American Chemistry Council | Pine Chemistry

May 21, 2015

Electronic Delivery:
stallworth.holly@epa.gov

Office of the Administrator
Science Advisory Board
1200 Pennsylvania Ave., NW
Washington, DC 20460

Attention: Dr. Holly Stallworth:

The Pine Chemistry Panel (PCP) at the American Chemistry Council (ACC) appreciates the opportunity to submit these comments on the Accounting Framework for Biogenic $CO_{2,}$ and specifically on the critical issue of indirect emissions (leakage). The PCP commends EPA and the SAB for its diligence on this critical and complex issue.

The PCP is composed of leading companies[1] engaged in the business of pine chemistry, i.e., the production of high-performance, naturally-derived chemicals used in diverse downstream industries. Members of the Panel operate bio-refineries, derivatives manufacturing and R&D facilities in the United States and in the EU and sell their products into those, as well as other, international markets. They are leaders in the bio-based products space with a long track record of optimizing processes to upgrade pine-based feed stocks into products whose value in a competitive market is significantly greater than its fuel value.

The principal raw materials for the pine chemistry industry are crude tall oil ("CTO") and Crude Sulfate Turpentine ("CST"), both produced in the papermaking process. CTO is a bio-liquid produced by acidulating black liquor soap which has been separated from the cooking chemicals or "black liquor" used in the pulping process. As noted in Addendum 6 (page D-23) of the draft Framework, CTO, or "tall oil", and CST are co-products of the Kraft pulping process and are sold commercially.

[1] Arizona Chemicals; Georgia-Pacific Specialty Chemicals; MeadWestvaco Specialty Chemicals

CTO is fractionated into specialty chemicals such as tall oil fatty acid[2], distilled tall oil, tall oil rosin and pitch. These chemicals are then used in a number of downstream bio-derived and bio-renewable products, for instance in paints and coatings, adhesives, synthetic rubber used in tires, printing ink, papermaking chemicals, soaps and detergents, and food additives. CST is also fractionated into its pure components and used in consumer products such as cosmetics, beverages, soaps, perfumes, disinfectants and specialty adhesives.

The PCP recently commissioned Franklin Associates, a division of ERG, to conduct a cradle-to-gate peer-reviewed greenhouse gas and energy life cycle assessment of CTO and its derivatives. The assessment documents the direct carbon footprint of the industry and further considers the significant potential for indirect greenhouse gas emissions that may be caused by the diversion of black liquor soap or CTO to bio-energy uses and the corollary substitution of other chemicals in the marketplace. While the assessment as completed does not address carbon storage in the final products, we believe there is potential for sequestration in many of these products, particularly resins that will not decompose over the long term, and that evidence should be considered when determining the Biogenic Assessment Factor assigned to either black liquor soap or CTO.

Thank you very much for your consideration of these comments. I have included a copy of the executive summary of our CTO assessment for your reference.

Respectfully submitted,

Kevin M. Moran
Director, Pine Chemistry Panel
American Chemistry Council

[2] Which EPA has included in its Designed for the Environment (DfE) Program. See http://www.epa.gov/dfe/saferingredients-cas.htm#61790123

GREENHOUSE GAS AND ENERGY LIFE CYCLE ASSESSMENT OF PINE CHEMICALS DERIVED FROM CRUDE TALL OIL AND THEIR SUBSTITUTES

EXECUTIVE SUMMARY

Submitted to:
The American Chemistry Council (ACC)
Pine Chemistry Panel

Submitted by:
Franklin Associates,
a Division of ERG

FRANKLIN Associates
A Division of ERG

American Chemistry Council

ABSTRACT

Pine chemicals are co-products of the papermaking process and are upgraded into many diverse products such as adhesives, inks, rubber, paints, coatings, surfactants, oilfield chemicals, paper size, and fuel. This life cycle assessment (LCA), conducted according to ISO 14040/14044 standards, investigates the U.S., European, and global industry carbon and energy footprint of pine chemicals derived from crude tall oil (CTO). This study has three specific goals: 1) to determine the cradle-to-gate carbon and energy footprint for the production of pine-based chemicals derived from CTO, 2) to leverage the cradle-to-gate carbon and energy footprint of pine chemicals to develop comparative analyses between pine chemicals derived from CTO and their most likely substitutes for the primary end applications in which pine chemicals derived from CTO are used, and 3) to calculate the possible carbon and energy footprint effects of shifting all CTO resources from the current pine chemical production profile to 100% biodiesel production in Europe. Current and proposed U.S. and European government policies have resulted, or could result, in CTO being classified as renewable biomass for energy production purposes; this can create incentives to convert CTO into a fuel rather than use it for production of pine chemicals. Assessments of the environmental impacts of such renewable fuel policies typically cover only greenhouse gases (GHGs), or in some cases energy savings; accordingly, this study only examines those two impact categories. Because the scope of this analysis is an assessment of energy and GHG impacts and does not cover other environmental impact categories, the study is not intended to be used as the basis for public claims or assertions about the overall comparative environmental performance of pine chemicals and alternatives. Only comparative statements relating to GHG and energy impacts are intended be made public based on the findings of this study.

The data used in the life cycle inventory model represent 100% of the U.S. CTO distillation industry and approximately 90% of the European CTO distillation industry for the year 2011. Since the U.S. and Europe distill the majority of CTO, U.S. and European findings are also used to develop profiles for global CTO distillation products. The baseline results for CTO-derived chemicals include an allocated portion of energy and GHG impacts for upstream forestry and kraft pulping operations, and do not include a credit for storage of biogenic carbon in the pine chemicals during their useful life. The study found that the baseline carbon footprint is 1,466 kilograms of carbon dioxide–equivalent (kg CO_2 eq) per tonne of CTO distillation product for the U.S. and 740 kg CO_2 eq per tonne of CTO distillation product for Europe. Most energy required for the production of CTO distillation products is renewable energy (81% to 86%), which is primarily biomass feedstock or biomass process energy. Globally, the weighted average pine chemical carbon footprint is approximately 50% lower than the most likely mix of pine chemical substitutes. Pine chemical substitutes with notably higher carbon footprints than the pine chemical they replace include hydrocarbon resins for rubber, ink, and adhesive end applications, along with alkyl succinic anhydride for paper size and heavy fuel oil #6 for fuel combustion. Similarly, the weighted average global pine chemical non-renewable energy footprint is approximately 57% lower than the most likely mix of pine chemical substitutes. In addition, by comparing the carbon footprint of European CTO biodiesel products to those of pine chemicals derived from CTO in Europe, the study found that differences in the carbon footprints of utilizing CTO for biodiesel versus utilizing CTO for pine chemicals are insignificant. Therefore, there is no carbon or energy footprint benefit that accrues by diverting CTO that is currently being used as a feedstock for pine chemicals to new biodiesel production in Europe.

For compliance with ISO 14044:2006 standards, this study has been peer-reviewed by an independent three-person panel of LCA experts. Its results offer important quantified information to public policymakers, operators of kraft pulping and recovery systems, manufacturers of pine chemicals, users of pine chemicals, and other private and public stakeholders.

PREFACE

This pine chemicals greenhouse gas and energy life cycle assessment (LCA) study was conducted for the Pine Chemistry Panel of the American Chemistry Council (ACC). Kevin Moran and Seth Barna coordinated the project for the ACC Pine Chemistry Panel. The report was made possible through the cooperation of member companies and non-member companies that provided data on the production of pine chemical products. The following participating companies made significant contributions: Arizona Chemical LLC, Georgia-Pacific LLC, MeadWestvaco Corporation, Forchem, and DRT (Dérivés Résiniques et Terpéniques). The Pine Chemicals Association also made notable contributions to the project.

Franklin Associates, a division of Eastern Research Group (ERG), carried out the work as an independent contractor for this project. Sarah Cashman was the project manager and primary author. Beverly Sauer, senior chemical engineer and principal, and Melissa Huff, senior chemical engineer, provided technical input and editorial review. Anthony Gaglione, chemical engineer, conducted key process modeling tasks. Greg Schivley, environmental engineer, and Janet Mosley, LCA analyst, contributed to modeling tasks. Lori Snook contributed to report preparation tasks.

The report was peer-reviewed by an expert panel consisting of Beth Quay, an independent consultant with expert knowledge of LCA (serving as review chair), Dr. H Scott Matthews of Avenue C Advisors LLC and the Carnegie Mellon University, and Dr. Roland Hischier, a senior LCA expert from Empa (the Swiss Federal Laboratories for Material Science and Technology). The revisions made in response to the peer review panel's insightful comments added greatly to the quality and credibility of this project.

Franklin Associates and the ACC Pine Chemistry Panel are grateful to all of the companies that participated in the life cycle inventory data collection process. These companies made significant contributions to ensure that high-quality data were provided for this study.

Franklin Associates makes no statements other than those presented within the report.

August 30, 2013

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1

ES.1. INTRODUCTION 1

ES.2. IMPACT ASSESSMENT 3

ES.2.1. Uncertainty 3

ES.3. GOAL 1: CRADLE-TO-GATE GHG AND ENERGY LIFE CYCLE ASSESSMENT OF DISTILLATION PRODUCTS FROM CTO 5

ES.3.1. Scope and Boundaries 5

ES.3.2. Data Sources 7

ES.3.3. Summary Results 8

ES.3.4. Carbon Footprint 9

ES.3.5. Energy Footprint 11

ES.3.6. Sensitivity Analyses 12

ES.3.7. Summary Conclusions 12

ES.4. GOAL 2: COMPARATIVE ANALYSIS OF PINE CHEMICALS VERSUS PINE CHEMICAL SUBSTITUTES 13

ES.4.1. Scope and Boundaries 13

ES.4.2. Data Sources 15

ES.4.3. Comparative Analysis Limitations 16

ES.4.4. Carbon Footprint Results 17

ES.4.5. Non-Renewable Energy Footprint Results 20

ES.4.6. Total Energy Footprint Results 20

ES.4.7. Summary Conclusions 23

ES.5. GOAL 3: COMPARATIVE ANALYSIS OF CTO USED FOR PINE CHEMICALS VERSUS BIODIESEL 25

ES.5.1. Scope and Boundaries 25

ES.5.2. Combustion Analysis Results 27

ES.5.3. Combustion Analysis Conclusions 29

ES.6. PEER REVIEW 31

TABLE OF CONTENTS (cont'd)

LIST OF TABLES

Table ES-1. Summary of Impact Categories 3

Table ES-2. Summary of Cradle-to-Gate Data Sources 7

Table ES-3. Comparative Carbon Footprint Results for 1 Tonne of CTO Distillation Product Output by Geographic Region 10

Table ES-4. Summary Pine Chemical Cradle-to-Gate Conclusions by Impact 12

Table ES-5. Comparative Analysis End Markets 14

Table ES-6. Summary of Comparative Analysis Data Sources 16

Table ES-7. Relative Carbon Footprint of Pine Chemicals Compared to Weighted Average Carbon Footprint of Pine Chemical Substitutes 19

Table ES-8. Relative Non-Renewable Energy Footprint of Pine Chemicals Compared to Weighted Average Non-Renewable Energy Footprint of Pine Chemical Substitutes 21

Table ES-9. Summary Comparative Conclusions by Impact 23

LIST OF FIGURES

Figure ES-1. Flow Diagram of Cradle-to-Gate CTO Distillation Product System Boundaries 6

Figure ES-2. Comparison of CTO Distillation Product Composition by Geographic Region 9

Figure ES-3. Summary of Baseline Carbon Footprint Results by Geographic Region 10

Figure ES-4. Breakdown of Baseline Total Energy Footprint Results by Geographic Region 11

Figure ES-5. System Boundaries for Comparative Analysis 15

TABLE OF CONTENTS (cont'd)

LIST OF FIGURES (cont'd)

Figure ES-6. Carbon Footprint for Global Pine Chemicals and Global Pine Chemical Substitutes by End Application **18**

Figure ES-7. Net Carbon Footprint Avoided Burdens for Using Pine Chemicals Rather Than Pine Chemical Substitutes **19**

Figure ES-8. Non-Renewable Energy Footprint for Global Pine Chemicals and Global Pine Chemical Substitutes by End Application **21**

Figure ES-9. Net Non-Renewable Energy Footprint Avoided Burdens for Using Pine Chemicals Rather Than Pine Chemical Substitutes..... **22**

Figure ES-10. Total Energy Footprint for Global Pine Chemicals and Global Pine Chemical Substitutes by End Application..... **22**

Figure ES-11. Combustion Comparative Analysis System Boundaries **26**

Figure ES-12. Carbon Footprint of Using CTO for Pine Chemicals Versus Biodiesel from Hydrogenation **27**

Figure ES-13. Non-Renewable Energy Footprint of Using CTO for Pine Chemicals Versus Biodiesel from Hydrogenation..... **28**

Figure ES-14. Total Energy Footprint of Using CTO for Pine Chemicals Versus Biodiesel from Hydrogenation **28**

EXECUTIVE SUMMARY

ES.1. INTRODUCTION

The American Chemistry Council (ACC)'s Pine Chemistry Panel has commissioned Franklin Associates, a division of ERG, to conduct a cradle-to-gate life cycle assessment (LCA) of average U.S. and European pine chemicals. Pine chemicals are made from co-products of the kraft pulping process, such as crude tall oil (CTO). A full LCA quantifies and characterizes products' use of energy and materials and the releases to the air, water, and land for each step from raw material extraction through production, use, and end-of-life management. For commodity chemicals such as pine chemicals, the use phase and end-of-life management depend upon the chemicals' specific application. Therefore, LCAs on commodity materials are typically conducted as cradle-to-gate analyses that cover all steps from raw material extraction through production of the material ready for use.

