oil

Substituted products by tall oil fractions	Specific GHG emissions (kg CO_2 eq./t CTO)
Alternatives to CTO-derived chemicals	1523
Heavy oil	1338

As a rough approximation to the management of waste chemicals at the end of their life cycle, it was considered that waste composed of paints, alkyds, coatings, adhesives, inks and related products (where the fraction containing crude tall oil makes up the solid portion), as well as waste composed of rubber, lubricants and oil emulsions can be incinerated (see section 5.1.3). Only the impact associated with the amount of CTO in these waste categories was considered (492 kg/t CTO, see Table 5-1). The potential impact associated with the amount of crude tall oil fractions for other uses (i.e., for mining, oil extraction and for use as fuel additives), which represents a minor part (138 kg/t CTO, 14 % of the total distilled product), was not estimated: the products that contain them may end up as waste that follow other management pathways or they may mainly be released to water or air during the use stage. Table 5-5 shows the mass and energy balance for incinerating waste chemicals, and the corresponding greenhouse gas emissions.

Table 5-5: Mass and energy balance for incinerating 492 kg of waste chemicals with energy recovery, and specific greenhouse gas emissions

Mass or energy flow	Amount	Heating value (MJ/kg)	Specific GHG emissions	References
Inputs				
Waste chemicals	492 kg	10 (mixed with other waste fractions)	40.2 kg CO_2 eq./t waste	ELCD-dataset: EU-27: Waste incineration of wood products
Electricity	30 MJ	-		
Heat	108 MJ	-		
Outputs				
Electricity	953 MJ	-	0.162 kg CO_2	GaBi dataset

Mass or energy flow	Amount	Heating value (MJ/kg)	Specific GHG emissions	References
			eq./MJ	"EU-25: Electricity grid mix"
Heat	2926 MJ	-	0.0687 kg CO_2 eq./MJ	GaBi dataset: "EU-27: Thermal energy from natural gas"

Replacement of fossil diesel

Table 5-6 shows the products obtained in the renewable diesel system, their corresponding applications, substituted fossil fuels, and specific greenhouse gas emissions associated with the production and combustion of substituted fossil fuels. The lower heating values used for the calculation of greenhouse gas emissions are shown in

Table 5-3.

Table 5-6: Products derived from CTO hydroprocessing, their applications, substituted products in the European market, and specific greenhouse gas emissions

Product	Amount (kg product/t CTO)	Application	Substituted products	Specific GHG emissions (g CO_2 eq./MJ fossil fuel)	Ref. GHG emissions
Renewable diesel	542	Fuel	Fossil diesel	83.8	European Parliament and Council of the European Union (2009)
TOP	370	Fuel	Heavy oil	89.1	GaBi dataset: "EU 27 process steam from heavy oil, 90 % efficiency

5.2 Data collection and life cycle inventory analysis

Data on the amount of greenhouse gas emissions associated with the production of CTO (from the cultivation of pines to the acidulation process) was obtained from the literature (see Table 5-7 and Table 5-8)

Use of CTO to produce crude tall oil fractions for chemicals

The inventoried data for Case 1 are shown in Table 5-7. Data on final energy use to distill CTO to produce crude tall oil fractions were taken from Cashman et al (2015). But in contrast with the above mentioned study, heavy oil was considered as the heat source for a boiler having an energy efficiency of 75 %

(Tanaka et al.-1980). All CTO was assumed to end up as tall oil fractions without generating waste.

Table 5-7: Mass and energy balance associated with the distillation of 1 t CTO to 1 t of CTO fractions for chemicals, and specific greenhouse gas emissions

Mass or energy flow	**Amount**	**Background data**	**Ref. back-ground data**	**Specific GHG emissions**	**Ref. GHG emissions**
Inputs					
CTO	1 t			678 kg CO_2 eq./t CTO	Cashman et al (2015)
Electricity	173 kWh		Cashman et al (2015)	0.238 kg CO_2 eq./kWh electricity	GaBi dataset: "RER: Power grid mix (NORDEL)"
Heat (steam)	2230 MJ	3280 MJ (from natural gas, oil and biomass), boiler efficiency: 68 %	Cashman et al (2015)	0.099 kg CO_2 eq./MJ steam	GaBi dataset: "EU 27 Process steam from heavy oil, 90 % efficiency"
Outputs					
Crude Tall oil fractions for chemicals	630 kg		Internal data		
TOP	370 kg		Internal data		

Use of CTO to produce renewable diesel

The datasets used for the system of renewable diesel are shown in Table 5-8. The pitch fraction removed in the first step was considered to be 37 % (in mass) of CTO. To determine the mass balance for hydroprocessing of depitched CTO, literature data reported for the composition of hydroprocessed depitched CTO between 375 and 400 °C were used (Anthonykutty et al.-2013). The mass ratio renewable diesel to depitched CTO was calculated to be 0.86. The stoichiometric amount of hydrogen considered for complete deoxygenation and hydrogenation was considered to be 40 kg H_2/t depitched CTO (Anthonykutty et al.-2013). The sixth column of Table 5-8 shows the specific greenhouse gas emissions assigned to the inventoried flows.

Table 5-8: Mass and energy balance for hydroprocessing 1 t CTO to 0.54 t renewable diesel, and specific greenhouse gas emissions

Mass or energy flow	**Amount**	**Background data**	**Ref. back-ground data**	**Specific GHG emissions**	**Ref. GHG emissions**
Inputs					

Mass or energy flow	Amount	Background data	Ref. back-ground data	Specific GHG emissions	Ref. GHG emissions
CTO	1t			678 kg CO_2 eq./t CTO	Cashman et al (2015)
Electricity	57 kWh	106 kWh/t renewable diesel	Neste Oil (2012)	0.238 kg CO_2 eq./kWh electricity	GaBi dataset: "RER: Power grid mix (NORDEL)"
Heat (steam)	2160 MJ	600 kWh steam/t CTO	Stigsson et al. (2014)	0.099 kg CO_2 eq./MJ steam	GaBi dataset: "EU-27 Process steam from heavy oil, 90 % efficiency"
Hydrogen	27 kg	Stoichiometric mass H_2: 40 kg H_2/t depitched CTO; make-up H_2: 7.89 %	Anthonykutty et al. (2013); Neste Oil (2012)	11.50 kg CO_2 eq./kg H_2	GaBi dataset: "EU-27: H_2-Steam reforming-natural gas"
Outputs					
Renewable diesel	0.54 t	Mass ratio depitched CTO/TOP: 0.77, mass ratio renewable diesel/depitched CTO: 0.86	Anthonykutty et al. (2013; 2015)		
TOP	0.37 t		Internal data		
CO_2, CO, H_2O, naphtha	115 kg	Calculated mass balance (without make-up H_2)			

5.3 Global warming potential of Crude Tall Oil applications

In this section the results of the environmental impact assessment in terms of global warming potential are shown.

5.3.1 Use of crude tall oil to produce tall oil fractions for chemicals

Figure 5-3 (see also Table 5-9) shows the distribution of greenhouse gas emissions (in kg CO_2 eq./t CTO) linked to the production and distillation of CTO to tall oil fractions for chemicals. The total amount of emissions is 940 kg CO_2 eq./t CTO, with the two main contributing processes being CTO production (72 % of the total emissions) and steam production for CTO distillation (24 %). But the amount of TOP that is produced (370 kg/t CTO) is sufficient to substitute all the heavy oil needed to generate steam for distillation (amount of

TOP needed to produce 2230 MJ of steam considering a boiler efficiency of 75 % and a heating value for TOP of 40.6 MJ/kg: 73 kg/t CTO); therefore, subtraction of the amount of emissions attributed to steam generation from the total amount gives 719 kg CO_2 eq./t CTO.

Figure 5-3: Distribution of greenhouse gas emissions (kg CO_2 eq./t CTO) assigned to CTO production and distillation to bio-based chemicals

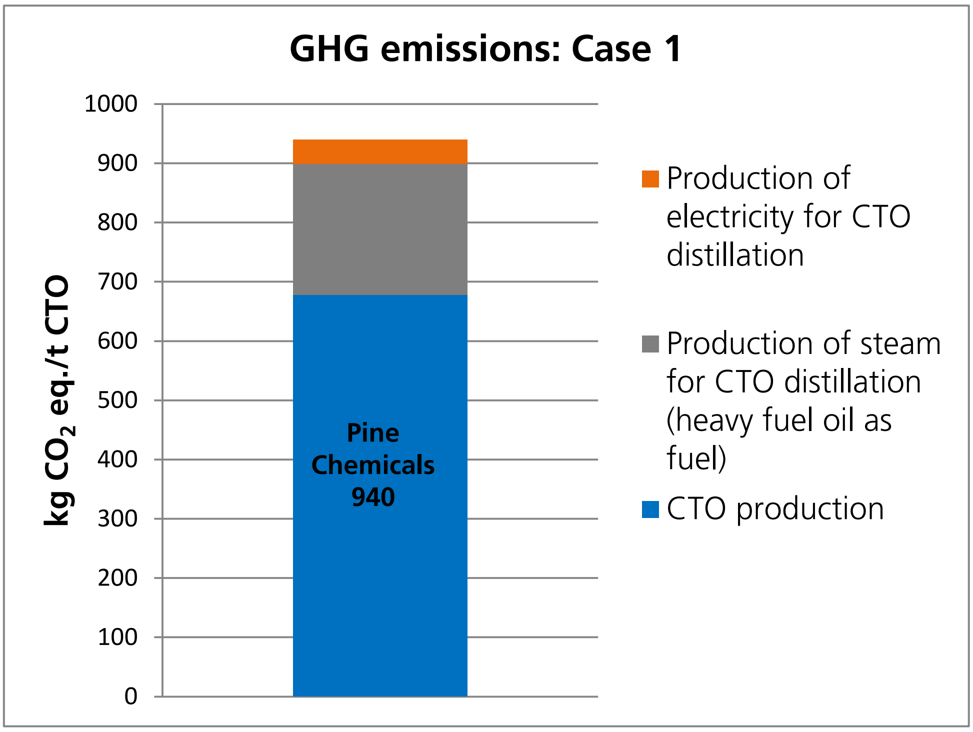
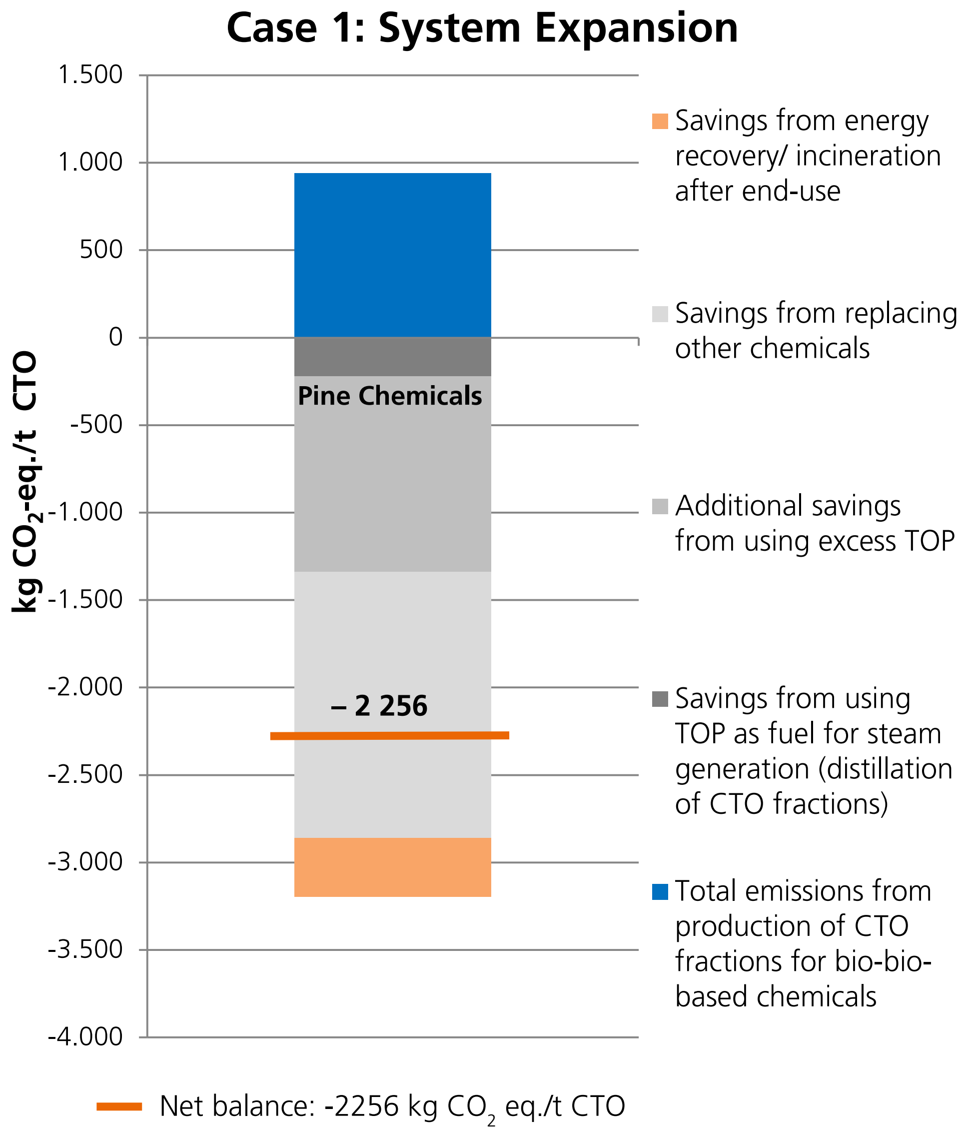


