Renewable and Sustainable Citrus Oils
A Life Cycle Profile

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Citrus oils are the essential oils expressed from peels of citrus fruit during the juicing process. These natural oils are 100% biobased, renewable and sustainable. The Life Cycle Assessment (LCA) for citrus oils has been performed and demonstrates that essential oils derived from citrus have an extremely small carbon footprint, or in other words, a low potential to contribute to global warming.

The citrus crop is a renewable crop that is harvested every year. In addition, utilizing the peel for citrus oils and cattle feed is a sustainable practice and does not consume a human food crop. Citrus oils are employed as alternative raw materials for many different value-added products.

Citrus oils are cradle-to-cradle products that sequester their carbon as carbon dioxide from the atmosphere (the cradle) and return their carbon to the environment at end-of-life as carbon dioxide where it is available for more biological processes. This cycle is commonly called the closed carbon cycle for biomass. Citrus oils offer a cradle-to-cradle solution in that the carbon sequestered through photosynthesis is made available again at end-of-life through the degradation pathways for the oils.

Governmental agencies and consumers are showing interest in sustainability and replacing petroleum-based materials with biobased resources. As more biobased products appear on the market there has been increased interest in evaluating the energy and environmental impacts of these products. The standard method of measuring these impacts is to conduct an LCA.

LCAs are a standardized technique for measuring and comparing the environmental consequences of manufacturing, using and disposing of a product or service. The typical cradle-to-gate LCA studies the environmental aspects and potential impacts associated with producing a product from raw material acquisition through production and transportation to a receiving organization's door or gate. A cradle-to-grave LCA also includes use, recycling and disposal of the product or subsequent release to the environment. The general impacts under review include resource use, human health, ecological consequences, and global warming potential commonly referred to as a carbon footprint.

Cradle-to-Gate Assessment for a Cradle-to-Cradle Product

Citrus oils are unique in that the building blocks (carbon dioxide and water) come from the environment through photosynthesis and most uses return the carbon to the environment. This closed carbon cycle allows the LCA to track these building blocks from their origin in nature to their return to the environment or "cradle-to-cradle". This carbon neutral approach demonstrates the carbon neutrality associated with renewable citrus oils.

A key objective of performing the LCA was to provide a cradle-to-gate assessment of citrus agriculture, juice production and processing of citrus oils, employing the carbon neutral approach. A cradle-to-gate study usually ends at the factory "gate" and as in this study sometimes includes transportation to the receiving organization's gate.

This LCA was commissioned by the Renewable Citrus Products Association (RCPA) and follows the ISO 14040 Standard and provides the following:

- Calculates the carbon footprint measured in CO_2-equivalents of the various citrus oils using the PAS 2050 Specification
- Demonstrates other energy and environmental benefits of citrus-derived feedstocks, especially when compared to their petroleum-based counterparts
- Documents the overall greenhouse gas reduction benefits of citrus agriculture and processing that carry through to commercial and consumer products
- Provides life cycle practitioners with new data that eliminates the use of outdated and hypothetical data
- Serves as a ready-to-use platform for companies who wish to conduct life cycle studies on their specific products made using citrus oils.

Previous to this study, existing life cycle inventory (LCI) databases for citrus were limited. This LCA is comprehensive and evaluates the entire process of growing citrus, squeezing for juice, and processing the peel for citrus oils and cattle feed. The study collected U.S. agriculture data from major processors for the 2008-2009 growing season.

The data contained in this LCA is now available to be placed in the U.S. Life Cycle Inventory (U.S. LCI) Database (http://www.nrel.gov/lci/) and the Ecoinvent Centre database (http://www.ecoinvent.org). The U.S. LCI is managed by the Department of Energy's National Renewable Energy Laboratory (NREL). Ecoinvent Centre is managed by the Swiss Centre for Life Cycle Inventories. Life cycle practitioners can access the databases to perform their assessments on products made with a citrus-derived feedstock.

Findings Show Environmental Benefits

Overall the results of the LCA indicate that citrus oils have a more favorable and more sustainable environmental profile when compared to petroleum-based counterparts. Utilizing citrus peel for production of citrus oils is a sustainable practice that promotes or

contributes to sustainability and sustainable outcomes, since sustainability is a process or goal.