The first goal of this study is to determine the cradle-to-gate greenhouse gas (GHG) emissions and energy demand for distillation products of CTO, including tall oil fatty acid (TOFA), tall oil rosin (TOR), distilled tall oil (DTO), tall oil pitch, and tall oil heads. Since the U.S. and Europe distill the majority of CTO produced in the world, U.S. and European findings are also leveraged to develop LCA results for global CTO distillation products.

The second goal of this project is to build upon the cradle-to-gate carbon and energy footprint of pine chemicals to develop carbon and energy footprint comparative analyses between pine chemicals and their most likely substitutes for use in end applications such as adhesives, inks, rubber, paints, coatings, surfactants, oilfield chemicals, paper size, and fuel. The comparative analysis results are then used to calculate a weighted average carbon and energy footprint for pine chemicals versus the most likely mix of alternatives. This comparative analysis provides insights into the relative cradle-to-gate energy and GHG impacts of pine chemicals and alternatives.

The last goal of this study is to determine the possible carbon and energy footprint effects of shifting all CTO resources from the current pine chemical production profile to 100% biofuels production in Europe, e.g., based on the mix of alternatives that would take the place of pine chemicals diverted from material use to fuel use.

This executive summary and the full report are organized into three separate sections based on the three goals stated above. The first cradle-to-gate benchmarking section was conducted independently of the comparative analysis to ensure that the highest-quality data were developed for the pine chemicals industry as a whole. The comparative analysis then builds on the data developed in the benchmarking section.

The intended audience of this study is operators of kraft pulping and recovery systems, manufacturers of pine chemicals, users of pine chemicals, public policymakers, and other private and public stakeholders. The study has been conducted in accordance with ISO 14040/44:2006 series of international standards.

Because this analysis addresses energy and GHG impacts and does not cover other environmental impact categories, the study is not intended to be used as the basis for public claims or assertions about the overall comparative environmental performance of pine chemicals and alternatives. Only comparative statements relating to GHG and energy impacts are intended be made public based on the findings of this study.

The functional unit used for reporting cradle-to-gate CTO distillation product results in this study is a weight basis of one metric ton (or "tonne") of average U.S., European, or global CTO distillation product, made up of the average mix of the intermediate products listed above (TOFA, TOR, DTO, heads, pitch) for the region of interest. For the comparative analysis, the functional unit is one tonne of pine chemicals content used in a specific end application or the mass of substitute required to displace one tonne of pine chemicals used in the same end application.

The life cycle impact assessment (LCIA) for this study is limited to global warming potential (i.e., a carbon footprint) and energy demand. A summary of these two impacts is provided in Table ES-1. Current and proposed national (U.S. and European) and state (U.S.) government policies have resulted, or could result, in CTO being classified as renewable biomass for energy production purposes; this in turn can create incentives to convert CTO into a fuel rather than use it for production of pine chemicals. This study does not include a review of such policies, and is intended as a stand-alone scientific analysis. Assessments of the environmental impacts of such renewable fuel policies typically cover only greenhouse gases (GHGs), or in some cases energy savings; accordingly, this study only examines those two impact categories. Carbon footprint results are presented before energy footprint results in this report, as GHGs are the primary environmental indicator covered in such renewable fuel policies. Generally speaking, comparisons are often made between the GHG impacts of biofuels and those of their conventional (fossil) alternatives. This study goes one step further to show the broader, system-wide potential GHG impacts of incentivizing one biomass product over another.

Table ES-1. Summary of Impact Categories

Impact Category	Description	Unit	LCIA Methodology
Global warming potential	Represents the heat-trapping capacity of the GHGs. Important emissions: CO_2 fossil, CH_4, N_2O.	Kilograms of carbon dioxide–equivalent (kg CO_2 eq)	IPCC (2007) GWP 100a
Energy demand	Measures the energy from point of extraction. Results are presented for total energy demand, which includes all renewable and non-renewable fuels (both feedstock energy and combusted fuel). Results are also presented for non-renewable energy demand, which only covers fossil fuel and nuclear energy (e.g., hydro and biomass energy are excluded).	Gigajoules (GJ)	Cumulative inventory method

ES.2.1. Uncertainty

LCAs have limitations associated with data accuracy and uncertainty. In a complex study with literally thousands of numeric entries, the accuracy of the data and how it affects conclusions is truly a difficult subject, one that does not lend itself to standard error analysis techniques. The reader needs to keep in mind the uncertainty associated with LCA models when interpreting the results. The comparative analysis includes minimum percent difference thresholds (25% for both energy demand and global warming potential) to help indicate whether differences between comparative results are actually meaningful given the uncertainty inherent in an LCA model.

ES.3. GOAL 1: CRADLE-TO-GATE GHG AND ENERGY LIFE CYCLE ASSESSMENT OF DISTILLATION PRODUCTS FROM CTO

This section of the executive summary covers the cradle-to-gate carbon and energy footprint for U.S. and European distillation products from CTO.

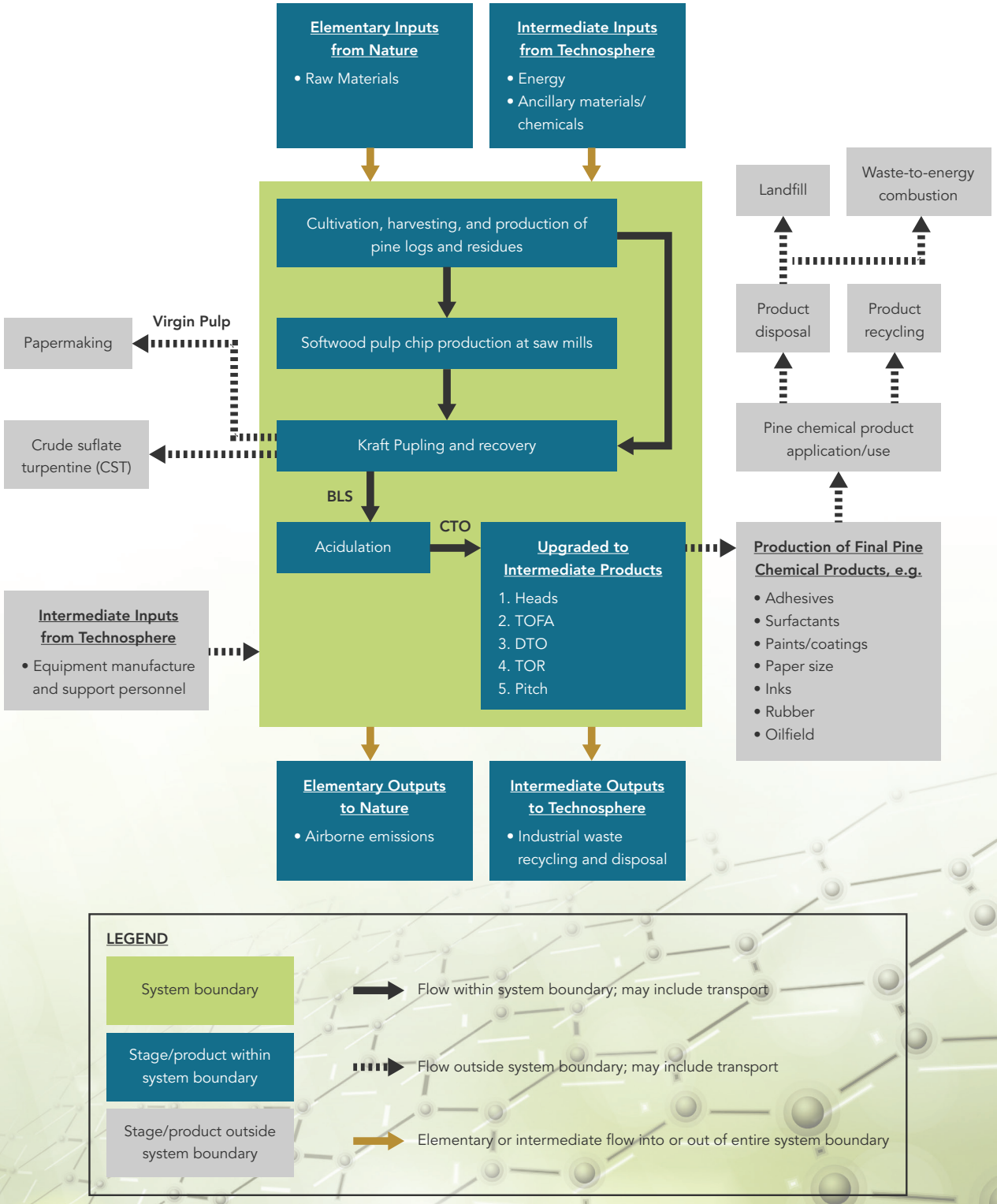
ES.3.1. Scope and Boundaries

For production of CTO distillation products from co-products of the kraft pulping and recovery processes, six life cycle stages have been identified, starting with softwood tree cultivation and harvesting and ending with CTO distillation products ready to be used in the manufacture of products such as adhesives, surfactants, and coatings.

- **Stage 1 (cultivation through transport of pulpwood to pulp and paper mill):** This stage starts with the cultivation of pine trees from seedlings and ends at delivery of the raw forestry materials to the pulp and paper mill.
- **Stage 2 (kraft pulping):** During the kraft pulping process, forestry products from harvesting and the saw mill are transformed into materials ready for the papermaking process. Black liquor soap (BLS) is recovered as a byproduct of this process.
- **Stage 3 (BLS transportation):** This phase includes transport of the BLS to the acidulation plant.
- **Stage 4 (acidulation):** After being recovered and taken to the acidulation plant, BLS is reacted with acid to produce CTO.
- **Stage 5 (CTO transportation):** CTO is then taken from the acidulation plant to a tall oil refinery.
- **Stage 6 (distillation):** After being recovered and transported to the tall oil refinery, CTO is distilled in a fractionation column to more valuable intermediate pine chemicals such as TOR and TOFA.

Figure ES-1 illustrates the system boundaries for this phase of the project. Transportation requirements between all life cycle stages within the boundaries of this study are accounted for. The system boundaries for this study phase end at the CTO distillation plant. Outgoing product transport, final product manufacture, product use, and end-of-life are outside the system boundaries of this cradle-to-gate analysis.

Figure ES-1. Flow Diagram of Cradle-to-Gate CTO Distillation Product System Boundaries



ES.3.2. Data Sources

Primary data was collected for 100% of the U.S. CTO distillation facilities and a majority (approximately >90%) of European CTO distillation facilities. For the U.S., acidulation data was also collected from CTO refining companies that conduct acidulation at the location of the CTO refinery. European acidulation data was developed for this study based on average European data provided by industry experts within the ACC Pine Chemistry Panel.

For unit processes for which primary data was not collected or made available for this study, data from credible published sources or licensable databases (e.g., ecoinvent) were used wherever possible in order to maximize transparency. For U.S. processes and materials where reliable current published data were not available, data sets from Franklin Associates' United States industry average Life Cycle Inventory (LCI) database were used.