Figure 5-4 shows the balance of greenhouse gas emissions (derived from fossil fuel) considering the expanded system. Combustion of TOP instead of heavy oil may replace a total amount of 1338 kg CO_2 eq./t CTO (Table 5-4) : 221 kg CO_2 eq./t CTO in the production of steam and the additional amount of 1118 kg CO_2 eq./t CTO is shown in the negative axis. Use of TOR, TOFA and DTO for the production of chemicals replaces 1523 kg CO_2 eq./t CTO (Table 5-4). Incineration of waste chemicals with energy recovery replaces 335 kg CO_2 eq./t CTO. The net balance results in an amount of saved greenhouse gas emissions of 2256 kg CO_2 eq./t CTO.

Figure 5-4:
Balance of greenhouse gas emissions (kg CO_2 eq./t CTO) assigned to CTO production and distillation to crude tall oil fractions for chemicals in the expanded system



5.3.2 Use of crude tall oil to produce renewable diesel

Figure 5-5 (see also Table 5-9) shows the distribution of greenhouse gas emissions (in kg CO_2 eq./t CTO) associated with CTO production and hydroprocessing to renewable diesel. The total amount of emissions is 1218 kg CO_2 eq./t CTO, with the amount associated with CTO production representing 56 %, the amount attributed to hydrogen production for CTO hydroprocessing representing 26 %, and the amount linked to steam generation for renewable diesel production being 17 %. But as for the system of CTO-derived chemicals, the amount of TOP that is produced (370 kg/t CTO) is sufficient to replace all the heavy oil needed to generate steam for the process (amount of TOP needed to produce 2160 MJ of steam considering a boiler efficiency of 75 % and a heating value for TOP of 40.6 MJ/kg: 71 kg/t CTO); therefore, subtraction of the amount of emissions attributed to steam generation from the total gives 1004 kg CO_2 eq./t CTO.

Figure 5-5: Distribution of greenhouse gas emissions (kg CO_2 eq./t CTO) attributed to CTO production and hydroprocessing to renewable diesel

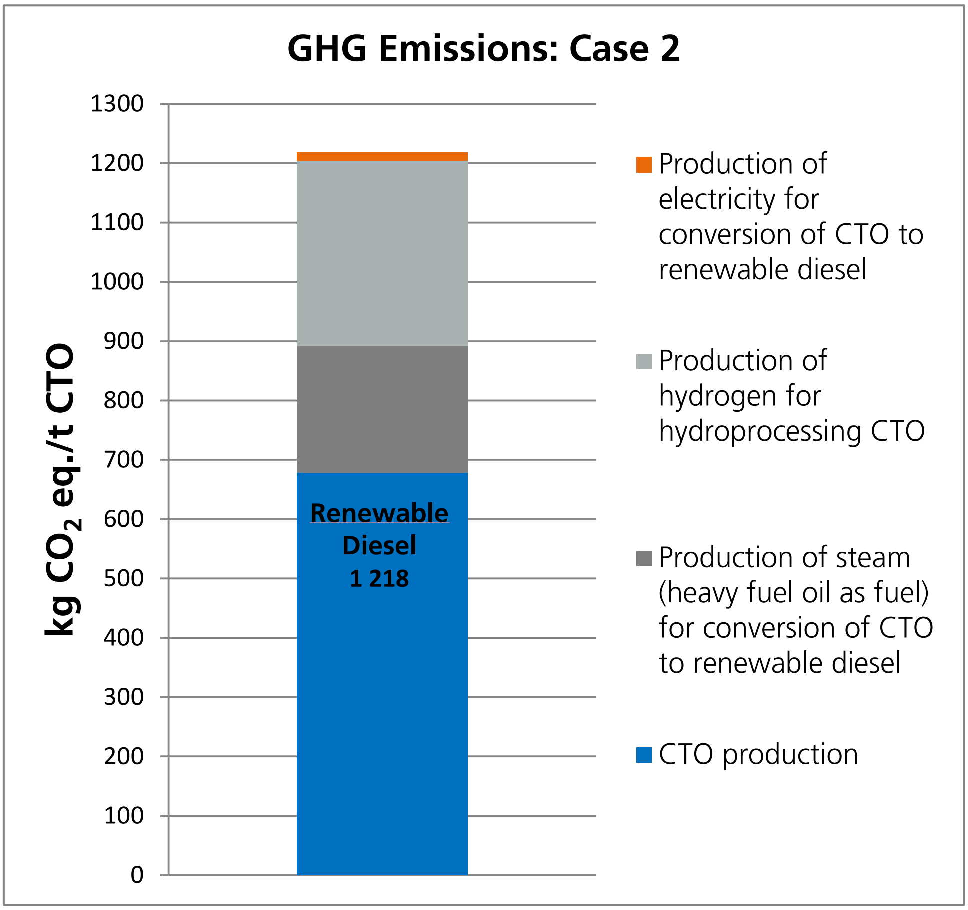
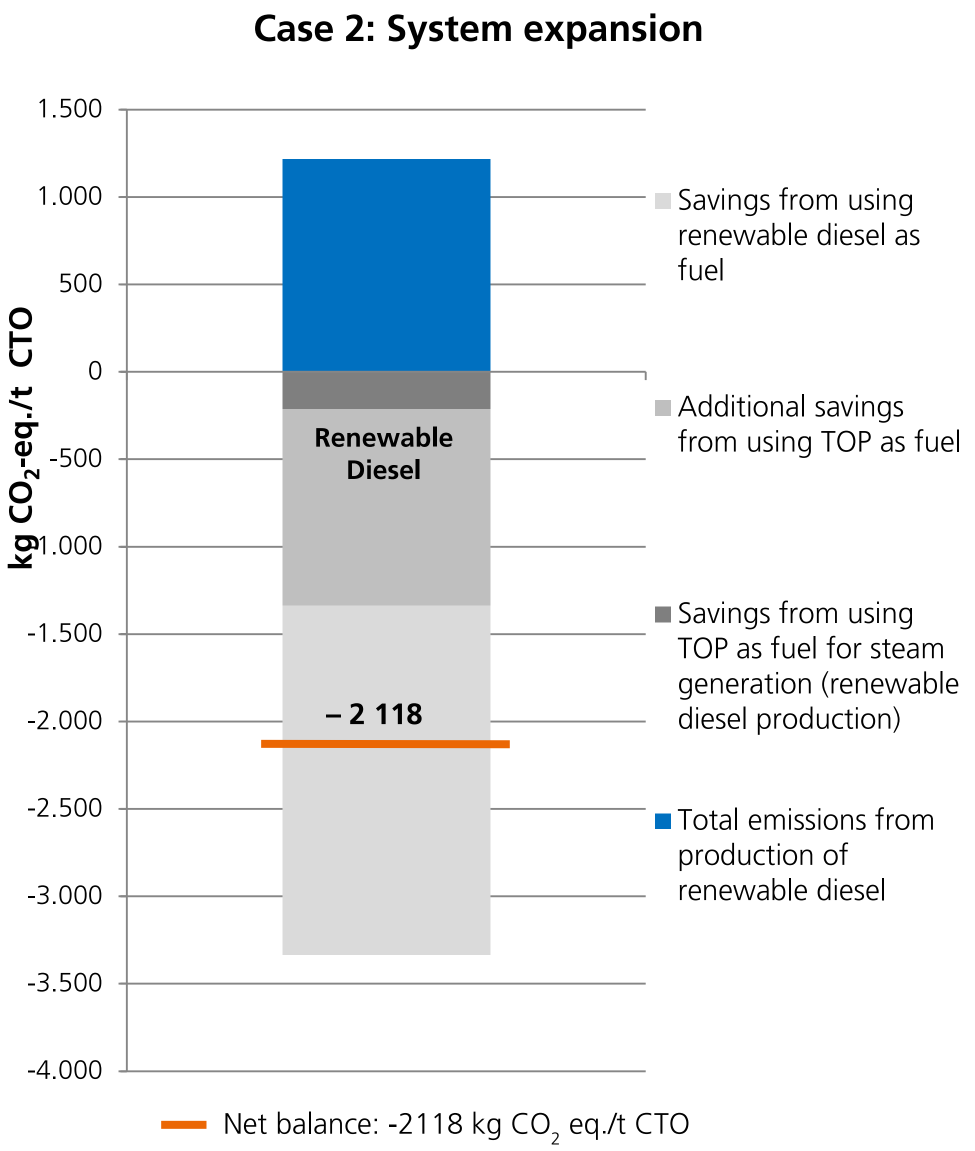


Figure 5-6 shows the balance of greenhouse gas emissions taking into account the expanded system. Combustion of TOP instead of heavy oil may replace a total amount of 1338 kg CO_2 eq./t CTO (214 kg CO_2 eq./t CTO in the production of steam, and 1125 kg CO_2 eq./t CTO shown in the negative axis as additional savings). Combustion of renewable diesel instead of fossil diesel allows a savings of 1998 kg CO_2 eq./t CTO. The net balance gives an amount of saved greenhouse gas emissions of 2118 kg CO_2 eq./t CTO.

Figure 5-6:
Balance of greenhouse gas emissions (kg CO_2 eq./t CTO) associated with CTO production and hydroprocessing to renewable diesel in the expanded system



5.3.3 Overall comparison

According to the results of the LCA study, the amount of greenhouse gas emissions associated with the use of 1 tonne of CTO to produce tall oil fractions for bio-chemicals is about 1.3 times less than the amount assigned to the use of 1 tonne CTO for the production of renewable diesel. As shown in Table 5-9, the major environmental impact attributed to Case 2 is due to the use of hydrogen for the hydroprocessing of CTO. The conventional process for hydrogen production is steam reforming of natural gas, which is associated with a high amount of greenhouse gas emissions (see Table 5-8). For both cases, production of CTO and production of steam with heavy oil represent large contributions to the positive balance of greenhouse gas emissions, but for both cases, these contributions amount to very similar values.

Table 5-9: Distribution of greenhouse gas emissions associated with the use of 1 t CTO for the production of tall oil fractions for chemicals (Case 1), and with the use of 1 t CTO for the production of renewable diesel (Case 2).