The Carbon Trust's PAS 2050 methodology was used to assess the global warming potential or carbon footprint of orange juice, cold pressed orange oil, 5-fold orange oil, orange terpenes, citrus terpenes (d-limonene), and citrus-based cattle feed.

Global Warming Potential or Carbon Footprints* for Orange Products

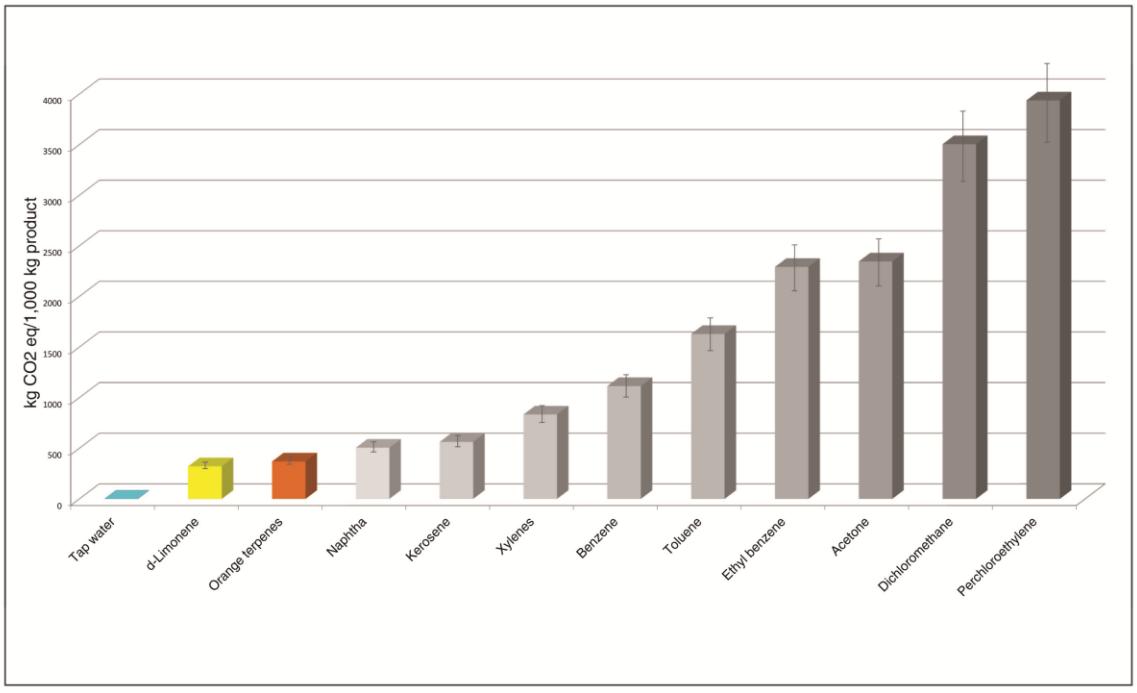
Orange Juice	Cold Pressed Orange Oil	d-Limonene (Citrus Terpenes)	Orange Terpenes	5-Fold Orange Oil	Citrus-Based Cattle Feed
584 kg CO2-eq per 1000 kg Orange Juice	**362 kg** CO2-eq per 1000 kg Cold Pressed Orange Oil	**321 kg** CO2-eq per 1000 kg d-Limonene	**370 kg** CO2-eq per 1000 kg Orange Terpenes	**1359 kg** CO2-eq per 1000 kg 5-Fold Orange Oil	**8 kg** CO2-eq per 1000 kg Citrus-Based Cattle Feed

* The carbon footprints in this table are consistent with the PAS 2050:2008 Specification and include transportation of 1200 miles to the receiving organization's door or "gate".

The orange juice results are consistent with the Tropicana study by the Carbon Trust. For more information go to: http://www.tropicana.com/pdf/carbonFootprint.pdf

The global warming potential for orange terpenes and d-limonene were graphically compared to data for petroleum-based counterparts in the bar graph below:

Life Cycle Global Warming Results



*Includes a 10% margin of error as shown at the top of each bar

The graph shows orange terpenes and d-limonene have a significantly lower global warming potential than other petroleum-based counterparts. Citrus oils are also a leading performer in the biobased materials category.