A summary of the data sources utilized in the cradle-to-gate analysis is provided in Table ES- 2.

Table ES- 2. Summary of Cradle-to-Gate Data Sources

	U.S. Data Sources	European Data Sources	Temporal Coverage
Electrical and Energy Sources	Energy sources are publicly available in the U.S. LCI Database (data originally compiled by Franklin Associates, with internal Franklin data updates and enhancements to U.S. LCI included); the U.S. electricity grid has been updated to eGRID 2008	Fuel and electricity data are available in the ecoinvent database for all major countries in Europe	U.S.: 2002-present Europe: 2005-2010
Pine Forestry Cultivation, Harvesting, and Saw Mill Processes	CORRIM: Phase I Report Module C, Softwood Lumber—Southeast Region	ecoinvent data, from database report: *Life Cycle Inventories of Wood as Fuel and Construction Material;* usage data from primary sources (participating companies)	U.S.: 2005-2009 Europe: 2000
Raw Materials Extraction for Ancillary Chemicals/ Components	Franklin Associates' private database, the U.S. LCI Database, or adapted from corresponding European data sets in ecoinvent; information on types and amounts of chemicals used in pine chemical production is from primary sources (participating member companies)	ecoinvent European LCI database; usage data from primary sources (participating companies)	U.S.: 1990s and 2000s Europe: 1990s and 2000s *(covers large number of unit processes)*
Pulping Process	Data adapted from publicly available sources (pulping mills)	Data adapted from ecoinvent database	U.S.: 1990s and 2002-2004 Europe: 2000
Acidulation	Primary data from ACC Pine Chemistry Panel and other participating companies	Industry average data from ACC Pine Chemistry Panel	U.S.: 2011 Europe: 2011

Table ES- 2. Summary of Cradle-to-Gate Data Sources (cont'd)

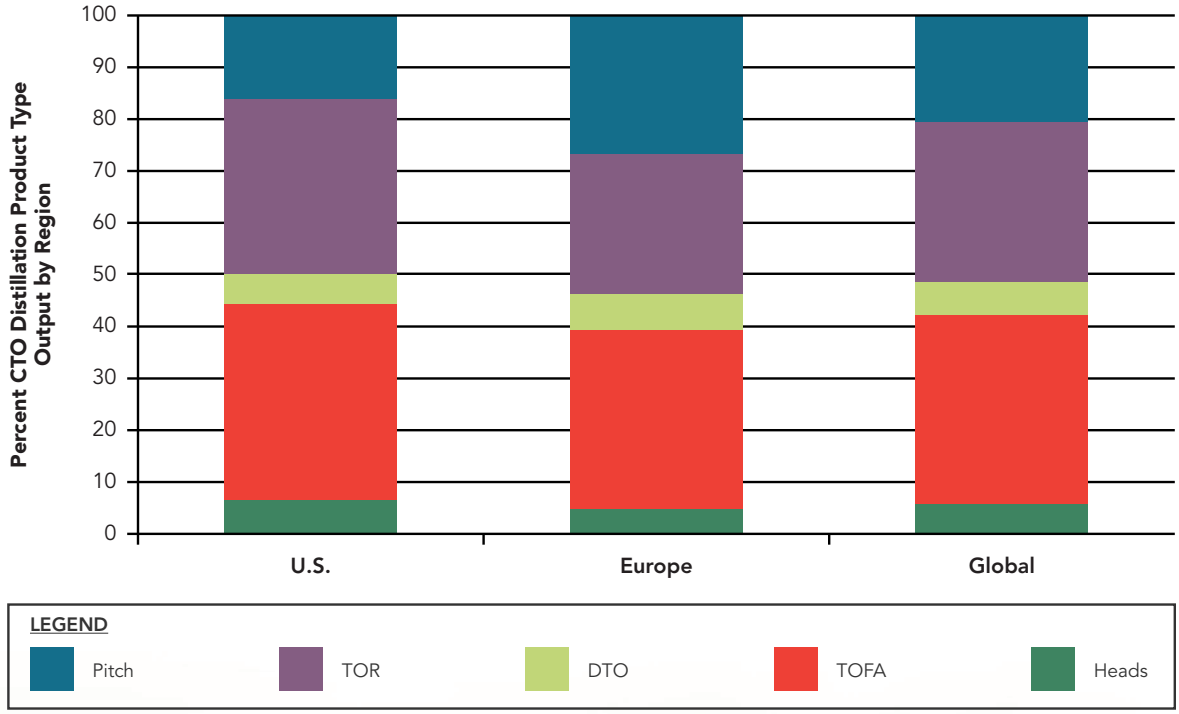
	U.S. Data Sources	European Data Sources	Temporal Coverage
Pine Chemical Distillation Processes	Primary data on types and quantities of material inputs, process energy, emissions, and wastes from ACC Pine Chemistry Panel and other participating companies	Primary data from ACC Pine Chemistry Panel and other participating companies	U.S.: 2011 Europe: 2010–2011
Transport Processes	Primary data from ACC Pine Chemistry Panel and participating companies for distribution configurations and private company locations; data adapted from public sources (pulping mills); LCI data for transport modes from Franklin Associates data compiled for the U.S. LCI Database	Primary data from ACC Pine Chemistry Panel and other participating companies for distribution configurations and private company locations; LCI data for transport modes from ecoinvent database	**Distances:** U.S.: 2011 Europe: 2010–2011 **Unit Processes:** U.S.: 2002–2005 Europe: 2007

ES.3.3. Summary Results

The baseline results in this study allocate a portion of the pulping and upstream forestry operations to CTO, since CTO is a co-product of the kraft pulping process and has economic value. Additionally, the baseline results exclude biogenic carbon storage in the CTO distillation products as this is a cradle-to-gate analysis and the end-of-life (EOL) of the products is not known. Biogenic carbon storage in the CTO chemicals is only considered temporary, since many of the final products made from CTO have short half lives (e.g., break down rapidly during use or at end-of-life) according to the ACC Pine Chemistry Panel. These assumptions are considered the baseline case for the cradle-to-gate CTO distillation products.

Figure ES- 2 compares the average CTO distillation product output for the U.S., Europe, and the global average. The composition of 1 tonne of average CTO distillation product globally is 0.36 tonne TOFA, 0.31 tonne TOR, 0.20 tonne pitch, 0.063 tonne DTO, and 0.060 tonne heads. There is a notably higher rosin output in the U.S. compared to Europe, and a notably higher pitch output in Europe as compared to the U.S.

Figure ES- 2. Comparison of CTO Distillation Product Composition by Geographic Region



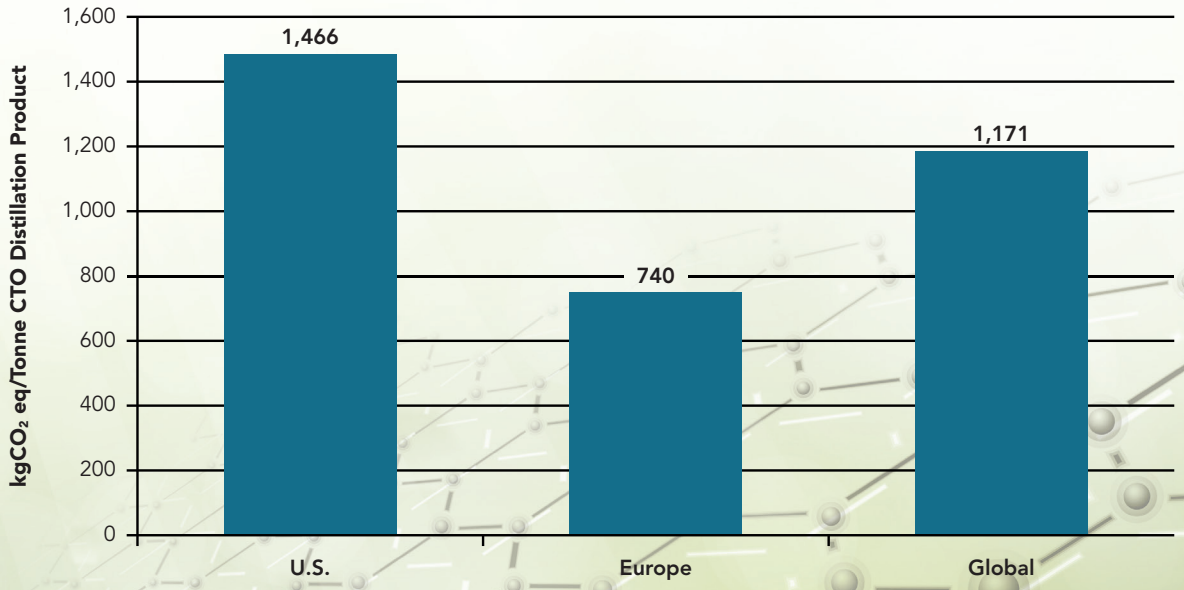
ES.3.4. Carbon Footprint

Table ES-3 shows the baseline carbon footprint results by life cycle stage for the functional unit of 1 tonne of average CTO distillation products for three different regions (with compositions provided in Figure ES-2). For the U.S., the pulping process makes the greatest contribution to the total carbon footprint of U.S. CTO distillation products, followed by the distillation process, forestry activities, and acidulation. Transport of BLS and CTO each contribute approximately 1% to the total overall carbon footprint of U.S. CTO distillation products. For the European system, the pulping process also makes the greatest GHG contribution to the total carbon footprint of CTO distillation products, followed by forestry activities, acidulation, distillation, and CTO transport. Transport of BLS contributes less than 1% to the total overall carbon footprint. The overall carbon footprint, and specifically the distillation carbon footprint, is notably lower in Europe than in the U.S. (highlighted in Figure ES-3), primarily because the European system relies on low-carbon fuels (e.g., nuclear, hydro, biomass) and many plants combust some of their own products (e.g., heads, pitch, DTO) to use for fuel during processing. Since CTO distillation products are derived from biomass, the carbon dioxide from combustion of these products is considered carbon-neutral. The global CTO distillation product carbon footprint is based on a weighted average of U.S. and European results, since the vast majority of global CTO is distilled in the U.S. or Europe.

Table ES-3. Comparative Carbon Footprint Results for 1 Tonne of CTO Distillation Product Output by Geographic Region

	kg CO_2 eq/Tonne CTO Distillation Product					
	U.S.		Europe		Global	
Cultivation through pulpwood to mill	300	20.5%	148	20.0%	238	20.4%
Kraft pulping (BLS as co-product)	559	38.1%	451	60.9%	515	44.0%
BLS transportation	16.2	1.10%	2.55	0.34%	10.7	0.91%
Acidulation	173	11.8%	76.4	10.3%	134	11.4%
CTO transportation	15.4	1.05%	25.6	3.46%	19.5	1.67%
Distillation	402	27.4%	36.7	4.96%	254	21.7%
Total	**1,466**	***100%***	**740**	***100%***	**1,171**	***100%***