	Case 1	**Case 2**
Process	**GHG (kg CO_2 eq./t CTO)**	**GHG (kg CO_2 eq./t CTO)**
CTO production	678	678
Electricity	41	14
Steam	221	214
Hydrogen	0	313
Total	**940**	**1218**

The balances of greenhouse gas emissions for the expanded systems show overall saving values of the same order of magnitude (-2256 kg CO_2 eq./t CTO for Case 1 and -2118 kg CO_2 eq./t CTO for Case 2). For both cases, the balance of greenhouse gas emissions is sensitive to the specific greenhouse gas emissions considered for the potentially substituted products, but for Case 1, the range of potentially substituted products is wider and the uncertainty of the specific emissions linked to their production may be considerably larger. Datasets for gum resin, alkylsuccinic acid, C5 hydrocarbon resins and petroleum sulfonates were not available in reviewed LCA databases but were obtained from the literature (see section 5.1.5).

It was assumed that the largest part of chemicals containing crude tall oil fractions can be managed as waste at the end of their lifecycle. There is uncertainty in this assumption: for example, some chemicals may be disposed of in a landfill, others may be recycled or incinerated, or a larger amount of chemicals may end up in the environment during the use stage.

A main difference between Case 1 and Case 2 is that, in general, chemicals have a longer lifetime than fuels before they end up in the environment. For the LCA it was assumed that carbon dioxide emitted by burning biofuels (e.g., renewable diesel or pitch) can be readily captured by forest regrowth, but it should be noted that the annual uptake by forest regrowth is very limited (-0.9 ± 0.6 Gt C/yr.) (IPCC-2007b). Resorption of carbon dioxide by forest regrowth takes place in several decades (Agostini et al.-2013). Therefore, the release of greenhouse gases over a given period of time (even if they are released from biomass burning) occurs at a faster rate if CTO is used to produce renewable diesel instead of chemicals.

This implies, crude tall oil can contribute to mitigating climate change in two ways: (a) by replacing non-renewable materials and energy, and (b) by storing carbon for a longer time in the form of products until the end of their useful life. In a qualitative assessment, if the longer storage of carbon in Case 1 is considered, the GWP associated with Case 1 would be comparatively lower. However, only the GWP was used as impact category in this study. Other potential effects linked to the lifecycle of both biofuels and bio-based chemicals, such as toxicity to living beings or tropospheric ozone formation, were not investigated.

6 Economic Added Value and Job Impact

6.1 Goal and scope

The goal of this section of the study is to estimate the total job impact and the total economic added value (EAV) measured in terms of revenue generated from the previously mentioned product application areas of crude tall oil fractions. Based on the available market data on production volumes and end use applications, the direct and indirect value add along the chain were calculated.

This was performed by summing up the estimated downstream value and the number of jobs per tonne of CTO per product line in each of the 9 application areas. In addition to the revenue generated from the final sale of the respective CTO fractions (TOFA, TOR, TOP and DTO), the additional downstream revenue generated was calculated for each product application down the supply chain.

6.1.1 Scope, assumptions and boundary conditions

Assumptions and boundary conditions for the Economic Added Value estimation for chemicals and fuels:

The calculation of the Economic Added Value is limited to the inter-industry B2B (business-to-business) trading. Additional added value is generated within the B2C (business-to-customer) section, wherein typical multipliers from 3 to 50 (e.g. Inks) can be expected. This added value is not included within this study. To be able to compare the different utilisation pathways, all prices for the calculation of the Economic Added Value (EAV) have been extrapolated to 2015 as a base year using Eurostat the producer price index (PPI) for the manufacture of Chemicals and chemical products.

The estimation of the Job Impact includes both the total number of associated jobs within the CTO fractionators and refiners as well as the inter-industry downstream jobs associated with the CTO chemical product upgraders down the value chain.

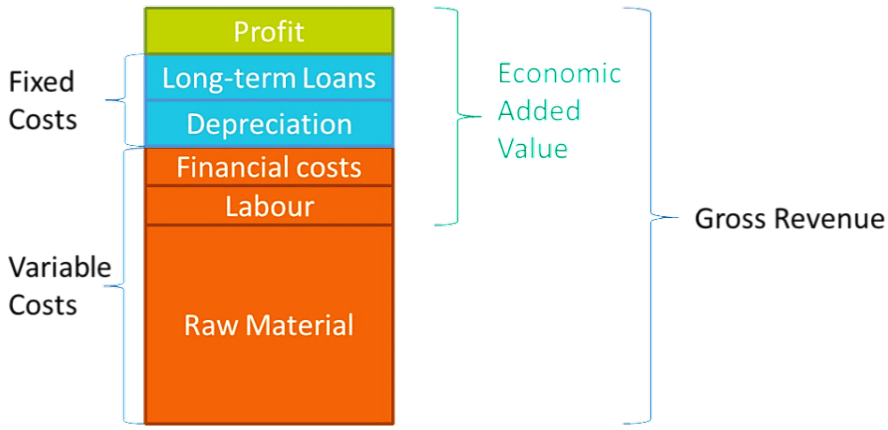
For the biofuels case, it is assumed that no downstream jobs are generated by the economic activity. The rationale is that no further product upgrading follows the production of Renewable Diesel, the total number of generated jobs will be consolidated within the biodiesel industry and its exchange of goods and services with inter-industry suppliers and distributors.

6.2 Methodology for estimation

6.2.1 Economic added value estimation

The calculation of the Economic Added Value (EAV) is based on market volumes and market prices for the selected value chains. These prices and volumes are aggregated within each step of the value chain as well as for each product within the selected applications areas (see chapter 4.4) to calculate the added value for the production of chemicals from CTO. Figure 6-1 shows the context between added value, gross revenue and raw material for each selected product.

Figure 6-1:
Economic Added Value calculation and costs elements

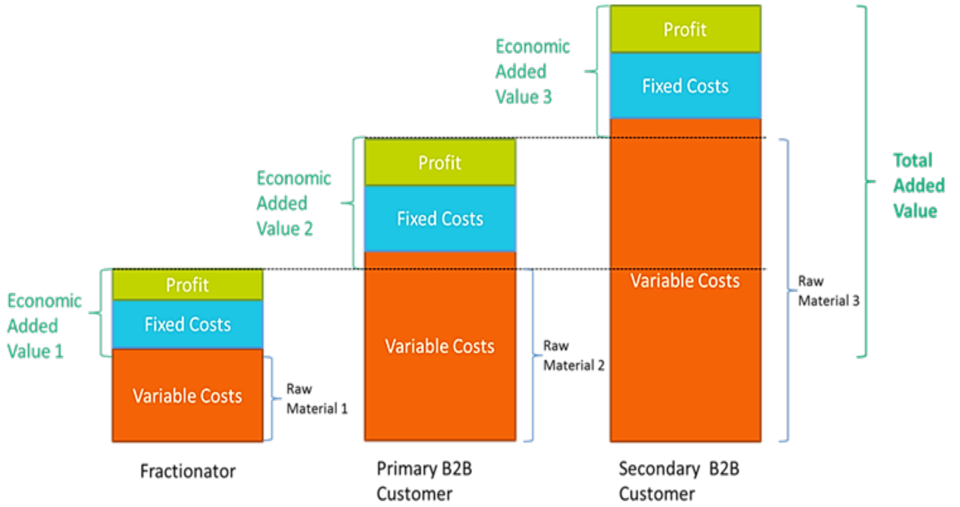


It should however be noted, that the varying proportions within Figure 6-1 are illustrative values and do not represent actual values. The EAV can be calculated by subtracting raw material costs (RMC) from gross revenue. This applies both for individual products as well as their respective product lines when all revenues generated by a certain raw material are taken into account. In total the calculation is made according to the following equation, wherein wt.% is the weight percentage of the corresponding crude tall oil fraction, p is the price of the product and RMC, the raw material cost.

$$\mathbf{EAV = wt\%_i \times p_i - wt\%_i \times RMC}$$

Additionally, by summing up the added values derived from all raw materials a specific stakeholder of the value chain processes (e.g. a CTO fractionator or a CTO product upgrading company), the total share of this stakeholder within the value chain can be calculated. As depicted in Figure 6-2 the outcome from one stakeholder is the input for the subsequent stakeholder within the value chain.

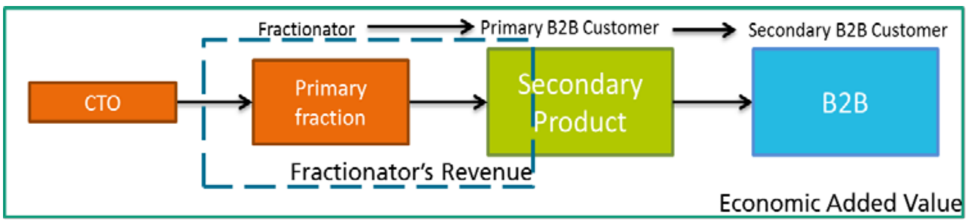
Figure 6-2:
Calculation of the Total Added Value along the value chain.
Connection to Economic Added Values



The sum of all added values, e.g. the added value 1-3 in Figure 6-2 made out of all CTO fractions will henceforth be referred to as "Total Added Value" (TAV) within this report. The corresponding term "Total Revenue" (TR) includes both added values due to partial upgrading of CTO fractions into valuable products as well as revenue that is made by selling CTO fractions to upgrading companies.

Figure 6-3 shows the relationship between Fractionators Revenue and Added Value for a specific primary fraction. The sums of the fractionator's revenues for all primary crude tall oil fractions account for the TR. The sum of the added values results in the TAV, likewise.

Figure 6-3:
Connection between Fractionators Revenue and Economic Added Value along the value chain



The percentages of crude tall oil within products along the value chain used for the calculations are aggregated values from multiple sources. This applies for primary fractions as well as typical crude tall oil percentages within secondary products and further down the value chain. All percent values are broken down to an average value and a range indication. In the same way the pricing indications for each considered product and each application area along the value chain are aggregated to an average price and a corresponding price spread. All estimations are based on the premise that 650,000 tonnes of CTO is processed in the EU each year, and have been adjusted to the base year 2015.

6.2.2 Job impact estimation

As the estimation for economic contributions in terms of the EAV were outlined earlier, this section aims to estimate the total number of jobs generated by the existing pine chemical industry as well as the potential number of jobs that could be generated if all available CTO were diverted to biofuel production.

Numerous methods and models exist to estimate and quantify industry level or even economy wide green jobs (EPI-2011; Gueye-2013). These methods include the following (ILO-2013):

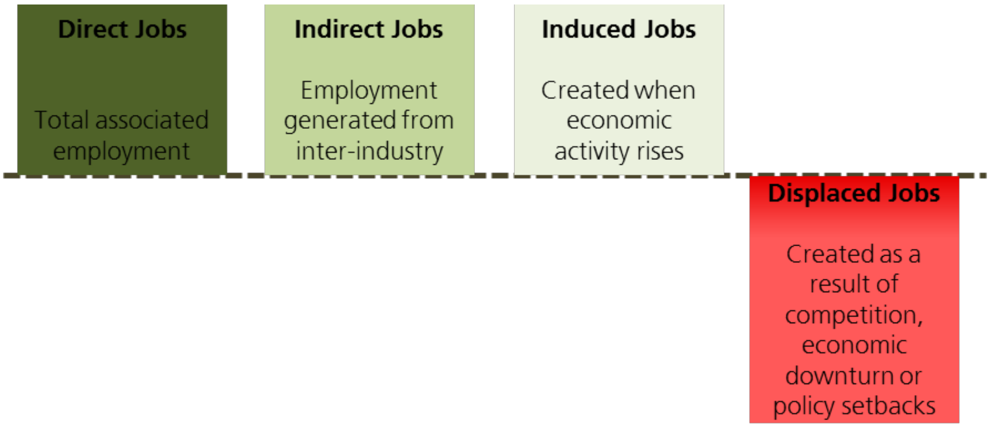
- Inventories and surveys focussing specific sector, or regions
- Employment factors, as jobs created per unit product
- Input-Output (I/O) analysis and Social Accounting Matrices (SAMs) as empirical tools

This study takes a mixed methodology approach combining inventories and surveys along with I/O analysis to estimate the total generated employment. The inventories and survey using primary data sources were employed to estimate the generated 'Direct jobs' for both the above mentioned cases. The Input-Output analysis in the form of multipliers based on the resultant sectoral rise in demand and output were used to estimate the generated 'Indirect Jobs'. These multipliers were obtained from chemical industry specific multiplier from CEFIC (CEFIC-2014) and EU wide multiplier based on industrial output from Eurostat (Eurostat-2014). Other secondary sources used were Eurobserv'er, JRC reports, ePure and other EU wide statistics.