The specific case of greenhouse gas emissions is useful for illustrating the magnitude of environmental impact differences between citrus oils and petroleum-based counterparts. One thousand kg of citrus oils is associated with 370 and 321 kg of CO_2-equivalent emissions from orange terpenes and d-limonene respectively. These emissions can be compared to those produced by manufacturing and using petroleum-based counterparts. For example, replacing 1,000,000 kg of acetone with d-limonene would be equivalent to the carbon footprint impact of traveling 5,037,000 miles in a passenger car. This distance is comparable to removing 531 passenger cars from the road annually.

The Building for Environmental and Economic Sustainability (BEES) impact assessment methodology, as used by the USDA for assessing biobased products for the Federal BioPreferred Program, was used to assess all the impact categories. The conclusions are based on an overall assessment of all the following environmental impacts, as identified in the BEES methodology:

- Global warming potential
- Acidification
- Eutrophication
- Ecotoxicity
- Smog
- Natural resource depletion
- Habitat alteration
- Water intake
- Ozone depletion
- Human health cancer
- Human health noncancer
- Criteria air pollutants

Results of the BEES assessment indicate that across a wide range of impact categories citrus oils have significantly lower environmental impacts than petroleum-based counterparts.

To demonstrate the differences between the citrus oils and the petroleum-based counterparts the results for d-limonene and orange terpenes were averaged and the results for all the non-chlorinated petroleum-based counterparts found in the bar graph above were averaged:

Difference in Life Cycle Impacts Between Average of Citrus Oils and Average Petroleum-based Counterparts

	Units (per 1,000 kg)	**Average Citrus Oils**	**Average Petroleum-based Counterparts**	**Citrus to Petroleum Ratio**
Global warming	kg CO_2 eq	345	1,859	0.19
Acidification	H+ moles eq	96,380	603,954	0.16
HH† cancer	kg C_6H_6 eq	0.33	5.80	0.06
HH non cancer	kg C_7H_7 eq	512	5,913	0.09
HH criteria air pollutants	microDALYs	19	211	0.09
Eutrophication	kg N eq	1.07	1.21	0.88*
Ecotoxicity	kg 2,4-D eq	0.37	14.69	0.03
Smog	kg NOx eq	2.01	8.17	0.25
Natural resource depletion	MJ surplus	528	7,671	0.07
Habitat alteration	T&E count	1.48E-12	7.73E-13	1.91
Water intake**	m^3	242	283	**
Ozone depletion	kg CFC-11 eq	4.89E-06	2.42E-02	0.0002