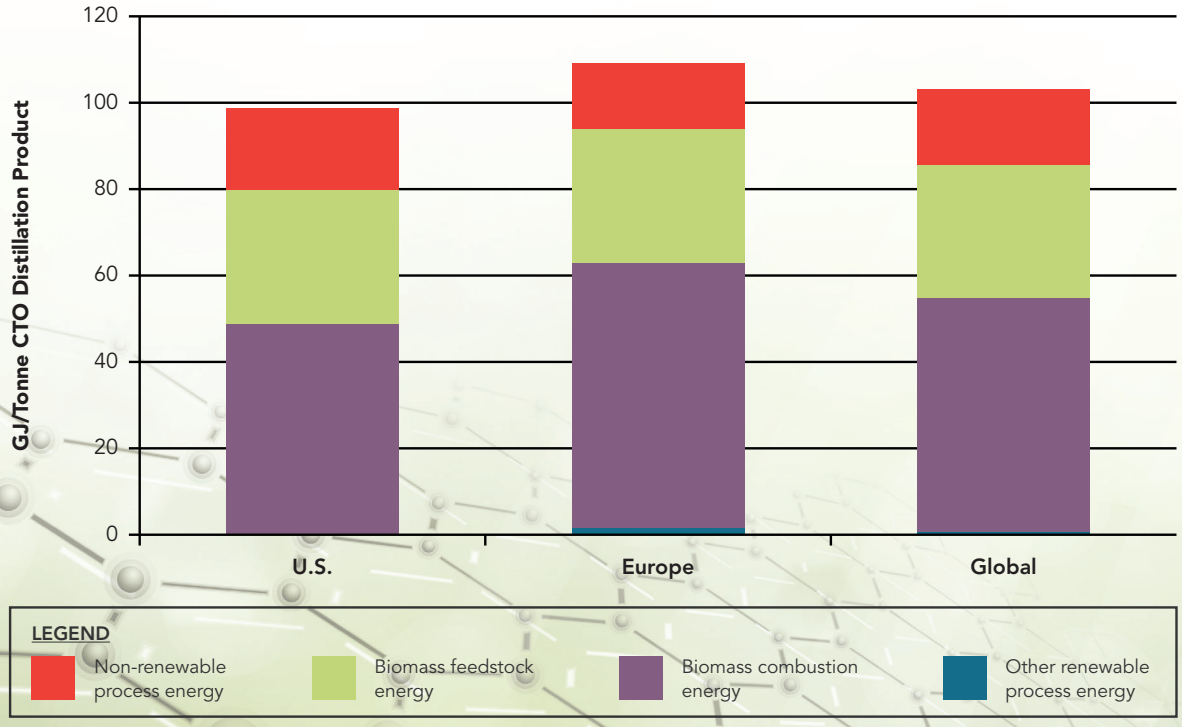
Figure ES-3. Summary of Baseline Carbon Footprint Results by Geographic Region



ES.3.5. Energy Footprint

This study found that the majority of energy required for the production of CTO distillation products is renewable energy (81% to 86%), specifically biomass either used as a feedstock or combusted for energy during processing. Biomass feedstock energy accounts for 33% to 39% of the renewable energy. Figure ES-4 shows that while total energy demand (non-renewable and renewable energy) for cradle-to-gate CTO distillation products is higher for Europe than the U.S., the non-renewable energy demand is higher for U.S. products. The total energy demand is higher for Europe because many European plants combust their own products (e.g., pitch, heads, DTO) for fuel during CTO distillation, which increases the raw material required for production of these pine chemicals. The total energy demand increases with an increase in the biomass raw material combusted, as illustrated in Figure ES-4 by the higher "biomass combustion energy" required for European CTO distillation products than for U.S. CTO distillation products. U.S. facilities do not combust their own products for fuel. However, because the European system relies more on biomass energy than the U.S. system, and because the electrical grids serving the plants in Europe have a larger percentage of fuel from renewable sources, the non-renewable energy demand for cradle-to-gate CTO distillation products is higher in the U.S. than in Europe.

Figure ES-4. Breakdown of Baseline Total Energy Footprint Results by Geographic Region



ES.3.6. Sensitivity Analyses

As noted earlier, the baseline results for CTO-derived chemicals include an allocated portion of energy and GHG impacts for upstream forestry and kraft pulping operations, and do not include a credit for storage of biogenic carbon in the pine chemicals during their useful life. Because these modeling choices affect the net energy and carbon footprint results, sensitivity analyses have been run on these assumptions. Specific sensitivity analyses modeled in this study are:

- Treatment of CTO as a byproduct of the kraft pulping and recovery process with no burdens upstream of BLS transport to the acidulation plant allocated to the CTO distillation product.
- Inclusion of carbon storage in the pine chemical products.
- Economic allocation between pulp and BLS at the mill (Appendix A of full report).

All of these sensitivity analysis scenarios result in large reductions in the carbon footprint for cradle-to-gate CTO distillation products. Excluding pulping and forestry processes and applying an economic allocation at the pulp mill also greatly reduces the energy footprint for CTO distillation products. These sensitivity analyses support the likelihood that the baseline assumptions represent a conservative carbon and energy footprint scenario for pine chemicals.

ES.3.7. Summary Conclusions

Table ES-4 summarizes the cradle-to-gate CTO distillation product conclusions that can be drawn from this study, organized by impact category.

Table ES-4. Summary Pine Chemical Cradle-to-Gate Conclusions by Impact

Impact Category	Conclusions
Global warming potential	• The U.S. CTO distillation product carbon footprint is approximately double that of Europe, primarily due to Europe's higher use of biomass as a fuel. • For both regions, kraft pulping and recovery is the life cycle stage with the most impact. • Forestry operations account for approximately 20% of the carbon footprint in both regions. • Acidulation accounts for 10% to 12% of the carbon footprint in both geographic regions. • Distillation burdens are more significant in the U.S. because of the higher use of fossil fuels there than in Europe, which consumes more biomass. For instance, many of the distillation facilities in Europe combust their own products (e.g., heads, pitch, DTO) for a fuel source.
Energy demand	• Most energy required for the production of CTO distillation products is renewable (81% to 86%), primarily biomass feedstock or biomass process energy. Since this study tracks biomass energy from the point of extraction, forestry operations is the life cycle stage that shows the highest energy demand in both regions. • The total energy demand (non-renewable and renewable) for cradle-to-gate CTO distillation products is higher for Europe than the U.S. because Europe requires more raw material input than the U.S. This is because Europe combusts more of its raw material input for fuel during the processing steps (e.g., acidulation and distillation). • The non-renewable energy demand is higher for U.S. products than European products, because Europe combusts more of its biomass raw material during production processes (e.g., pulping and acidulation); the U.S. uses a higher percentage of other fuel sources (i.e., fossil fuels) for these processes.

ES.4. GOAL 2: COMPARATIVE ANALYSIS OF PINE CHEMICALS VERSUS PINE CHEMICAL SUBSTITUTES

ES.4.1. Scope and Boundaries

The comparative analysis has a broad material basis rather than addressing specific end products, with comparative results limited to the content of pine chemicals or pine chemical substitutes in a product. It does not model other elements (materials or processes) of the end product, which are not affected by the use of pine chemical or substitute material content. This material approach is taken to capture as much of the pine chemicals industry as possible because pine chemicals are used in a very diverse set of final end products. Additional data collection on the CTO side was only needed so that the process of upgrading tall oil rosin to tall oil rosin ester (TORE) could be included, allowing the analysis to cover the key adhesives and inks end markets.

Figure ES-5 displays the system boundaries for the CTO distillation products and associated substitutes included in the study. Table ES-5 displays the specific end markets examined for the comparative analysis. Comparative analyses are conducted separately for the U.S. and European markets. The U.S. and European comparative analysis results are then leveraged to calculate a weighted average global comparative analysis.

Because the end applications for CTO derivatives are so diverse, the study does not include all of them. However, they represent at least 80% of all uses of pine chemicals per geographic region. The primary CTO distillation product substitutes for each end application were identified by the ACC Pine Chemistry Panel. Because of the diversity of the potential substitutes, only the primary substitutes for each end application are included. The market share of each substitute is scaled up to 100% of the total market in the LCA model. For the paper size and adhesive end applications, more than one primary substitute was identified. In these cases, the Pine Chemicals Association provided the approximate market share of each possible substitute for both the U.S. and European markets.

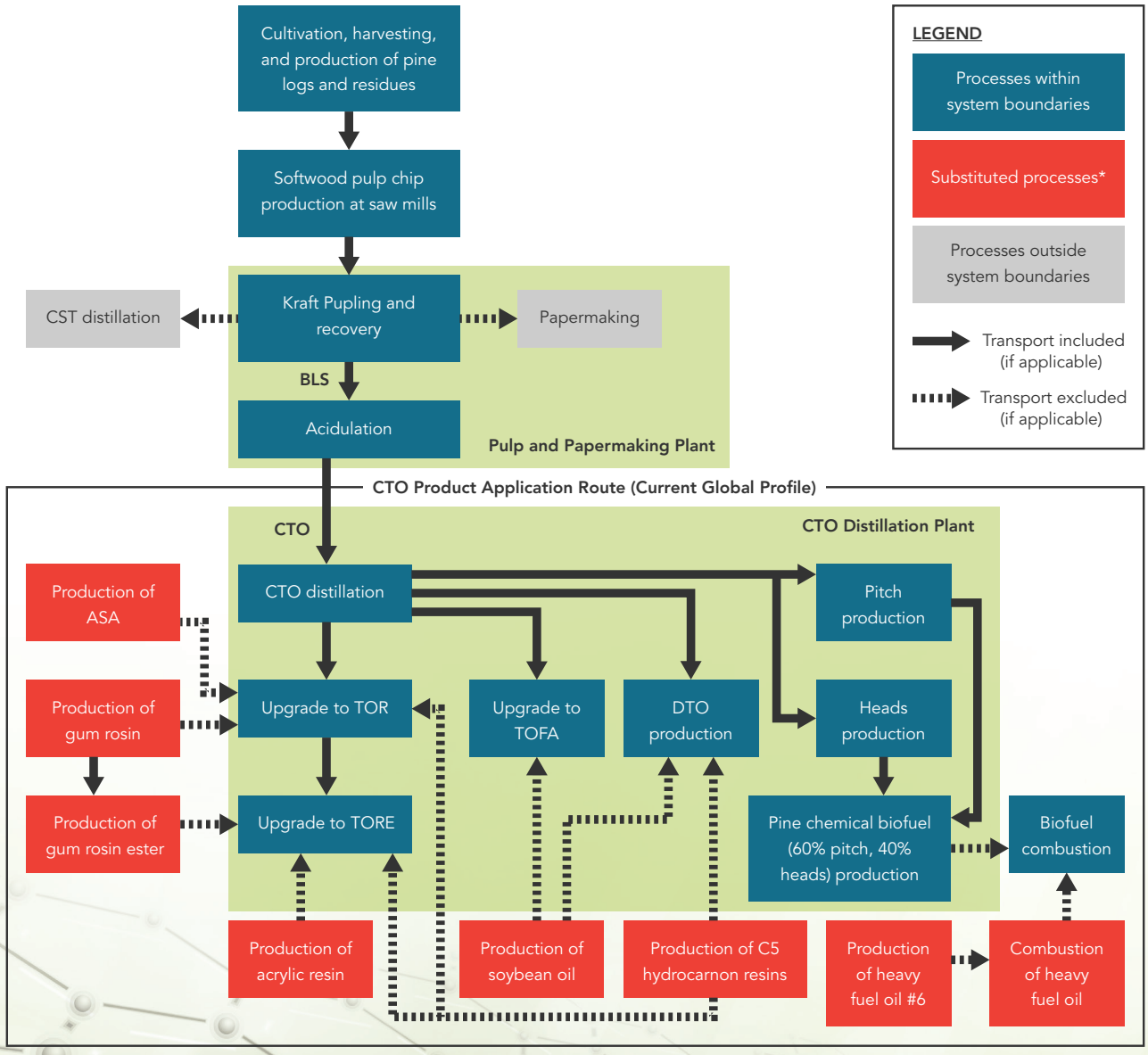
Based on information from industry experts, the CTO distillation products and their associated substitutes are generally expected to perform equivalently in the relevant end product; therefore, manufacture and use of the final end products is excluded from the analysis. In some cases, the substitution ratio may differ. For instance, the substitution ratio between pitch/heads biofuel mix and heavy fuel oil is not 1:1, as there is some variability in the heating values of these two fuels. Since there also may be differences in EOL carbon emissions of the end products based on using fossil-derived versus bio-based materials, the EOL life cycle stage is included in the analysis where there are known differences between pine chemicals and their alternatives. The disposal of the end products is based on average U.S. or average European municipal solid waste (MSW) fates, with the exception of fuel, which is combusted and does not enter the MSW stream. Only disposal of the CTO product or CTO product substitute is accounted for (i.e., no other components of the final end product are included in the disposal modeling).

Table ES-5. Comparative Analysis End Markets

Pine Chemical	End Market	Primary Substitutes
TOR	Paper size	Alkylsuccinic acid (ASA)
	Paper size	Gum rosin[1]
	Paper size	C5 hydrocarbon resins
TORE	Adhesives	Gum rosin ester[1]
	Adhesives	C5 hydrocarbon resins
	Ink	Acrylic resin
TOFA	Oilfield chemicals	Vegetable oils (soybean—food grade)
	Surfactants	Vegetable oils (soybean—food grade)
	Paints/coatings	Vegetable oils (soybean—food grade)
DTO	Surfactants	Vegetable oils (soybean—food grade)
	Paints	Vegetable oils (soybean—food grade)
	Rubber	Vegetable oils (soybean—food grade)
Pitch	Fuel	Heavy fuel oil #6
Heads	Fuel	Heavy fuel oil #6

[1] Gum rosin is derived from pine trees, but not from CTO. Therefore, it is considered an alternative to CTO derivatives in this analysis.