Investments and or effective policies directed towards green sectors will provide new employment and result in an expansion of manufacturing and production, and jobs generated from this activity are considered as 'direct jobs'. The result of an expansion of manufacturing and production requires material and economic input from suppliers and distributors resulting in an inter-industry exchange of goods and services, the employment generated from such an activity is considered as 'indirect jobs'. Finally secondary or induced effects resulting from overall economic activity from enhanced revenues, in these direct or indirect jobs will also generate a factor of 'induced jobs'.

Most methodologies account for changes in employment generated but seldom account for displaced or lost jobs resulting from unintended policy or economic setbacks, therefore in this study, 'Gross jobs' are estimated to account for changes in total employment that results in either a positive or negative 'Net jobs'. The various type of employment effects are illustrated in Figure 6-4.

Figure 6-4:
Various types of employment effects



The terminology used in job impact estimation is summarized in Table 6-1.

Table 6-1: Job impact assessment – terminology and standard definitions

Terminology	Standard definitions
Direct Jobs	The total number of associated primary jobs generated within the industry
Indirect Jobs	The number of jobs generated as a result of inter-industry transactions as a result of heightened demands in the primary industry
Induced Jobs	The number of new jobs generated per million euros of output value (revenues) resulting from the economic activity in the primary industry
Gross Jobs	The newly created direct, indirect and induced jobs add up to Gross jobs
Displaced Jobs	The displaced direct, indirect and induced jobs add up to Displaced jobs
Net Jobs	The difference resulting from the gross jobs and displaced jobs yield in final net difference in employment created or destroyed.

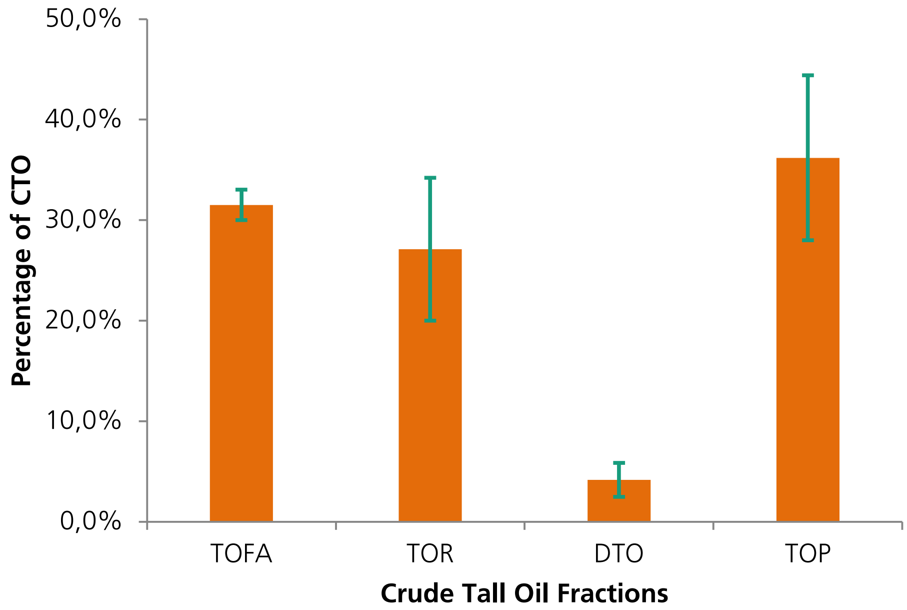
Finally, upon calculating the Net job effects in the primary industry, the subsequent downstream jobs associated to the CTO upgraders along the value chain was also estimated. This was done by assessing the generated employment resulting from the downstream upgrading of CTO fractions to functional bio-based chemicals and materials. For the biofuels case, it is assumed that no downstream jobs are generated, since the product chain terminates with the production of Renewable Diesel with no subsequent extension of the value chain.

6.3 Economic added value for biochemical

For detailed information about methodologies and interdependencies of added value and social impact calculation refer to section 6.2.

Figure 6-5 below shows the percentages of crude tall oil fractions (TOFA, TOR, DTO, TOP) that are used as input for the TAV and TR calculations. The green range indicator on each bar outlines the variations within the fractions based on the different information resources utilized.

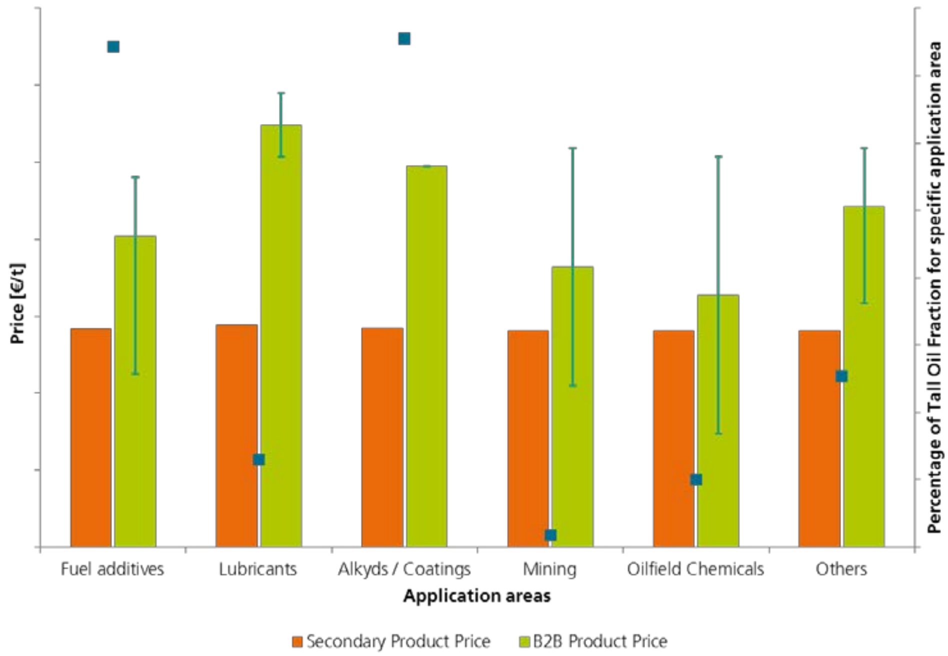
Figure 6-5:
Percentages of crude tall oil Fractions



The height of each bar represents the average value that has been taken for the calculation. For each fraction the application areas according to chapter 4.4 have been investigated with respect to typical percentages of crude tall oil fractions going into the applications as well as prices for secondary products plus prices further down the value chain. It has to be noticed that all pricing indications are still within the B2B range.

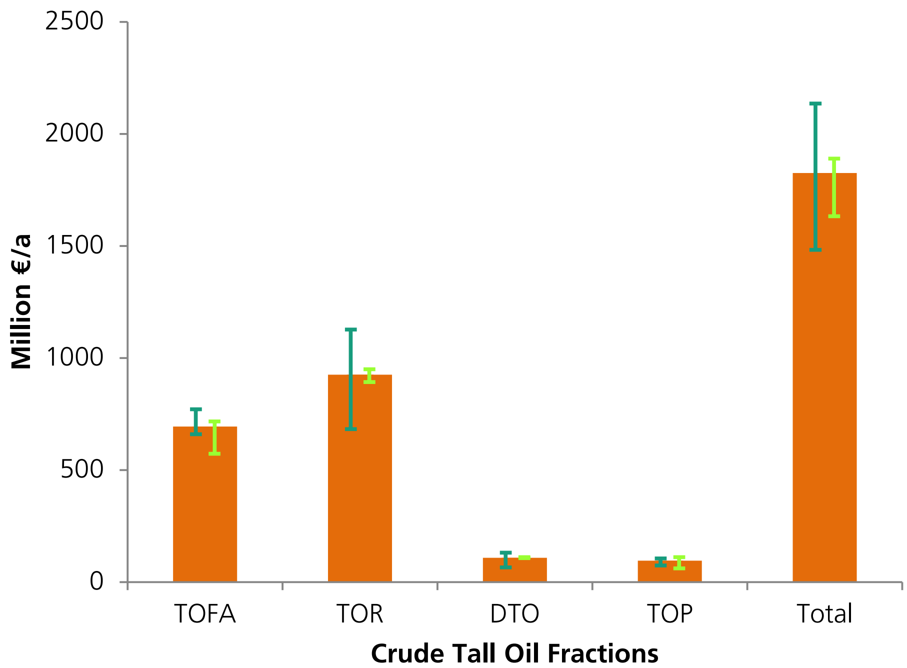
Additional added value is generated within the B2C section, wherein typical multipliers from 3 to 50 (e.g. Inks) can be expected. As an example Figure 6-6 depicts illustrative pricing indications for the 2nd and the 3rd step of the value chain (orange and green bars) of a certain crude tall oil fraction. The range indicator shows the range of pricing indications that can be found in market literature. Additionally, the split of the considered crude tall oil fraction into the different application areas is depicted with small square boxes.

Figure 6-6:
Illustrative prices and percentages of a certain crude tall oil fraction along the value chain in each application area



By varying both typical percentages for each fraction as well as their respective prices the TAV as depicted in. Figure 6-7 has been calculated. As shown below the result for the Total Added Value including two steps down the value chain. The dark green range indicator shows the influence of different percentages within the crude tall oil fractions. The lighter green indicator goes back to changes in pricing indications along the value chain.

Figure 6-7:
Calculated Total Added Value (TAV) broken down for the tall oil fractions



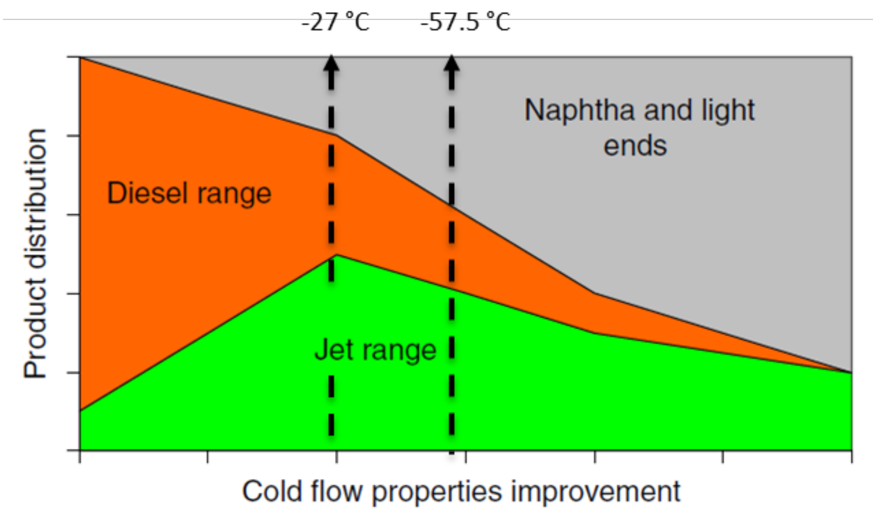
In total the tall oil industry generates an added value of about 1.75 Billion Euros within the European Union within B2B connections. 51 % of the TAV is made due to upgrading of TOR, 38 % from TOFA, 6 % from DTO and 5 % from TOP. The reason for the differences in the shares from the tall oil fractions between TAV and TR is the fact that TOP is not upgraded in the European Union.

6.4 Economic added value for biofuels

The calculation of the TAV for the production of renewable diesel from crude tall oil is based on the assumptions for the LCA. Please refer to chapter 5 for details regarding yields, process conditions and parameters as well as products and product distribution.