Citrus oils are better

Areas of possible improvement

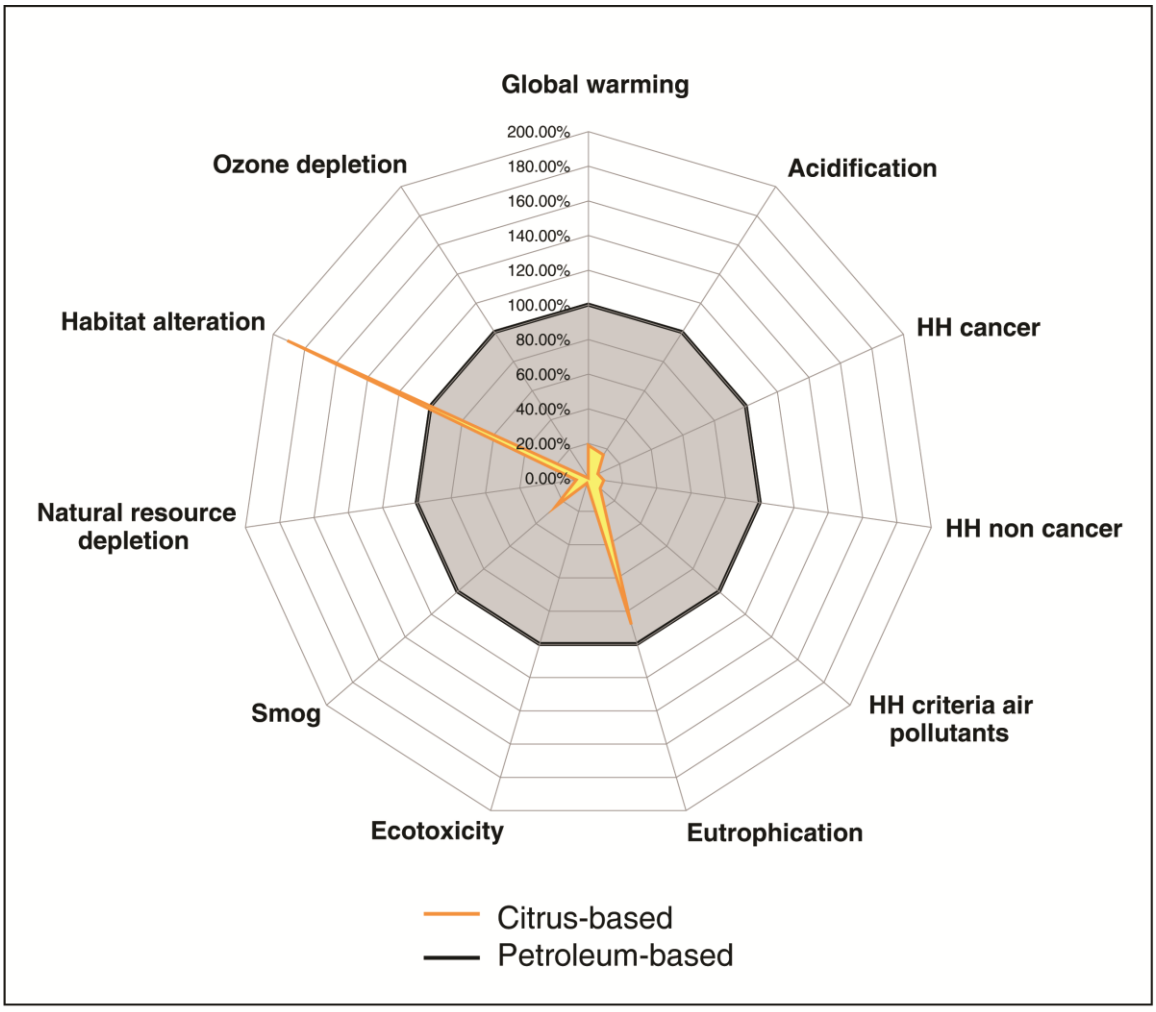
* Cells shaded yellow suggest area of possible improvement because the relative differences are not considered significant and therefore citrus oils likely do not perform better than petroleum-based counterparts in eutrophication impacts.

** Missing water usage data for electricity production (cooling water) and crude oil exploration and production prevents a meaningful comparison for this impact category.

†HH is the impact on human health

The life cycle impacts for the average of citrus oils were graphically compared to data for the average petroleum-based counterparts in the spider diagram below:

Difference in Life Cycle Impacts Between Average of Citrus Oils and Average Petroleum-based Counterparts



The diagram demonstrates the average of citrus oils have a significantly lower overall environmental footprint than the average petroleum-based counterparts.

Opportunities for Improvement

One of the benefits of conducting an LCA is that it identifies environmental impact areas where there is potential for improvement. The LCA shows water intake, habitat alteration and fertilizer consumption are potential areas for improvement when growing citrus. It is important to point out that these impacts are inherent in growing and cultivating agricultural crops such as citrus.

RCPA is committed to continuous improvement and incorporating sustainable agriculture practices that are economically viable, socially responsible and ecologically sound.

Acknowledgements

Renewable Citrus Products Association (RCPA) is a non-profit trade association representing more than 20 U.S. and international companies engaged in the citrus juicing and products industry. For more information go to www.renewablecitrus.org

Environmental Resource Management (ERM) conducted the study for RCPA. ERM is a leading global provider of environmental, health and safety, risk, and social consulting services based in 130 offices in 40 countries around the world. For more information go to http://erm.com

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