Figure ES-5. System Boundaries for Comparative Analysis



* Substitution occurs during end product use.

ES.4.2. Data Sources

Table ES-6 summarizes the data sources used in this comparative analysis. Data quality is lower for modeling of the pine chemical substitutes, as the best available data for these sources are often older than primary pine chemical data collected for this study. In some cases, there were no existing LCI data for certain substitutes, so theoretical process models were developed. Overall, there is a higher level of uncertainty associated with the LCI models for the pine chemical substitutes.

Table ES-6. Summary of Comparative Analysis Data Sources

	U.S. Data Sources	European Data Sources	Temporal Coverage
Rosin Ester Production	Primary data from ACC Pine Chemistry Panel and other participating companies	Primary data from ACC Pine Chemistry Panel and other participating companies	U.S: 2011 Europe: 2010–2011
Gum Rosin Production	Primary data from confidential source (producer of gum rosin); gum rosin produced in China and transported to the U.S.	Primary data from confidential source (producer of gum rosin); gum rosin produced in China and transported to Europe	From China: 2008–2009
Acrylic Resin Production	ecoinvent private European LCI database adapted to include U.S. fuels and material input	ecoinvent private European LCI database	U.S.:1990s Europe:1990s
C5 Hydrocarbon Resin Production	ERG process modeling based on reaction chemistry and process equipment with U.S. fuels and material input	ERG process modeling based on reaction chemistry and process equipment with average European fuels and material input	Theoretical process model developed in 2013
Alkylsuccinic Acid	ERG process modeling based on reaction chemistry and process equipment with U.S. fuels and material input	ERG process modeling based on reaction chemistry and process equipment with average European fuels and material input	Theoretical process model developed in 2013
Heavy Fuel Oil #6	Residual fuel oil data from Franklin Associates, compiled for the U.S. LCI Database	Residual fuel oil data from ecoinvent private European LCI database	U.S.: 2002 Europe: 2000
Soybean Oil Production	ecoinvent private European LCI database; soybean oil dataset specific to U.S. conditions	ecoinvent private European LCI database	U.S. 1998–2005 Europe: 1994–1998

ES.4.3. Comparative Analysis Limitations

Some specific limitations of this comparative analysis are outlined below.

- **Substitution factors and performance.** This study generally uses existing commercial formulations to determine the substitution factors between pine chemicals derived from CTO and their substitutes, except biofuel, which has a substitution factor based on the heating values of the fuels. While the Pine Chemicals Association and ACC Pine Chemistry Panel note that CTO distillation products generally perform the same as substitutes in the end applications, some performance variability is expected. Performance variability may affect the lifetime of the product, and in turn affect the substitution factor. No comprehensive assessment of product performance was conducted for this study—a necessary limitation, given the vast number of possible end products. If this study is used to develop an LCA for a specific end product, it is recommended that the performance of the products with pine chemicals derived from CTO versus the performance of the products with the substitutes be examined in more detail.

- **End-of-life modeling and carbon storage exclusion.** Given the wide number of possible end products for this industry analysis, it was determined that there would be too much uncertainty associated with including carbon storage in a comparative analysis. However, carbon storage is likely for pine chemicals held up in a resin that does not decompose over the 100-year time horizon. A limitation to this study is that carbon storage is not included in specific products. Another limitation is the simplification of assessing EOL differences in products. Carbon footprint EOL differences between products were included in the comparative analysis. However, energy differences between products at EOL were not included. There would be differences in waste-to-energy (WTE) and associated electricity displacement credits if pine chemicals and their substitutes have different heating values within their end products. A detailed assessment of the end product heating values was not conducted in this analysis. However, the heating value between the pine chemicals derived from CTO and their substitutes would need to be significant to meaningfully impact results, since only 11.7% of pine chemical end products (excluding biofuel) go to WTE combustion in the U.S. and only 3.6% of pine chemical end products (excluding biofuel) go to WTE combustion in Europe.
- **End applications and market share.** Because of the diverse set of end applications for CTO derivatives, not all possible end applications are included within the study. This is a limitation. However, the end applications included represent at least 80% of all uses of pine chemicals per geographic region.

The next section covers the carbon and energy footprint results for the comparative analysis. Generally, the executive summary provides only global comparative results, but comparative results specific to the U.S. and Europe are included within the full report.

The pine chemical results in the comparative analysis are only for the baseline assumptions noted in the previous cradle-to-gate section.

ES.4.4. Carbon Footprint Results

Figure ES-6 displays the carbon footprint for global pine chemicals and pine chemical substitutes by end application. The basis of results is 1 tonne of pine chemical input to the end product and the associated amount of substitute required to displace 1 tonne of the pine chemical. The carbon footprint of pine chemicals is notably lower than that for hydrocarbon resins (C5 resin and acrylic resin) and heavy fuel oil. Globally, gum rosin and gum rosin ester have larger carbon footprints than TOR and TORE, but not to the same extent as the fossil-derived material. There is not a significant difference between the global pine chemical carbon footprints and the soybean oil carbon footprint.

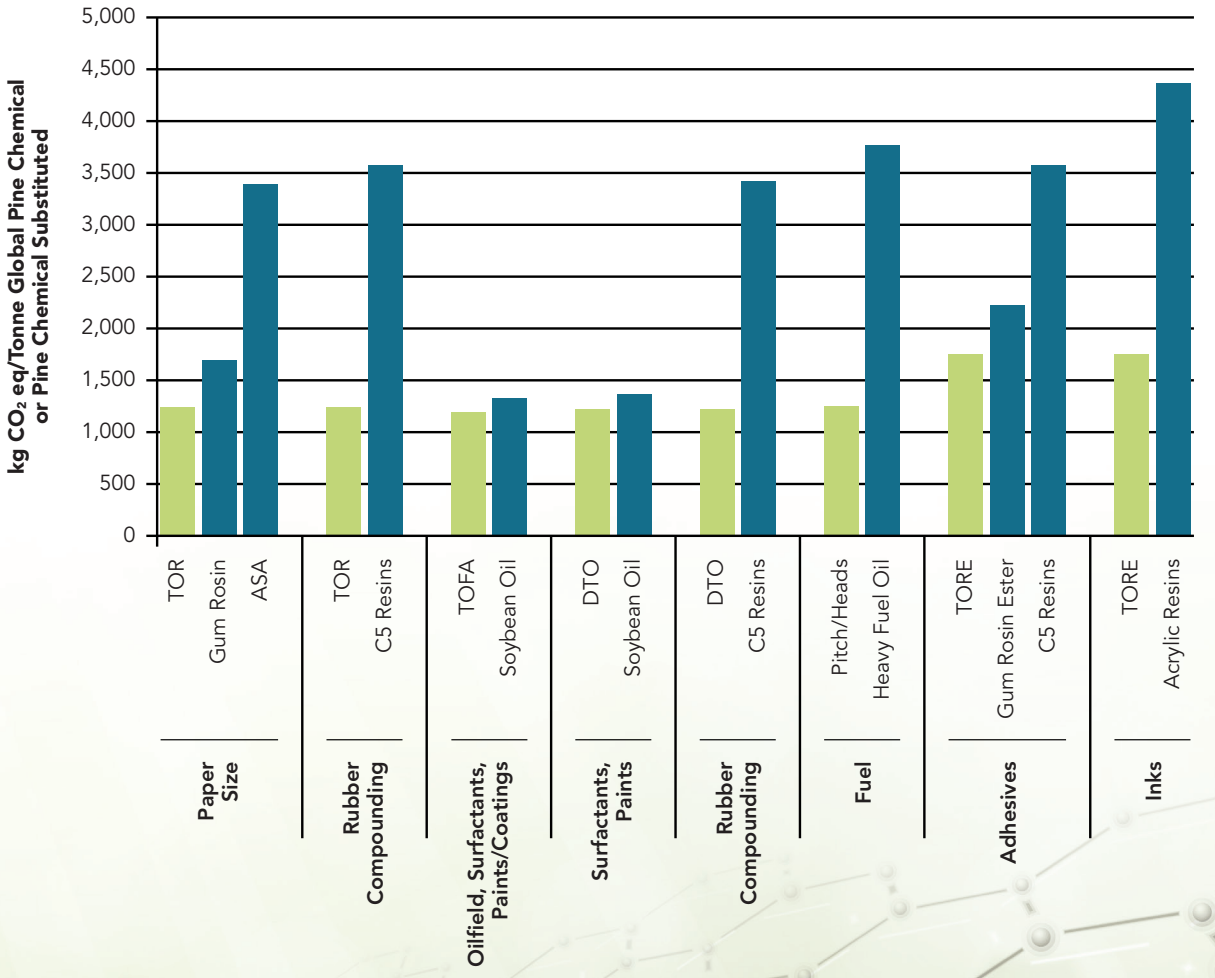
By applying the market share of the end products, weighted average reduction in carbon footprints of pine chemicals compared to their most likely substitute mix are calculated in Table ES-7. The carbon footprints of U.S. pine chemicals are approximately 40% lower than those of their substitutes, the carbon footprints of European pine chemicals are approximately 70% lower, and the carbon footprints of the weighted global pine chemicals are approximately 50% lower.

The total net carbon footprint burdens avoided by using pine chemicals instead of their substitute mixes are shown by substitute type in Figure ES-7. These values are calculated by subtracting the carbon footprint of the pine chemical substitutes from the carbon footprint of the pine chemicals for each associated end application. The end applications are weighted by overall end application market size, with information on the end application markets provided in the full report.

ES.4. GOAL 2: COMPARATIVE ANALYSIS OF PINE CHEMICALS VERSUS PINE CHEMICAL SUBSTITUTES

Using pine chemicals instead of their substitute mix results in an avoided burden of 1,032 kg CO_2 eq/tonne pine chemicals for the U.S., 1,929 kg CO_2 eq/tonne pine chemicals for Europe, and 1,367 kg CO_2 eq/tonne pine chemicals globally. Note the light green bar in Figure ES-7, showing that soybean oil substitutes have a lower carbon footprint than pine chemicals in the U.S., but a higher comparative carbon footprint in Europe.

Figure ES-6. Carbon Footprint for Global Pine Chemicals and Global Pine Chemical Substitutes by End Application

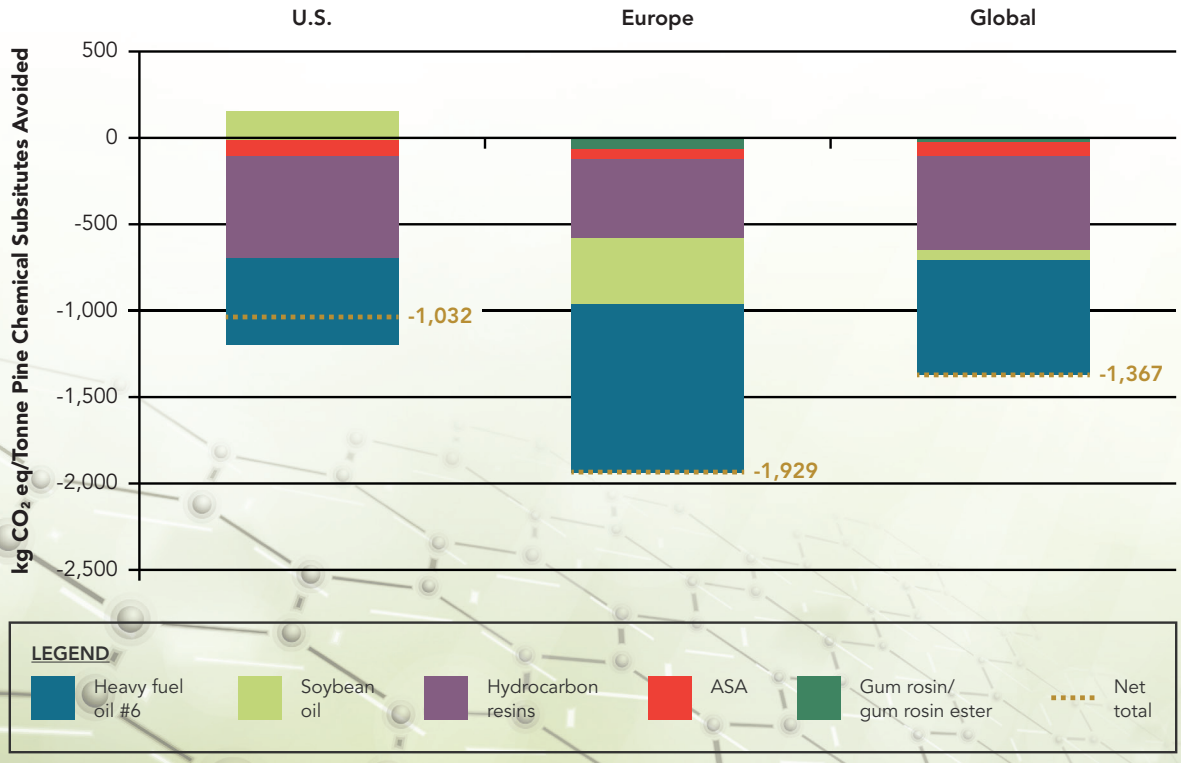


CTO-derived pine chemical carbon footprint results are displayed in green and CTO-derived pine chemical substitute results are displayed in blue.