Figure 6-8 shows the distribution of products from Hydroprocessing of fatty acids (similar to crude tall oil TOFA) and other esters depending on the desired cold flow properties for jet fuel, i.e. CFPP (cold filter plugging point). This is one of the key parameters for aviation fuels and thereby to a high degree determines the total value of the product mixture. Conventional jet fuel needs to have a CFPP of maximum -47°C to fulfil the requirements for Jet-A1.

Figure 6-8:
Product distribution from Hydrotreatment of fatty acids esters depending on cold flow properties of the jet fuel fraction (modified from (modified from Starck et al.-2014)



When linear molecules like fatty acids are employed as raw materials for hydrotreatment, the products are linear molecules that do not fulfil the cold flow requirement and are solids at room temperature. In order to improve the cold flow properties a certain degree of branching has to be introduced. This is done by means of isomerization that is always accompanied by losses which then determine the relative yield of naphtha and diesel, see Figure 6-8.

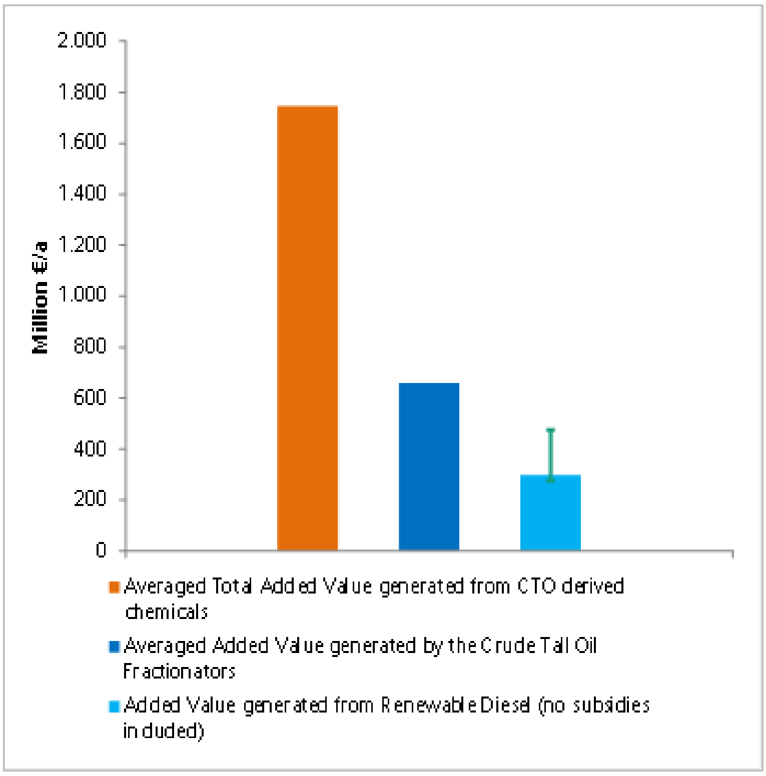
This in turn determines the total product value as jet fuel has higher value compared to diesel and naphtha. According to estimations published by the

Finish Ministry of Transport and Communications the prices for renewable jet fuel in 2017 will be around 1,400 €/t and for renewable diesel and renewable naphtha at 700 €/t respectively. As shown in Figure 6-8 the maximum share of jet fuel distribution is roughly 50%, a more realistic value for drop-in jet fuel for aviation would be about 40%. In the future this may be the product price and the product distribution to calculate the added value of producing fuels from crude tall oil which could potential be used in jet fuel.

At present, the calculations were made for the production of renewable diesel and only losses in carbon chain cracking that has to be applied for producing drop-in diesel fuel have been considered. The average price for diesel in 2015 was 480 €/t (indexmundi), all other relevant prices are taken from the TAV calculations. Likewise, the total raw material that can be used for the production of renewable diesel within the European Union is considered to be 650,000 tonnes per year.

Figure 6-9 below shows the comparison of the final outcome for the TAV calculation and the added value of the hypothetical production of renewable diesel. The upper quartile range in the green range indicator is attributable to the fact that existing companies producing renewable diesel get an extra margin on the fossil diesel price for the production of biofuels, while the lower quartile range refers back to the same pricing assumptions as for the Total Added Value calculation.

Figure 6-9: Comparison of the Total Added Value from the production of CTO derived bio-based chemicals vs the renewable diesel

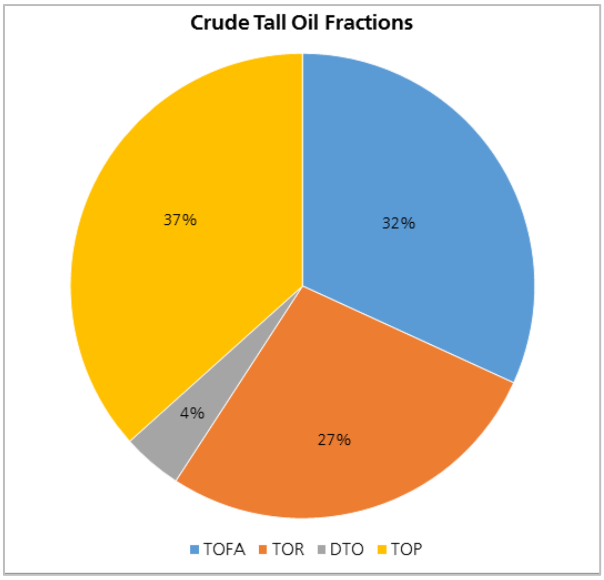


In total, the existing value chain for crude tall oil derived chemicals generate almost 4 times the added value than the best case scenario for the conversion of all crude tall oil available in the European Union into renewable diesel estimates. When considering actual market prices for diesel (light blue bar) the total added value generated by both the fractionators as well as the downstream industry for producing chemicals exceeds the value generated from the production of renewable diesel by 5 times assuming no incentives or tax subsidies included.

6.5 Jobs impact for biochemical process route

For detailed information about methodologies and interdependencies of added value and social impact calculation, refer to chapter 5.2. In the calculations for the Economic Added Value (EAV) in sections earlier for the biochemical process route, a range of revenues generated by the primary CTO fractionators and refiners were estimated for varying CTO compositions. For the job impact calculations however, a fixed composition shown below in Figure 6-10 was assumed. This composition is a typical profile of EU based CTO fractions which were estimated from an aggregated range of primary and secondary data.

Figure 6-10:
Percentages of typical crude tall oil Fractions



6.5.1 Upstream jobs impact

The total number of upstream jobs generated by the biochemical route is shown in Figure 6-11. Upstream CTO bio-refineries are spread across the geographical length of EU with operation revenues and jobs generated in Austria, Finland, France, and Sweden. Many of these bio-refineries also have operations to upgrade certain of the above mentioned crude tall oil intermediates into value add products such as paper size, printing ink resins and adhesive resins or other upgraded products that are subsequently sold into specific B2B market applications. The market applications considered in this study were elucidated previously in section 3.3. Therefore, the jobs impact for the upstream bio-based chemicals from CTO route starts with the first step by estimating the associated direct jobs in the EU CTO bio-refineries. The associated direct jobs were calculated from primary research in forms of surveys and questionnaires responded to by the bio refinery companies. Additional job numbers were obtained from annual reports and industry presentations.

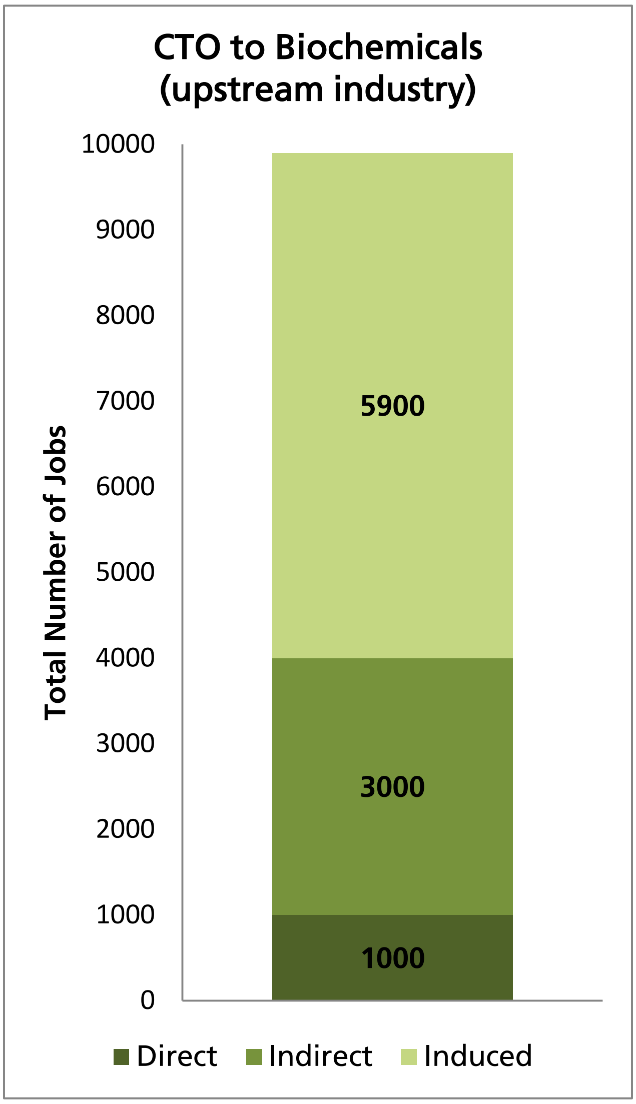
In order to strengthen the quality of the primary data longer time horizons were considered to make qualitative evaluations of the employment figures.

The second step was to estimate the indirect employment resulting from the inter-industry exchange of goods and services stemming from the expanded manufacturing and production in the primary industry. This was estimated by the aggregated sectoral data provided for the EU chemical industry (excluding the pharmaceuticals) by CEFIC (CEFIC-2015).

Following the estimation of the indirect jobs the last step was to assess the economy wide impact of the EU pine chemicals industry in the form of induced jobs. Economy wide multipliers (Eurostat-2014; EC, JRC-2014) were used to estimate the generated induced employment effects per million euros of industrial output (revenues). For this purpose only the total revenues by the primary industry (CTO fractionators and refiners) estimated in section 6.3 were used. In total, approximately 660 Million euros of added value was generated by the fractionators in the European Union in 2015. However, it must be noted that these multipliers are limited to the economy at a particular point in time, where the underlying assumption is that the trading patterns and market trends are fixed. Therefore, although they do not allow for any deviating probabilities from its linear model, without these multipliers the true nature of trickle down effects on the EU economy could be underestimated significantly.

According to the estimations the primary or the upstream industry processing CTO into intermediates and preliminary products generates about 9,900 jobs in total. Of which 1,000 jobs are directly attributed to the crude Tall-oil fractionators, 3,000 jobs are generated indirectly as a result in inter-industry exchange of goods and services, and finally an additional 5,900 jobs are created due to induced job effects. Figure 6-11 shows a detailed breakdown of the generated jobs.

Figure 6-11: Total number of direct, indirect and induced jobs generated by the 'upstream' CTO industry



6.5.2 Downstream End-use markets job impact

The crude tall-oil intermediates (TOFA, DTO, TOR and TOR) processed by the CTO fractionators and refiners of the primary industry are used by downstream industries to produce a spectrum of bio-based products and materials. These products find its use in everyday end-user applications. Figure 6-12 shows the typical percentage fractions of tall-oil intermediates ending in the selected market application areas of this study. It should be observed that these percentage fractions are absolute values. The estimations heavily relied on the secondary data from wide range of industrial sector groups and statistical sources (Eurostat, CEFIC, CEPI, FEICA, BASA, ETRMA, EUPIA, CEFIC-ATC). Unlike the estimation for the upstream jobs, the downstream jobs were directly calculated from the proportional volumes of the CTO intermediates ending in these EU wide application sectors.

Figure 6-12:
Absolute CTO fractions ending in downstream application areas

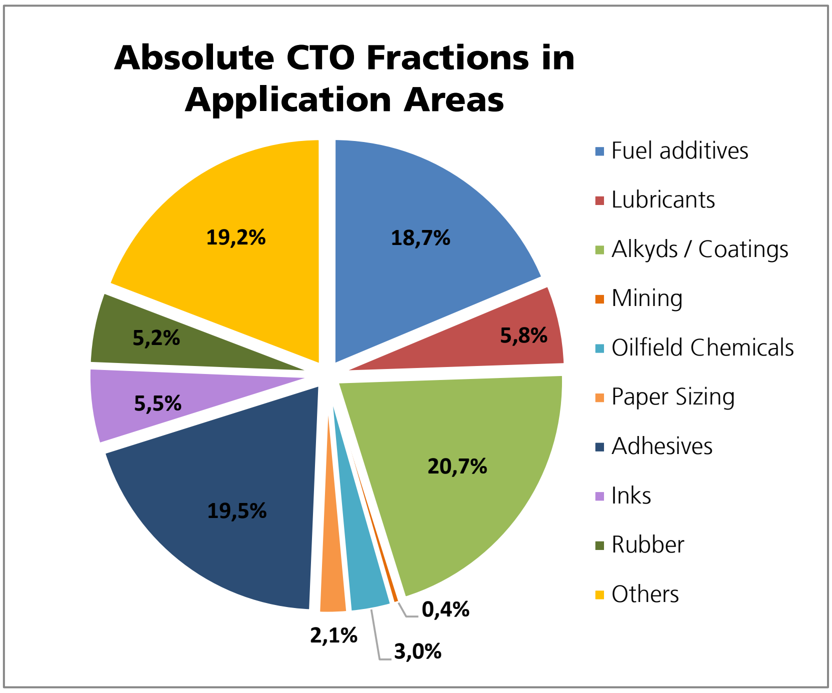


Table 6-2 below presents the total number of additional downstream jobs generated by the EU pine chemical industry. The pine chemical industry provides many skilled and semi-skilled jobs along its value chain in engineering, R&D, chemistry, logistics, sales & marketing. From its end-use markets, notably alkyd paints and coatings, adhesives, rubbers are the major markets.

In total about 5,132 direct jobs are generated in the downstream industry.

Table 6-2: Total number of downstream jobs generated by the EU pine chemical industry

Product Application	Absolute CTO fraction entering the EU market	Proportional EU Employment
Fuel Additives	18.7	82
Lubricants	5.8	341
Alkyds/Coatings	20.7	1,412
Mining Chemicals	0.4	24
Oilfield Chemicals	3.0	175
Paper Sizing Chemicals	2.0	273
Adhesives	19.5	965
Printing Inks	5.5	198
Rubber	5.2	710
Other Major Applications	19.2	952
TOTAL NUMBER OF DOWNSTREAM JOBS		**5,132**

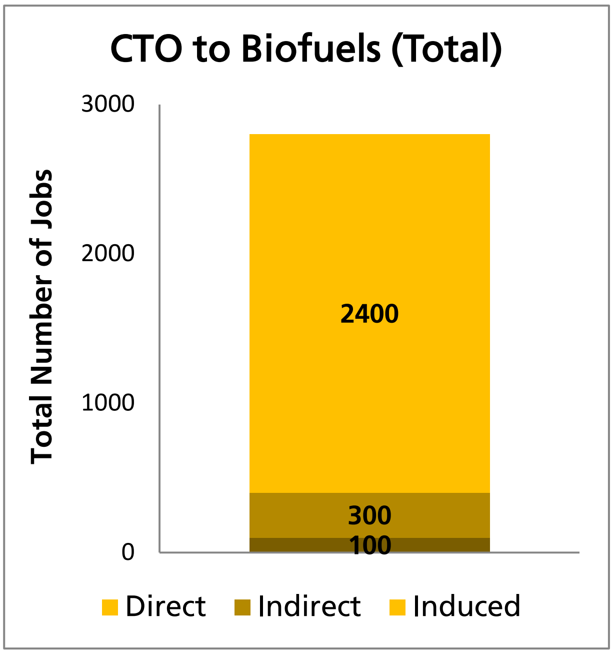
6.6 Job impact for biofuel process route

Figure 6-13 shows the total number of jobs generated by the process route when 650,000 tonnes of CTO is converted to renewable diesel. The first step in estimating the total number of associated jobs was to assess and quantify the number of direct jobs generated by the biodiesel plants across Europe that uses CTO as a feedstock. Annual reports and company data were used as a main source in estimating the direct jobs.

The direct jobs generated by the biofuel process route was interpolated by taking into account the publicly available employment numbers from the CTO to biofuel producers in Europe and that of the NESTE Oil plant processing used cooking oil (UCO) into advanced diesel. NESTE Oil (Neste-2014) processes around 2 million tonnes of UCO and employs about 250 people.

The next step was to estimate the indirect employment resulting from the inter-industry exchange of goods and services and other supply and distribution with the primary industry. Similar to the biochemical process, this was estimated by the aggregated sectoral data provided by CEFIC (CEFIC-2015). Finally the induced employment effects were calculated as the number of jobs created per million euros of revenues generated. It was calculated in section 6.3 that the biofuel production route generated a total added value of 300 Million euros in 2015, if all 650,000 tonnes were utilised. According to these estimations, the process route involving the conversion of CTO into renewable diesel generated only 2800 jobs in total. Of which only 100 jobs were direct jobs, while 300 jobs were generated indirectly as a result in inter-industry exchange of goods and services, and finally an additional 2,400 jobs were created due to induced job effects, these estimates are reflected in Figure 6-13. Furthermore, as explained in earlier section, the biofuels route does not generate any downstream jobs.

Figure 6-13: Total number of direct, indirect and induced jobs generated by the biofuel process route



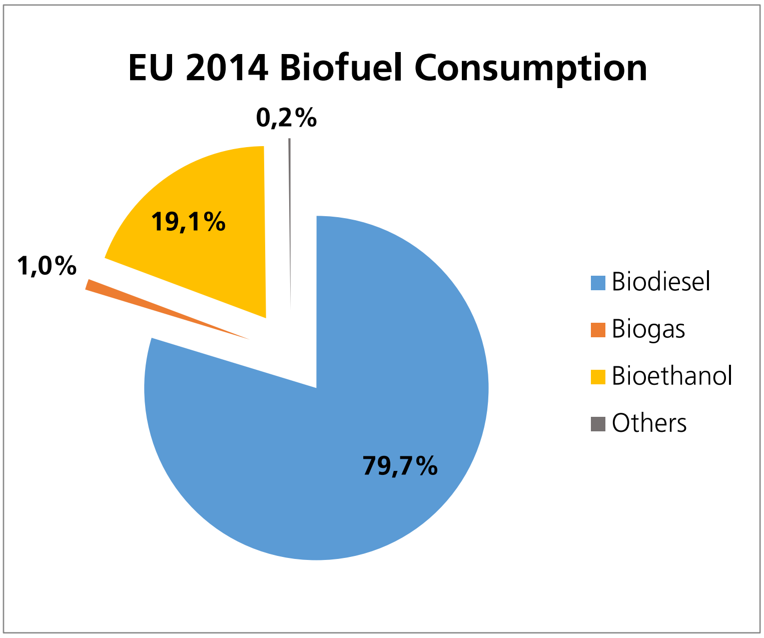
6.7 Cost-benefit Analysis

As CTO is a constrained resource, it is not realistically a viable raw material for simultaneous chemical use and renewable diesel production in Europe. The potential feedstock shortage and price escalation that could result from competing use of CTO to produce diesel fuels would likely have a negative impact on both the established pine chemical industry as well as the newfound biofuel industry. Plant closures and loss of employment would be a likely result for the CTO based pine chemical industry. Policy incentives to encourage CTO use in biofuels will have an adverse impact on the established pine chemical industry while generating no improvement in the GHG reduction or the EU economy.

From a short-term scenario for biofuels, it could be propounded that since the fuel business unlike chemical business operates on high volumes and low margins, the increase in the raw material price would render the process for producing biofuels from CTO economically unfeasible without large subsidies. Even if the biofuel manufacturer were to develop an upgraded renewable diesel with enhanced properties the CTO supply is simply inadequate to make it a viable raw material for the large biodiesel demand in Europe.

Figure 6-14 below shows the total European biofuel consumption for the year 2014 (EurObserv'ER-2015) at 14 Mtoe (million tonne oil equivalent). Of which 79.7% or about 11.2 Mtoe was attributed to biodiesel (FAME and renewable diesel), 19.1% or about 2.7 Mtoe for bioethanol.

Figure 6-14:
Total EU Biofuel consumption for the year 2014



Whereas the total consumption of transportation fuels in the EU for the 2014 was estimated to be 296 Mtoe. In a technically unfeasible hypothetical scenario, where all available 650,000 tonnes of CTO produced within the EU, were to be converted to biodiesel (in this case renewable diesel) with a theoretical yield of 100%, it would still contribute a mere additional 0.2% to the EU transportation fuels for 2014 levels. Furthermore, the LCA analysis presented in section 5 shows that pine chemicals allow for slightly higher savings of GHG emissions compared to renewable diesel. Therefore, incentivising the use of CTO to produce biofuels does not present a sustainable business case.

However, the scenario for the pine chemicals industry could play out differently. In the short-term the CTO based bio-refineries and upgrading could withstand a moderate raw material price rise and still remain operational, as it is common knowledge that chemical industry typically trades on a reasonably higher gross margin compared to fuel industry which relies on higher volumes (however this also depends on the level of incentives offered to the biofuel producers). However, it is crucial to note that these refineries usually operate at near name plate capacities. Therefore, any feed stock diversion to biofuels above the minimum operating threshold capacity, which is roughly about 80% of the total available CTO in the EU, will have an adverse effect which could lead to a shutdown of the manufacturing units. For the scenario where more than 20% of the raw material is diverted from the pine chemical industry, a net destruction of jobs is anticipated and invested capital at the bio refineries would be placed at risk.