Table ES-7. Relative Carbon Footprint of Pine Chemicals Compared to Weighted Average Carbon Footprint of Pine Chemical Substitutes

	kg CO_2 eq/ Tonne Pine Chemical	kg CO_2 eq/Tonne Pine Chemical Substituted	Percent Difference: Pine Chemical Carbon Footprint to Substitute Carbon Footprint
U.S.	1,604	2,636	**-39.2%**
Europe	813	2,742	**-70.4%**
Global	1,331	2,698	**-50.7%**

Figure ES-7. Net Carbon Footprint Avoided Burdens for Using Pine Chemicals Rather Than Pine Chemical Substitutes



CTO-derived pine chemical carbon footprint results are displayed in green and CTO-derived pine chemical substitute results are displayed in blue.

ES.4.5. Non-Renewable Energy Footprint Results

Figure ES-8 displays the non-renewable energy footprint for global pine chemicals and pine chemical substitutes by end application (same basis as carbon footprint comparative analysis). Pine chemicals have a notably lower non-renewable energy footprint than hydrocarbon resins (C5 resin and acrylic resin), followed by heavy fuel oil. There is not a significant difference between the non-renewable energy footprints for global pine chemicals derived from CTO and gum rosin/gum rosin ester. The non-renewable energy footprint for soybean oil is lower than that for the associated pine chemicals.

Table ES-8 shows the weighted average non-renewable energy footprints of pine chemicals and their most likely substitute mix, calculated by applying the market share of the end products. The non-renewable energy footprint of U.S. pine chemicals is approximately 54% lower than for their substitutes; for European pine chemicals it is approximately 61% lower, and for weighted global pine chemicals it is approximately 57% lower.

The total net avoided non-renewable energy burdens of using pine chemicals instead of their substitute mix are shown by substitute type in Figure ES-9. The values in Figure ES-9 are calculated by subtracting the non-renewable energy footprint of the pine chemical substitutes from the non-renewable energy footprint of the pine chemicals for each associated end application. The end applications are weighted by overall end application market size, with information on the end application markets provided in the full report.

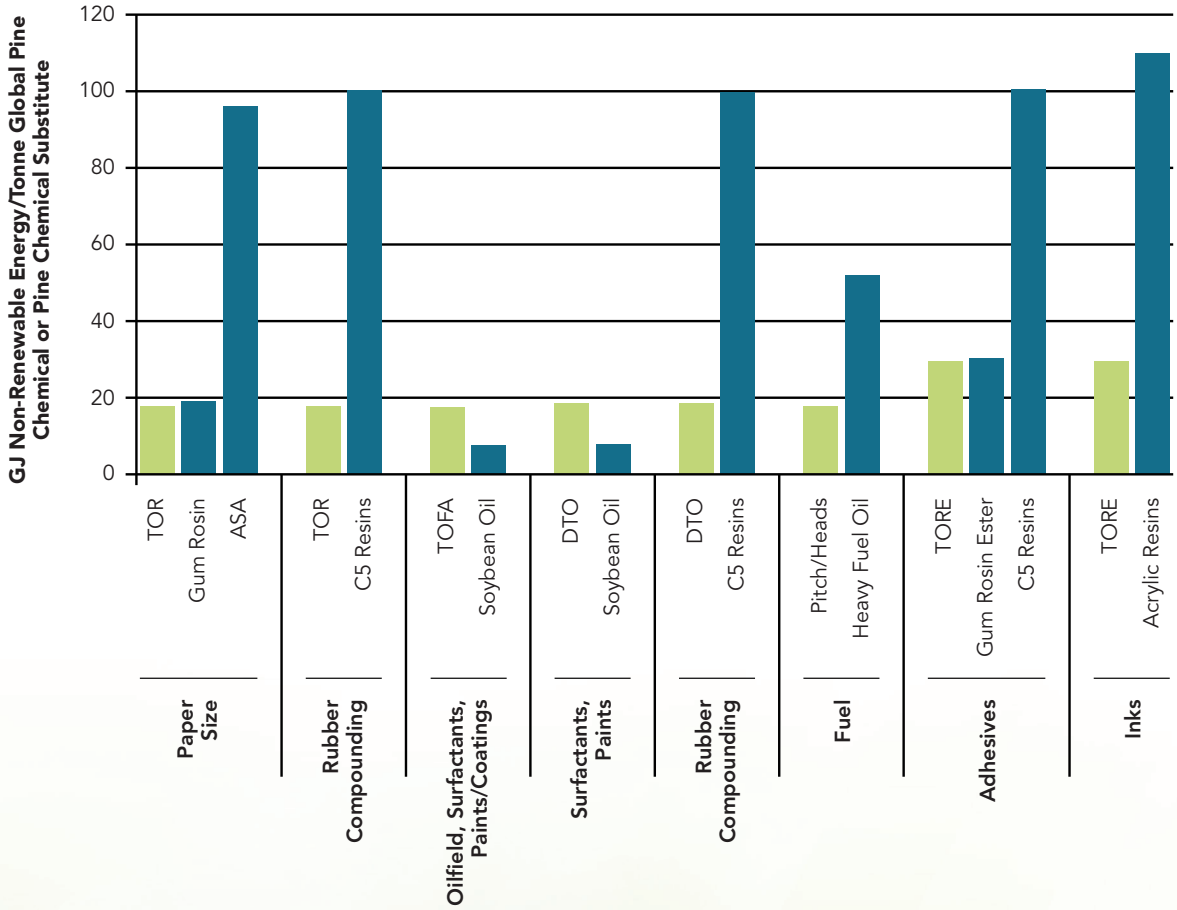
Using pine chemicals instead of their substitute mix results in an avoided burden of 25.6 GJ of non-renewable energy/tonne pine chemicals for the U.S., 27.5 GJ non-renewable energy/tonne pine chemicals for Europe, and 26.5 GJ non-renewable energy/tonne pine chemicals globally.

ES.4.6. Total Energy Footprint Results

Figure ES-10 displays the total energy footprint for global pine chemicals and pine chemical substitutes by end application. The contribution to the total energy demand of renewable versus non-renewable energy categories is shown in the figure's stacked columns, with renewable energy further split by renewable process energy and renewable feedstock energy. The total energy footprint for pine chemicals is primarily renewable biomass feedstock and biomass combustion energy. The total energy for pine chemicals is not significantly different from the total energy for hydrocarbon resins. However, the total energy demand is significantly higher for pine chemicals than for heavy fuel oil. The total energy for the biomass-derived substitutes (gum rosin and soybean oil) is lower than that for pine chemicals. The renewable energy for these substitutes is primarily biomass feedstock energy, and there is not a significant biomass combustion energy required for these substitutes like there is in the case of CTO-derived pine chemicals..

Weighted comparative energy results are only displayed for non-renewable energy and not for total energy, since the weighted energy comparison is focused on the potential for energy depletion by replacing pine chemicals with their associated substitutes.

Figure ES-8. Non-Renewable Energy Footprint for Global Pine Chemicals and Global Pine Chemical Substitutes by End Application



Pine chemical carbon footprint results are displayed in green and pine chemical substitute results are displayed in blue.

Table ES-8. Relative Non-Renewable Energy Footprint of Pine Chemicals Compared to Weighted Average Non-Renewable Energy Footprint of Pine Chemical Substitutes

	GJ/Tonne Pine Chemical	GJ/Tonne Pine Chemical Substituted	Percent Difference: Pine Chemical Non-Renewable Energy Footprint to Substitute Non-Renewable Energy Footprint
U.S.	21.7	47.3	-54.1%
Europe	17.4	44.9	-61.2%
Global	20.3	46.8	-56.7%

Figure ES-9. Net Non-Renewable Energy Footprint Avoided Burdens for Using Pine Chemicals Rather Than Pine Chemical Substitutes

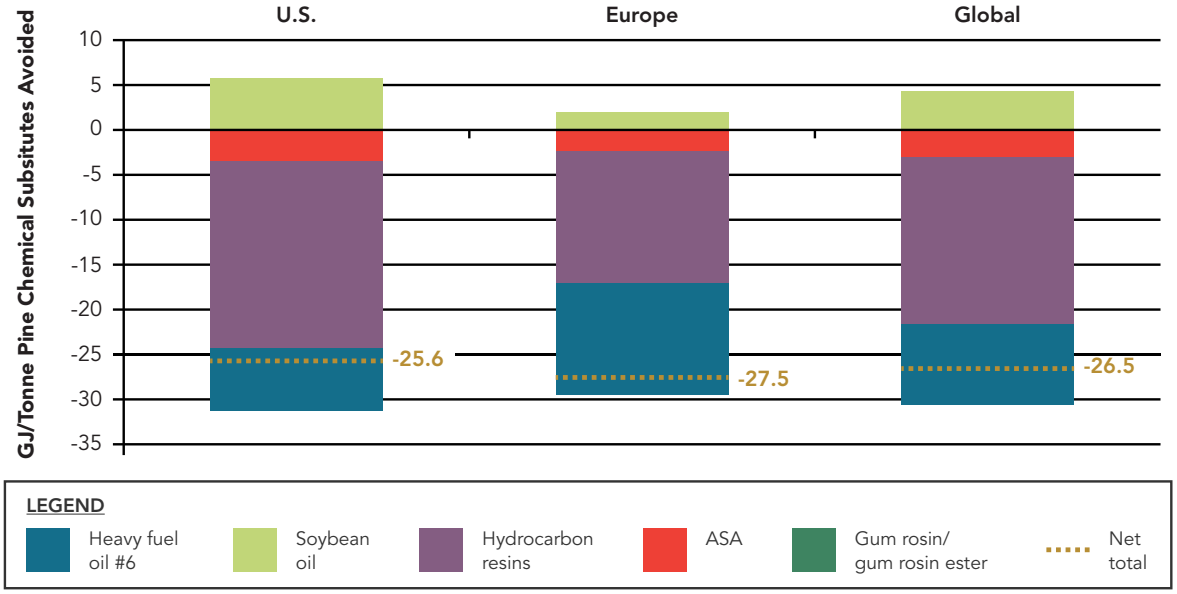
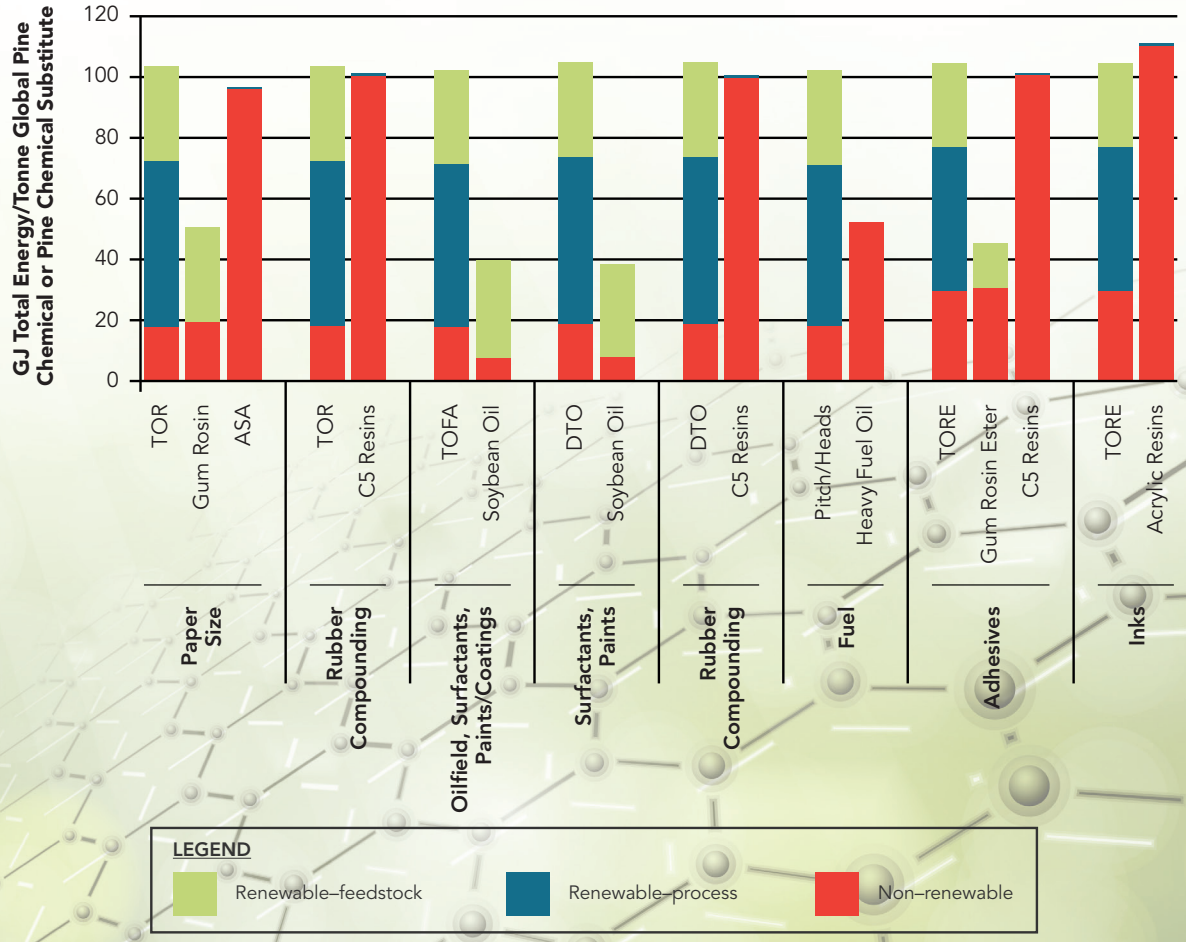