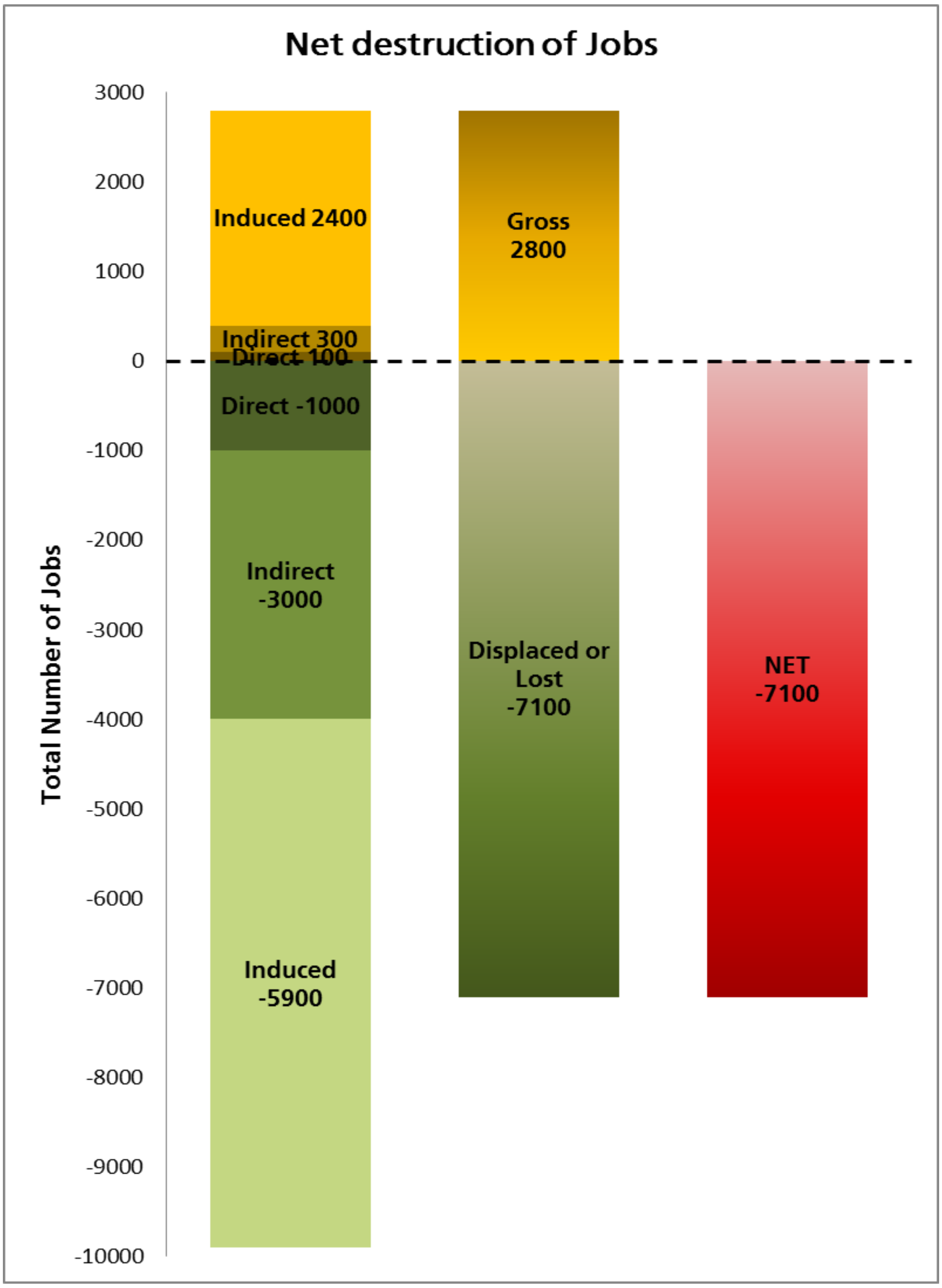
Drawing from the employment estimates generated by the both the cases (CTO to biochemical, CTO to biofuels), Figure 6-15 illustrates that the feedstock diversion from the existing pine chemical industry towards biofuel use might tend to appear favourable, when purely looking into the gross number of newly created green jobs. However, when considering the displaced or lost number of existing green jobs resulting from plant closures due to raw material shortages in the pine chemical industry, a direct net destruction of 7,100 jobs just with in the 'upstream' CTO industry would occur. In addition, the diversion of this scarce raw material from a cascading use would not only inhibit the production of a spectrum of bio-based chemicals and materials discussed in the previous sections, but also result in an additional loss of the 5,132 direct jobs in the 'downstream' CTO industry.

Therefore, from these analyses the following could be concluded:

- The production of biofuels from CTO does not comply with the best practice principle of cascading use of raw materials.
- Biofuels can be produced from CTO, but the long term viability of a business model to produce only biofuels is questionable.

- The pine chemicals industry has a broad, diversified well integrated value chain making valuable contributions through functional products used in many consumer applications such as Paints, Coatings, Inks, Adhesives, Lubricants etc. replacing petroleum based products and other products with larger carbon footprints.
- The pine chemical industry on the whole without any subsidies generates more jobs and added value per tonne of the available biomass raw material (CTO) than that generated by biofuels.

Figure 6-15: Impact scenario – 20% and more raw material diversion to biofuels



7 Conclusions and Summary

The main aim of the study was to make a scientific, quantified and holistic analysis to estimate and compare added value generated from the resource use of CTO in producing bio-based chemicals to that resulting from the production of renewable diesel. For the production of renewable diesel a scenario was estimated assuming a 100% diversion of the CTO raw material into fuel production. All the estimates made for the respective cases were adjusted to the base year 2015. To realise the objective of this study, the analysis and estimation of the study comprised of the following steps:

- Determination of the environmental impact in utilisation of the CTO towards the bio-based chemical route as well as the renewable diesel route.
- Determination of the economic added value generated by the bio-based chemical route as well as the renewable diesel route
- Finally, the social impact measured in terms of employment effect generated by the bio-based chemical route as well as the renewable diesel route was determined and analysed in detail.

The environmental impact was quantified by conducting a Life Cycle assessment (LCA) to estimate the amount of greenhouse gases (GHG) emitted with Global Warming Potential (GWP) as the key indicator for both the cases. It was found that the amount of greenhouse gas emissions associated to the production of bio-based chemicals from CTO is clearly lower than that associated with the production of renewable diesel. The GHG emissions for the production of chemicals was calculated to be 940 kg CO_2 eq./t CTO, whereas the GHG emissions for the production of renewable diesel resulted in a higher value of 1,218 kg CO_2 eq./t CTO. This difference is mainly accredited to the intensive energy demand for hydrogen production which is a vital raw material for the hydroprocessing of CTO into renewable diesel. Furthermore, expanded system calculations were also made to estimate the total amount of saved emissions for both cases in comparison to their respective fossil based substitutes. The expanded systems estimations reveal that there was no significant difference in comparative savings potential of greenhouse gas emissions resulting from both cases. Where, the estimated savings generated from the utilising CTO for biochemicals was -2,256 kg CO_2 eq./t CTO, for the renewable diesel route this estimation was at -2,118 kg CO_2 eq./t CTO. Therefore, it could be concluded from an environmental impact standpoint there is no significant advantage in producing renewable diesel by diverting the CTO biomass from its current use in pine chemicals.

The Economic Added Value (EAV) was estimated for both the biochemical as well as the biofuel route on the primary assumption that, the total volume of 650,000 tonnes of CTO is utilised for each respective process routes. For the renewable diesel route the process conversion route was assumed to be through hydrotreatment of CTO. The EAV generated by the existing pine chemical industry by processing and upgrading CTO into valuable products was calculated for within the business-to-business (B2B) limits. This was conducted by taking into consideration all major crude tall oil derived product lines that are subjected to further downstream processing along the value chain for two steps from the primary industry (CTO fractionators). The typical crude tall oil fractions entering into these secondary downstream industries as well their respective product prices along the value chain were determined.

The calculations show that the conversion of crude tall oil into bio-based chemicals generates an EAV of at least 4 times greater than that generated through the production of renewable diesel yields. It was estimated that the EU pine chemicals industry (which includes CTO refiners as well as downstream operators along the value chain) generates an added value of around 1,800 million, while the renewable diesel route would generate only 475 million euros when an additional margin for the production of renewable diesel is included. When considering a conservative scenario with fossil diesel prices the revenue numbers for the renewable diesel production route drop to 300 million euros. Thus the production and sale of bio-based chemicals exceeds the revenue generated from the production and sale of renewable diesel by 5 times.

Considering the fact that the value chain considered in this study for the bio-based chemicals route is limited to the business to business (B2B) transactions, this implies an even higher economic value is generated for the case of pine chemicals when business to customer (B2C) added value is taken into account. On the other hand, the best case scenario for renewable diesel included high additional margins for the production of green fuels. Thus, when actual market prices for fuels are considered the difference between the added values for both options increases further. In this case the added value for the production of bio-based chemicals was almost 6 times the added value for the production of renewable diesel. In conclusion, it can be stated that the existing pine chemical industry based on the constrained CTO as the sole raw material, generates a siginificantly higher economic added value to all possible scenarios that involve production of renewable diesel from CTO.

The final part of the study included the estimation of the social impact generated from the economic activity for both the process routes. The social impact assessments were made by determining the direct, indirect and the induced job effects. It was estimated that the upstream CTO processing alone generated 1000 direct jobs and 3000 indirect jobs. The upstream part of the pine chemical industry consists of primary CTO fractionators and partial upgrading of crude tall oil fractions. Furthermore, the downstream operations which process CTO intermediates and products into a multitude of consumer products generated an additional 5,100 direct jobs and thus processing CTO into chemical products generates about 9100 jobs in total along its value chain. This is a complex industry dealing with potential processing hazards and sophisticated operations, typical of specialty chemicals. The nature of the industry (safety, innovation, formulations and applications expertise, market servicing) requires skilled labor at many levels.

However, the process route involving the production of renewable diesel yielded a much lower number. The total number of direct and indirect jobs generated was 100 and 300 respectively, as the entire European crude tall oil volume (650,000 tonnes) could efficiently be processed within a single refinery. The renewable diesel route is assumed to not generate any downstream jobs, since the product chain terminates with the production of renewable diesel with no subsequent extension of the value chain. Therefore, it could strongly be asserted that the European pine chemical industry provides substantially greater social value than the biofuel route, as the EAV and employment is created with each subsequent product upgrading along the CTO value chain.

To summarise, the key findings and inferences from the study are presented as follows:

- CTO is a scarce resource with a global availability of just 2 million tonnes, therefore subjecting it to its present cascading use will ensure the most resource efficient utilisation of the scarce raw material.
- The European pine chemicals industry already serves as an example for resource efficiency through its cascading use of biomass resources (CTO). The cascading practise in the pine chemical industry ensures that highest value bio-based chemicals are produced first before utilising the any by-products or final residue for biofuels and energetic use, thus prolonging the value chain and maximizing the economic and social value.
- It was found that the amount of greenhouse gas emissions associated with the production of bio-based chemicals from CTO is slightly lower than that associated with the production of renewable diesel. The GHG emissions for the production of bio-based chemicals was 940 kg CO_2 eq./t CTO, whereas the GHG emissions for the production of renewable diesel resulted in a higher value of 1,218 kg CO_2 eq./t CTO.

- It was also found that there was no significant difference in comparative savings potential of greenhouse gas emissions resulting from replacing their respective fossil substitutes in both the cases. The estimated savings resulting from the utilisation of CTO in bio-based chemicals was -2,256 kg CO_2 eq./t CTO, while the estimated savings resulting from using CTO to produce renewable diesel was -2,118 kg CO_2 eq./t CTO. Therefore, from an environmental impact standpoint there is no significant improvement in GHG achieved by diverting the CTO from its current use in pine chemicals to biofuels.
- The pine chemical industry generates about 4,000 upstream jobs in Europe, of which 1,000 are directly generated by primary CTO operations and 3,000 are indirectly generated as a result of inter-industry exchange of goods and services
- The extended value chain of the pine chemical industry also generates an additional 5,100 jobs in Europe which are attributed to the downstream operations, where crude tall oil fractions and derivatives are converted in to several end-use consumer products.
- The renewable diesel production route processing 650,000 tonnes of CTO was estimated to generate only 400 jobs in total, of which 100 were direct jobs and 300 were indirect jobs. Unlike the pine chemical industry, the renewable diesel route does not generate any downstream jobs as the product chain terminates with the production of renewable diesel with no subsequent extension of the value chain.
- The Economic Added Value (EAV) calculations show that the conversion of crude tall oil into bio-based chemicals generates an EAV of at least 4 times than that generated through the production of renewable diesel yields. For a conservative scenario with current diesel prices, the EAV generated by bio-based chemicals rises by 5 times.
- Biofuels can be produced from CTO, but the long term viability of a business model to produce only biofuels is questionable. Most importantly, the production of only biofuels from CTO does not comply with the best practice principle of cascading use.
- Finally, if all available CTO in the EU (650,000 tonnes per year) were to be converted to biofuels with a theoretical yield of 100%, it would still contribute to a mere additional 0.2% to the EU transportation fuels for 2014 levels.

Therefore, in conclusion, incentivising and using CTO to produce biofuels does not present a sustainable business case compared to its current use in producing bio-based chemicals.