Figure ES-10. Total Energy Footprint for Global Pine Chemicals and Global Pine Chemical Substitutes by End Application



ES.4.7. Summary Conclusions

Table ES-9 summarizes conclusions that can be drawn from this study, organized by impact category.

Table ES-9. Summary Comparative Conclusions by Impact

Impact Category	Conclusions
Global warming potential	• Globally, the weighted average pine chemical carbon footprint is approximately 50% lower than the most likely mix of pine chemical substitutes. • Pine chemical substitutes with notably higher carbon footprints than the pine chemical they replace include hydrocarbon resins for rubber, ink, and adhesive end applications, along with ASA for paper size and heavy fuel oil #6 for fuel combustion (heat). • Globally, there is not a significant difference between the soybean oil carbon footprint and the associated pine chemical carbon footprint. • Globally, gum rosin has a 32% larger carbon footprint than TOR and gum rosin ester has a footprint just over 25% larger than TORE. These differences are less than those seen for hydrocarbon resins and hydrocarbon fuel, but are still notable.
Energy demand	• Globally, the weighted average pine chemical non-renewable energy (fossil fuels and nuclear) footprint is approximately 57% lower than the most likely mix of pine chemical substitutes. • Globally, the greatest avoided non-renewable energy burden comes from using pine chemicals rather than hydrocarbon resins for end applications such as inks, adhesives, and rubber compounding. The next greatest savings are seen from using pitch/heads biofuel rather than heavy fuel oil #6. • There is not a significant difference between the non-renewable energy footprints for pine chemicals versus gum rosin/gum rosin ester. • The non-renewable energy footprint for soybean oil is lower than that for the associated pine chemicals. • The comparative analysis focused on the non-renewable energy footprint, since the focus of the study is the potential for energy depletion by replacing pine chemicals with their associated substitutes. However, total energy demand results are also provided and shown by renewable versus non-renewable energy sources. Total energy demand results for pine chemicals are similar to those for hydrocarbon resins. The main difference is that the energy profile is primarily renewable for pine chemicals and primarily non-renewable for hydrocarbon resins. The total energy footprint for pine chemicals is higher than that for the other remaining substitutes. This is primarily related to the additional biomass combusted during the pulping and acidulation steps for pine chemicals.

ES.5. GOAL 3: COMPARATIVE ANALYSIS OF CTO USED FOR PINE CHEMICALS VERSUS BIODIESEL

ES.5.1. Scope and Boundaries

CTO is increasingly being used to produce biodiesel for transportation fuel, specifically in Europe.[1] This chapter examines the GHG and energy effects of CTO usage for pine chemicals versus biodiesel based on an example case study. To compare CTO usage for biodiesel versus pine chemicals, two specific routes are analyzed:

- **The CTO product application route**, which represents the current profile of CTO usage. Rosin ester, TOR, TOFA, DTO, pitch, and heads are produced at a CTO distillation plant, avoiding use of substitute products examined in the comparative analysis—hydrocarbon resins, heavy fuel oil, gum rosin, and vegetable oils.
- **The CTO biodiesel route**, in which the CTO is processed 100% into biodiesel via hydrogenation and avoids the production and combustion of diesel from fossil fuels. This route was explored in the abovementioned case study, which modeled the biodiesel pre-treatment and hydrogenation process based on publically available LCI data on biodiesel production from crude rapeseed oil in Finland.[2] Because this is a different feedstock than CTO, there is uncertainty surrounding the use of these LCI data for CTO biodiesel, but these are the most relevant LCI data for the hydrotreatment technology that is anticipated to be used for CTO. (Note that biodiesel is a likely route for future CTO usage, but this analysis should not be considered representative of a specific company.)

The focus of the analysis is the diversion of CTO from pine chemical production to biodiesel production. This is why the LCA is not directly comparing impacts of CTO biodiesel versus fossil-based diesel fuel.

A summary flow diagram of the two routes examined in the combustion comparative analysis is shown in Figure ES-11. Through an analysis in which the system is expanded and the avoided products are accounted for in each route, a complete understanding of the carbon and energy footprint trade-offs between these two routes can be obtained.

Because the purpose of this analysis is to understand the impacts of two different treatment options, results are displayed on the functional unit basis of 1 tonne of CTO utilized. This differs from the previous comparative results analyses, which are based on 1 tonne of pine chemicals produced.

Two likely routes for sourcing CTO are analyzed:

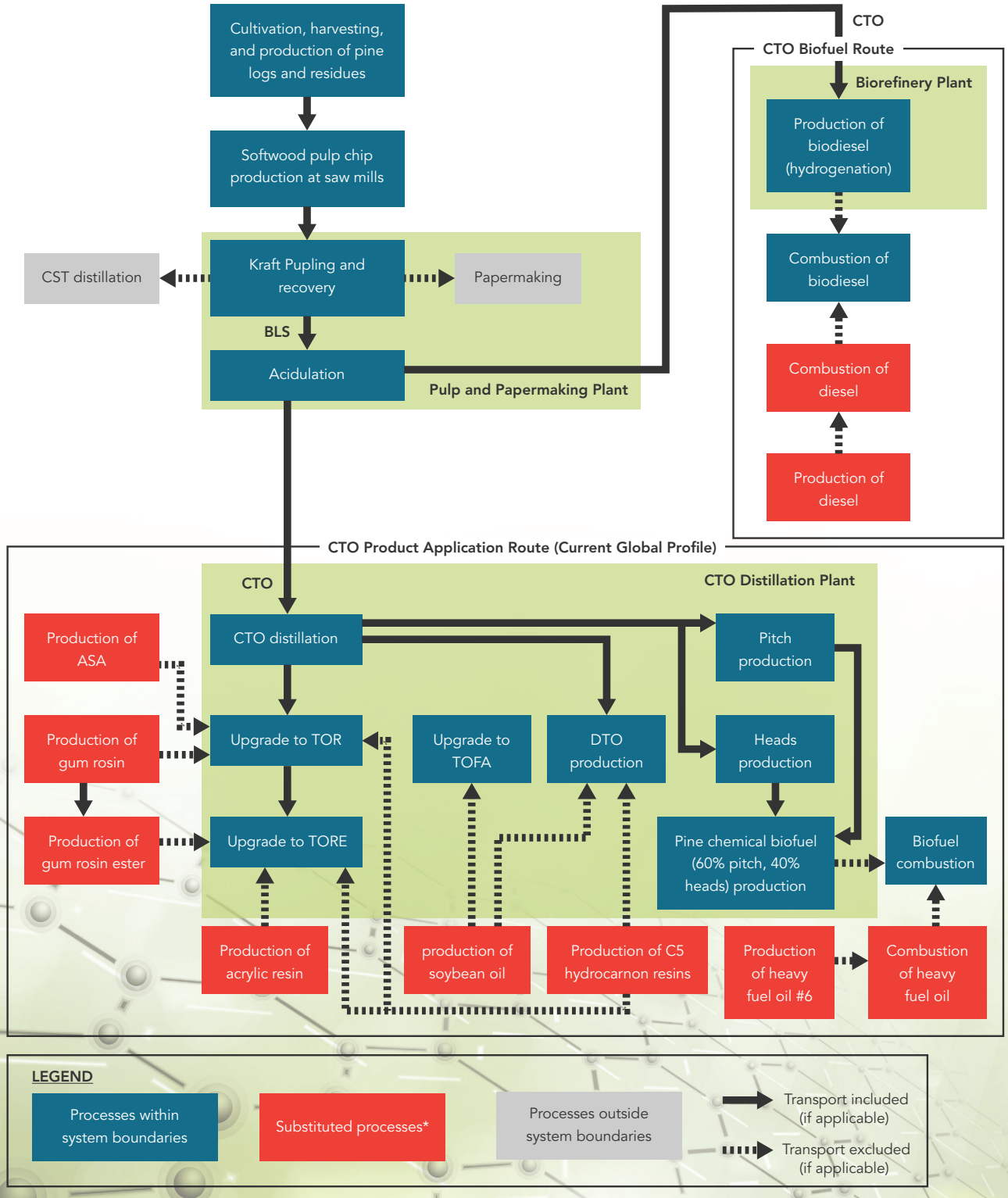
- **CTO sourced from Europe:** 50% of the CTO is sourced from an onsite European pulp and paper mill, and the remaining 50% of the CTO is sourced from within Europe.
- **CTO globally sourced:** 50% of the CTO is sourced from an onsite European pulp and paper mill; of the remaining 50%, 25% is sourced from within Europe and 25% is sourced from the U.S.

For the CTO sourced from Europe only, 0.92 tonnes of pine chemicals (including TORE) are produced from 1 tonne of CTO. For the globally sourced CTO, 0.94 tonnes of pine chemicals (including TORE) are produced from 1 tonne of CTO.

[1] European Biofuels Technology Platform. 2012. "Biodiesel Production from Tall Oil." http://www.biofuelstp.eu/talloil.html.

[2] Institute for Energy and Environmental Research Heidelberg GmbH. 2006. *Final Report: An Assessment of Energy and Greenhouse Gases of NExBTL*. By order of the Neste Oil Corporation, Porvoo, Finland.