8 Bibliography

[ACC-2011]	The Economic Benefits of the Pine Chemicals Industry, Economics & Statistics Department, American Chemistry Council, 2011
[Agostini et al. - 2013]	Agostini, A.; Giuntoli, J.; Boulamanti, A.: Carbon Offsetting of Forest Bioenergy – conclusions and recommendations from a critical literature review, European Commission - JRC Technical reports, 2013
[Anthonykutty et al.-2013]	Anthonykutty, Jinto M.; van Geem, Kevin M.; Bruycker, Ruben de; Linnekoski, Juha; Laitinen, Antero; Räsänen, Jari.: Value Added Hydrocarbons from Distilled Tall Oil via Hydrotreating over a Commercial NiMo Catalyst. Ind. Eng. Chem. Res. 52 (30), pp. 10114–10125, 2013. DOI: 10.1021/ie400790v
[Anthonykutty et al.-2015]	Anthonykutty, Jinto M.; Linnekoski, Juha; Harlin, Ali; Lehtonen, Juha: Hydrotreating reactions of tall oils over commercial NiMo catalyst. Energy Sci Eng 3 (4), pp. 286–299, 2015. DOI: 10.1002/ese3.70
[ATC-2013]	Fuel Additives: Uses and Benefits, Technical Committee of Petroleum Additive Manufacturers in Europe (ATC), CEFIC, 2013
[Biochem-2010]	Assessment of the Bio-based Products Market Potential for Innovation, BIOCHEM project
[Cashman et al. - 2015]	Cashman, Sarah A.; Moran, Kevin M.; Gaglione, Anthony G.: Greenhouse Gas and Energy Life Cycle Assessment of Pine Chemicals Derived from Crude Tall Oil and Their Substitutes. Journal of Industrial Ecology, pp. 1-13, 2015. DOI: 10.1111/jiec.12370
[CEFIC-2014]	CEFIC, The European Chemical Industry Council - Facts and Figures 2014, 2014. Online Available at: http://bit.ly/1U5pyd3
[CEPE-2015]	CEPE, European Confederation of Paint, printing Ink and Artists' Colours Manufacturers Association, 2015. Online Available at: http://bit.ly/1S3F1Ed
[COM/2015/0614]	European Commission: Closing the loop - An EU Action Plan for the Circular Economy, Brussels, 2015
[Coll et al.-2001]	Coll, Robert; Udas, Siddharth; Jacoby, William A.: Conversion of the Rosin Acid Fraction of Crude Tall Oil into Fuels and Chemicals. Energy Fuels 15 (5), pp. 1166–1172, 2001. DOI: 10.1021/ef010018a
[Defever and Polastro-2010]	Defever, K.; Polastro, E.: Crude tall oil: too valuable to burn. Pine Chemicals Association: 2010 International Conference: September 20th, Arthur D. Little, 2010
[DIN EN ISO 14040-2009]	DIN EN ISO 14040: Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006), 2009
[Directive 2009/28/EC-Annex IX]	DIRECTIVE (EU) 2015/1513 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 September 2015 amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources

[EC, JRC-2006] European Commission; Joint Research Centre: Integrated pollution prevention and control: Reference document on best available techniques for the waste treatment industries. Joint Research Centre, 2006

[EC, JRC-2009] European Commission; Joint Research Centre: Integrated pollution prevention and control: Reference document on best available techniques for management of tailings and waste rock in mining activities. Joint Research Centre, 2009.

[EC, JRC-2014] European Commission; Joint Research Centre: Structural Patterns of the Bioeconomy in the EU Member States – a SAM approach, 2014.

[EEB-2015] Eräjää, S.: Cascading use of biomass: Opportunities and obstacles in EU policies, remaining challenges, and future opportunities, EEB, 2015.

[EPI-2011] Bivens, J.: Method memo on estimating the jobs impact of various policy changes, Economic Policy Institute, 2011.

[ERRMA-2010] EU Public/Private Innovation partnership "Building the Bio-Economy by 2020" as part of "Innovation Union", A flagship initiative within the Europe 2020 strategy, 2010. Online Available at: http://bit.ly/1MzGxMz

[ETRMA-2015] ETRMA, European Tyre and Rubber Industry Statistics – Edition 2015. 2015, Online Available at: http://bit.ly/1pxclg0

[European Parliament and Council of the European Union-2006] European Parliament and Council of the European Union: Directive 2006/32/EC of the European Parliament and of the Council of 5 April 2006 on energy end-use efficiency and energy services and repealing Council Directive 93/76/EEC. Official Journal of the European Union, 2006.

[European Parliament and Council of the European Union-2009] European Parliament and Council of the European Union: Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC. Official Journal of the European Union, 2009

[Eurostat-2014] Eurostat - Annual detailed enterprise statistics on manufacturing, (NACE Rev.1.1,D), structural business statistics metadata, Product code – sbs_na_2a_dfdn, May 2014

[EuPIA-2015] EuPIA, European Printing Inks Association Statistics – Edition 2014, March 2015, Online Available at: http://bit.ly/1ZoHPS8

[FEICA-2015] FEICA, Association of European Adhesive and Sealant Industry, 2015. Online Available at: http://bit.ly/1MkIlZz

[Franklin Associates- 2013] Franklin Associates: Greenhouse gas and energy life cycle assessment of pine chemicals derived from crude tall oil and their substitutes. Submitted to the American Chemistry Council (ACC) Pine Chemistry Panel. Unpublished, 2013

[Gueye-2013] Gueye, M. K. Assessing the employment effects of greening economies, International Labour Organisation, 2013

[ILO-2013] Harsdorff, M; Phillips,D: Methodologies for assessing green jobs, Policy brief, International Labour Organisation, 2013

[Innocenti-2010] A Public Private Cooperation for Bio-based Products, 2010. Online Available at: http://bit.ly/25iIWH7

[IPCC-2007a] IPCC: Climate Change 2007. Mitigation of Climate Change. Contribution of working group III to the fourth assessment report of the Intergovernmental Panel on Climate Change. Intergovernmental Panel on Climate Change (IPCC). Cambridge, New York, 2007. Available online at http://bit.ly/1UKMBKm

[IPCC-2007b] IPCC: Climate Change 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change Climate Change (IPCC). Cambridge, New York, 2007. Available online at: http://bit.ly/1RrK59b

[Kalnes et al.-2016] Kalnes, T. M.; Marker, T.; Shonnard, D. R.; Koers, K. P. Green diesel production by hydrorefining renewable feedstocks. UOP, 2016. Available online at: http://bit.ly/1U44dRq

[Mikulec et al.-2012] Mikulec, Jozef; Kleinová, Andrea; Cvengroš, Ján; Joríková, L'udmila; Banič, Marek: Catalytic Transformation of Tall Oil into Biocomponent of Diesel Fuel. International Journal of Chemical Engineering, pp. 1–9, 2012. DOI: 10.1155/2012/215258

[Neste Oil-2012] Neste Oil: NExBTL renewable diesel: Singapore plant: Tallow pathway description. Neste Oil, 2012. Available online at: http://bit.ly/20L2kte

[Neste Oil-2014] Neste Oil: Neste Oil Annual report 2014 – Neste Oil Employees in 2014, 2014. Online Available at: http://bit.ly/1o4vchg

[Norlin-2000] Norlin, L.-H.: Tall oil. In Wiley (Ed.): Ullmann's Encyclopedia of Industrial Chemistry. Weinheim, Germany: Wiley-VCH Verlag GmbH & Co. KGaA, 2000

[Nousiainen et al.-2012] Nousiainen, J.; Rissanen, A.; Gutierrez, A.; Lindberg, T.; Laumola, H.; Knuuttila, P.: Process and apparatus for producing hydrocarbons. Patent no. US 2012/0260565 A1, 2012.

[Palanisamy et al. 2014] Palanisamy, S.; Gevert, B.S.: Hydroprocessing of fatty acid methyl ester containing resin acids blended with gas oil. Fuel Processing Technology, pp. 435-440. Elsevier, DOI: 10.1016/j.fuproc.2014.05.015

[PCA-2003] High Production Volume (HPV) chemical challenge program, Tall Oil and Substances, submitted to the US EPA by the HPV task force, Pine Chemicals Association, 2013

[Sotelo-Boyas et al.-2012] Sotelo-Boyas, Rogelio; Trejo-Zarraga, Fernando; Jesus Hernandez-Loyo, Felipe de (2012): Hydroconversion of Triglycerides into Green Liquid Fuels. In I. Karamé (Ed.): Hydrogenation. Rijeka: InTech.

[Sigsson et al.-2014] Stigsson, L.; Naydenov, V.; Lundbäck, J. (2014): Biorefining of crude tall oil. Applied for by Sunpine AB. Patent no. WO2014098763A1.

[Starck et al.-2014] Starck, L.; Pidol, L.; Jeuland, N.; Chapus, T.; Bogers, P.; Bauldreay, J.: Production of Hydroprocessed Ester and Fatty Acids (HEFA) – Optimisation of Process Yield. Oil & Gas Science and Technology – Rev. IFP Energies Nouvelles, 2014. DOI: 10.2516/ogst/2014007

[Stumborg et al.-1996] Stumborg, Mark; Wong, Al; Hogan, Ed (1996): Hydroprocessed vegetable oils for diesel fuel improvement. In Bioresource Technology 56 (1), pp. 13–18. DOI: 10.1016/0960-8524(95)00181-6.

[Tanaka et al.-1980] Tanaka, M.; Yokoyama, R.; Morimoto, A.; Yamashita, S. (1980): Process for distilling crude tall oil. Patent no. CA11554416 A1

9 Abbreviations

CAGR	Compound Annual Growth rate
CTO	Crude Tall Oil
DTO	Distilled Tall Oil
EAV	Economic Added Value
ELCD	European Reference Life Cycle Data System
EU-27	EU-27 member states
GHG	Greenhouse Gases
TOFA	Tall Oil Fatty Acid
TOH	Tall Oil Heads and light-ends
TOR	Tall Oil Rosin
TOP	Tall Oil Pitch
LCA	Life-Cycle Assessment
ILUC	Indirect Land Use Change
I/O Model	Input-Output Model

10 List of Tables

11 List of Figures

12 About Us

Fraunhofer-Gesellschaft and Fraunhofer UMSICHT

The Fraunhofer-Gesellschaft is the largest institution for applied research in Europe with a staff of more than 24 000 employees and a turnover of over 2 billion euros in 2014[1].

Fraunhofer UMSICHT[2] is one of 66 Institutes of the Fraunhofer-Gesellschaft Worldwide. The Fraunhofer UMSICHT comprises of 559 employees who generated a turnover of 38.1 million euros in 2014.

Competencies and business units

As a pioneer for technological innovations in the fields of energy, processes and products, Fraunhofer UMSICHT aims at advancing sustainable economies, environmentally friendly technologies and innovative approaches and thus actively shapes the energy transition and the raw material shift. The institute develops, examines and optimizes technical processes and materials and acts as an interface between science and business. Our customers are industrial enterprises, service companies and public authorities. Together with them Fraunhofer UMSICHT develops and conducts scientific research on the latest know-how and transfers it into industrial applications and marketable products through its five business units:

- Polymer Materials
- Chemistry
- Environment
- Biomass
- Energy

The institute employs scientists qualified in the fields of process technology, material sciences, chemical engineering, mechanical engineering, energy engineering, applied mathematics, chemistry, biology, physics, industrial engineering and business economics. They conduct work in interdisciplinary teams.

1 http://www.fraunhofer.de/en.html
2 http://www.umsicht.fraunhofer.de/en.html

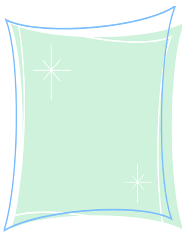
13 Contacts

Venkat K. Rajendran M.Eng., MSc.-MiM
Sustainability and Resources Management
Group: Sustainability Assessment
Phone: +49 (0) 208-8598-1417
E-Mail: venkat.rajendran@umsicht.fraunhofer.de

Dipl.-(econ. Chemist) Klaas Breitkreuz
Group: Biorefinery and Biofuels
Phone: +49 (0) 208-8598-1300
E-Mail: klaas.breitkreuz@umsicht.fraunhofer.de

Dr. Axel Kraft
Biorefinery and Biofuels
Head of Department
Phone: +49 (0) 208-8598-1167
E-Mail: axel.kraft@umsicht.fraunhofer.de

Dr. Daniel Maga
Sustainability and Resources Management
Group Leader: Sustainability Assessment
Phone: +49 (0) 208-8598-1191
Email: daniel.maga@umsicht.fraunhofer.de



Mercè Font Brucart
Sustainability and Resources Management
Group: Sustainability Assessment
Phone: +49 (0) 208-8598-1191
Email: merce.font.brucart@umsicht.fraunhofer.de