Figure ES-11. Combustion Comparative Analysis System Boundaries

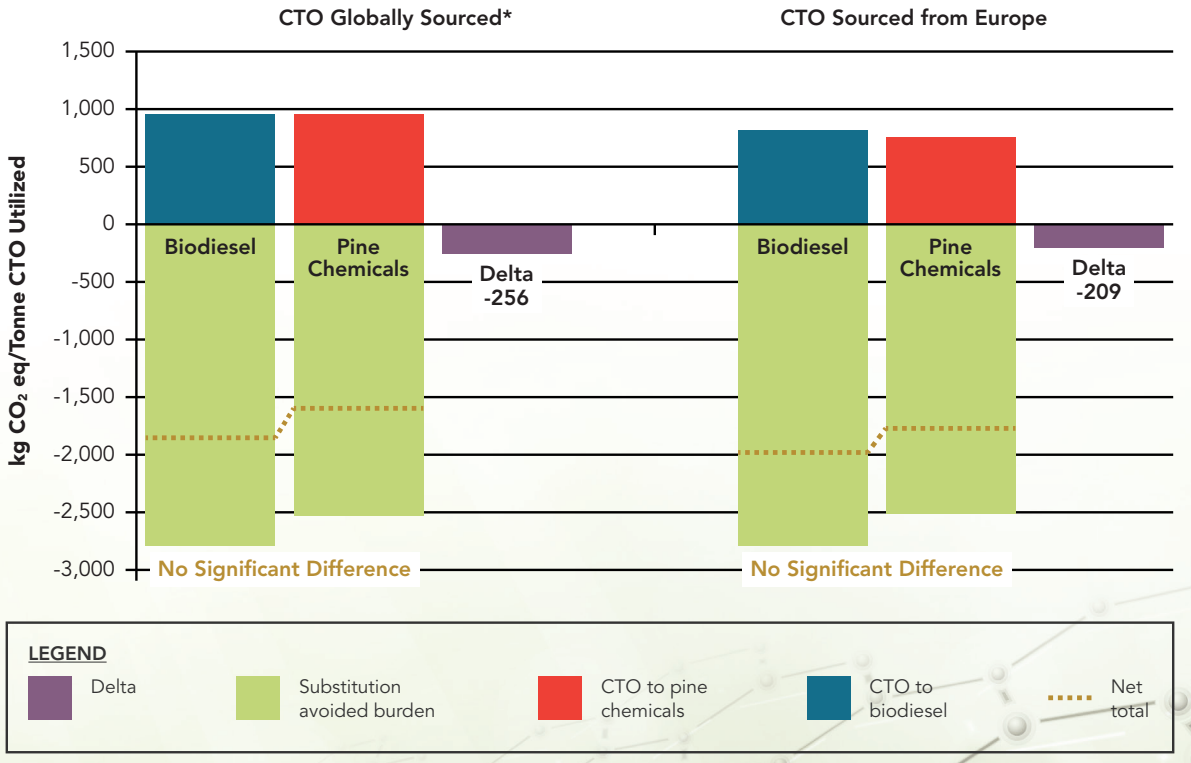


* Substitution occurs during end product use.

ES.5.2. Combustion Analysis Results

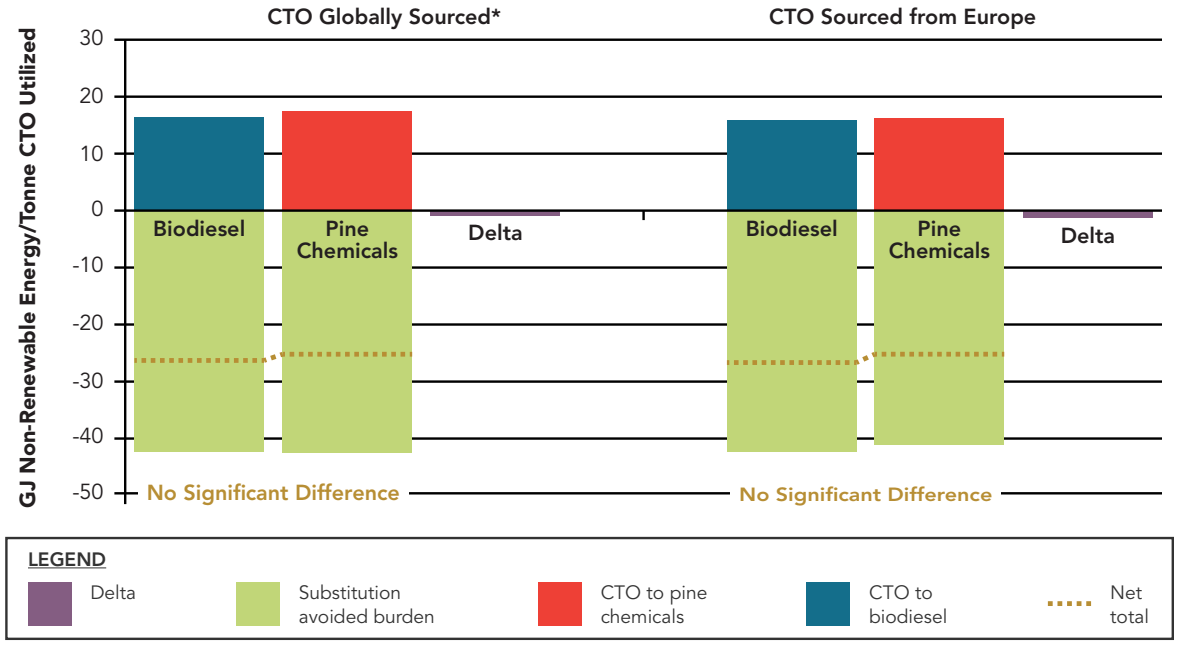
Figure ES-12 displays the comparative carbon footprint results for the combustion analysis, while Figure ES-13 displays the comparative non-renewable energy footprint and Figure ES-14 presents the total energy footprint for the combustion analysis. This study found no significant difference in carbon footprint impacts if shifting all CTO use from pine chemicals to biodiesel. That is, no significant GHG impacts are realized from shifting CTO use from pine chemicals to biodiesel in the case study, assuming the CTO industry is currently a fully utilized market (as indicated by the major global pine chemical companies). This study also found no significant difference between the non-renewable energy footprints or the total energy footprints when CTO is used for pine chemicals versus biodiesel.

Figure ES-12. Carbon Footprint of Using CTO for Pine Chemicals Versus Biodiesel from Hydrogenation



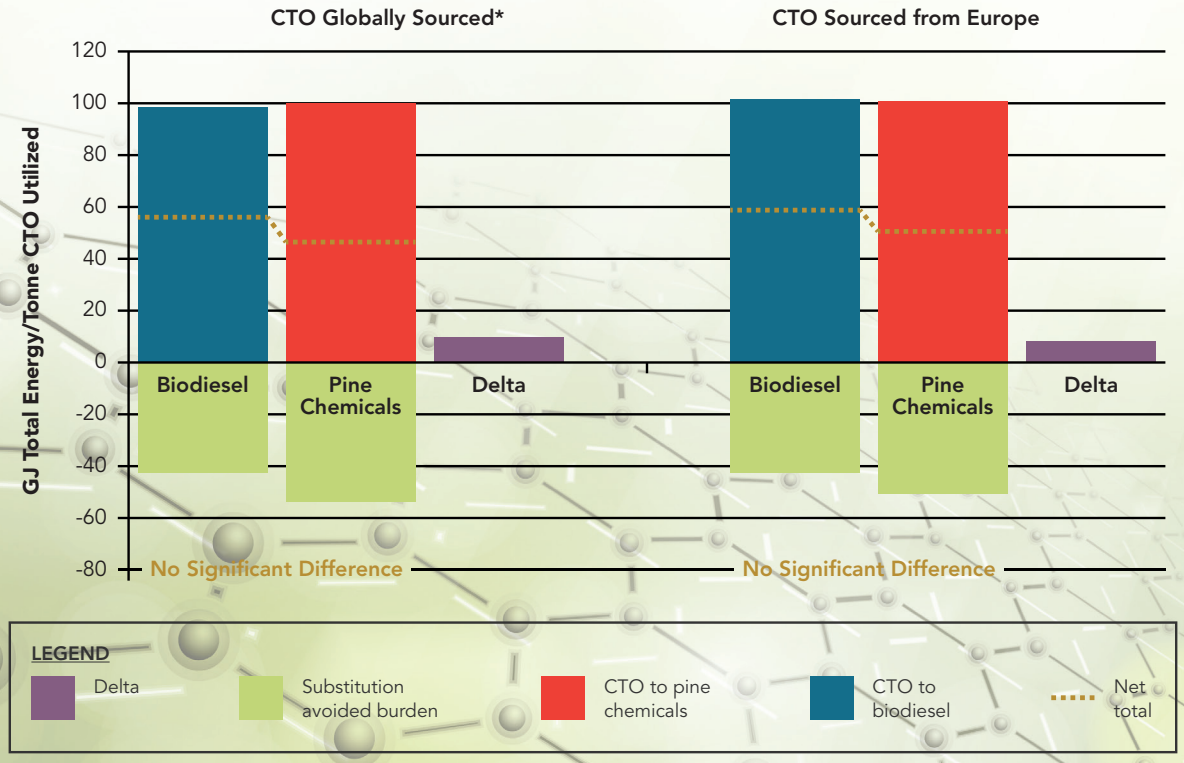
* 75% CTO sourced from Europe, 25% CTO sourced from U.S.

Figure ES-13. Non-Renewable Energy Footprint of Using CTO for Pine Chemicals Versus Biodiesel from Hydrogenation



* 75% CTO sourced from Europe, 25% CTO sourced from U.S.

Figure ES-14. Total Energy Footprint of Using CTO for Pine Chemicals Versus Biodiesel from Hydrogenation



* 75% CTO sourced from Europe, 25% CTO sourced from U.S.

ES.5.3. Combustion Analysis Conclusions

Under two regional scenarios, this study found no significance in carbon footprint between using CTO for biodiesel and using CTO for pine chemicals. This study also found no significant difference, in terms of non-renewable energy footprint, between using CTO for biodiesel and using it for pine chemicals under the two regional scenarios examined. Additionally, no meaningful difference is seen for total energy demand when shifting use of CTO from pine chemicals to biodiesel. (Because of the uncertainties inherent in the LCA model, these conclusions require a 25% difference threshold—for all impact categories examined—to assume a significant difference.) Overall, these results indicate that there is no carbon or energy footprint benefit that accrues by diverting CTO that is currently being used as a feedstock for pine chemicals to new biodiesel production in Europe.

ES.6. PEER REVIEW

The original full report, *Greenhouse Gas and Energy Life Cycle Assessment of Pine Chemicals Derived from Crude Tall Oil and Their Substitutes*, went through a thorough peer review process by a panel of three external LCA experts. While the full report is not made available here, a signed letter of resolution of all issues raised in the peer review is provided below.

August 30, 2013

Franklin Associates, a Division of ERG
110 Hartwell Avenue
Lexington, MA 02421

Subject: Peer Review Panel Conclusion--"Greenhouse Gas and Energy Life Cycle Assessment of Pine Chemicals Derived from Crude Tall Oil and Their Substitutes"

To Whom It May Concern:

The Panel reviewed a draft version of Franklin Associates' report for The American Chemistry Council (ACC) Pine Chemistry Panel, entitled "Greenhouse Gas and Energy Life Cycle Assessment of Pine Chemicals Derived from Crude Tall Oil and Their Substitutes". Subsequently, the Panel reviewed an additional "Chapter 10: Combustion Comparative Analysis". Franklin Associates has responded to the Panel's comments on both these documents, and is to be commended for its thorough job of making associated changes to the report.

One such change is the addition of Appendix A, to compare allocation on an economic basis versus the physical relationships used in the study. While the Panel appreciates this addition, it recommends Appendix A also be referenced in Chapter 2.

In summary, after reviewing Franklin Associates' responses, the Panel has found them to be reasonable and consistent with both ISO standards and current LCA practice. The Panel concludes that the revised report meets ISO 14040/14044 guidelines for its intended use.

Sincerely,

Peer Review Panel Members:

Dr. Roland Hischier
Senior Expert "Life Cycle Assessment"
Empa, Swiss Federal Laboratories for Materials Science and Technology (Switzerland)

Dr. H. Scott Matthews
Avenue C Advisors LLC (USA)

Beth Quay (Chair)
Private Consultant (USA)

Franklin Associates' Note: Appendix A ("Economic Allocation at the Pulp Mill") is referenced in the Executive Summary (ES 3.6) and Chapter 1 (Section 1.2.5 and Section 1.8) of the full report. Section 1.8 ("Allocation Procedures") was originally in Chapter 2, but moved to Chapter 1 based on the peer review report. Appendix A is also referenced in Chapter 3 (Section 3.3) and Chapter 4 (Section 4.3), where the cradle-to-gate U.S. and European sensitivity analysis results are presented.

FRANKLIN Associates
A Division of ERG

American Chemistry Council