

# Comparing Energy and Greenhouse Gas Emission Savings of Transformer Oils – Lifetime Energy Savings (LES)

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and **Anna Eriksson**



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As the Marketing Manager for Naphthenic Specialty Products at Nynas AB, **Anna Eriksson** leads the Go To Market strategy for the Transformer Oil Segment. With 20 years of experience in the industry, she focuses on creating value through close interdisciplinary collaboration and understanding customer needs, all while promoting sustainable development.

This technical report is an extract focusing on Transformer Oil, the full study covers net energy analysis across four different application areas: Tyres, Lubricants, Transformer Oil and Bitumen.

Full Report prepared by HedgeRow Analysis, LLC  
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April 2024

### Executive Summary

This white paper investigates the greenhouse gas and energy trade-offs between conventional market alternatives. The study aims to provide an in-depth evaluation using a dual analytical framework that includes components of both Life Cycle Assessment (LCA) and Net Energy Analysis (NEA). This innovative framework differs from almost all sustainability reporting and aims to reflect the actual tradeoffs that are made in the economy when companies make decisions between products.

The dual framework places sustainability assessment within an opportunity cost framework. For example, conventional sustainability analysis might conclude that a biogenic oil is “better” than a petroleum-based oil simply because it is not of fossil origin. But what if petroleum-based oils yield energy and greenhouse gas savings because it is simply more efficient when compared to the biogenic product? When does biogenic oil cost society energy and become an inferior product compared to the petroleum-based product?

### Transformer Oils

Transformer oils are specialty oils with excellent electrical insulating properties. They maintain lower operating temperatures and prevent degradation of solid insulation. By preventing overheating, transformer oils reduce energy losses, extend the service life of transformers, and provide protection against fires. There are three main types of transformer oils: naphthenic, paraffinic, and ester-based oils. The ester oils can be natural, i.e. derived from vegetable oils, or synthetic derived from fossil fuels. The three types of oils have different characteristics and there are trade-offs between pour point (suitability for colder climates), flash point (operation at higher temperatures), degradation, oxidation stability, environmental impact, and cost. The study includes a comparison of the life cycle cumulative energy demand (CED) and GHG emissions of; a low viscosity mineral naphthenic oil (7,7 cSt at 40 C°), a typical viscosity mineral naphthenic oil (9 cSt), a circular 9 cSt re-refined naphthenic oil, a biogenic hydrocarbon oil, a Paraffinic base oil produced in a gas-to-liquid (GTL) facility and a natural ester oil, made from soy grown in USA & Latin America and processed in USA.

### Methods

Overview of methods – using LCA within the net energy framework

The shift to broadband or wideband Life cycle assessment is a powerful analytical framework that enables researchers to assess the environmental impacts of products and services. Net energy analysis is another analytical framework that compares the energy produced (or saved) by a process to the energy required in its production.

In this analysis, life cycle assessment methods as well as data from ecoinvent 3.9.1 and the broader academic and professional literature, are used to develop cradle-to-gate models assessing both energy and GHG for transformer oils. For consistency, all energy results were calculated using primary energy equivalents, i.e. CED, and global warming potential, GWP100. The GWP100 results were calculated using the IPCC 2021 impact assessment methodology and are in units of kg CO<sub>2</sub> equivalents. All models were built and calculated in OpenLCA.

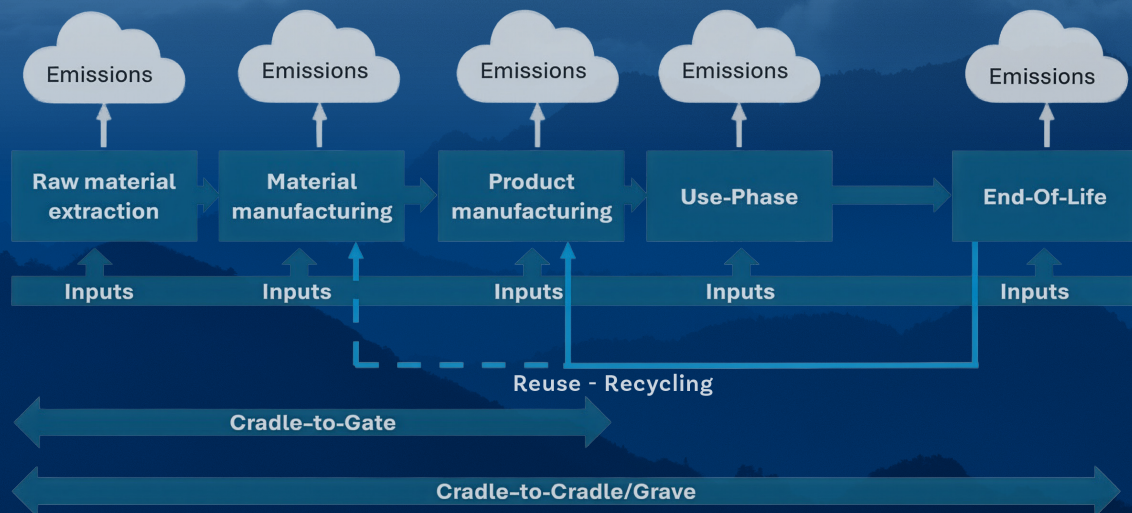


Figure 1. Generic flow diagram for a cradle to gate LCA.

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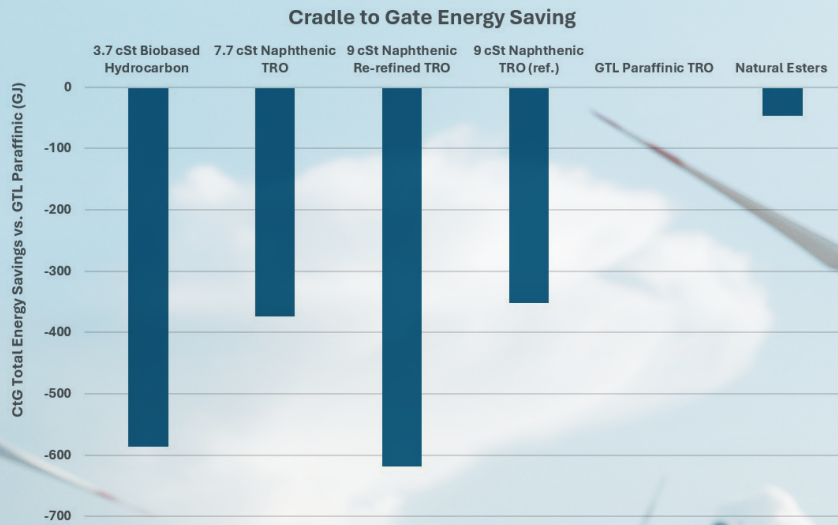


Figure 2. Cradle-to-gate energy savings for transformer oils used in a 40 MVA transformer, including density considerations and oil expected life time, compared to GTL Paraffinic.

### Lifetime Energy Savings Calculation

Lifetime energy savings (LES) for a product are calculated by comparing the energy savings of the product to the energy savings of a baseline product. The baseline product is usually an incumbent product to which all other products are compared. For this analysis, energy savings can come from two parts of the product's life cycle. First, cumulative energy demand is calculated for the generation for each product – this is the conventional cradle-to-gate (CtG) analysis conducted in LCA. Second, energy savings during the use-phase are calculated for each product

and compared with the alternative product.

### Cradle-to-Gate

#### 9 cSt Naphthenic Transformer Oil

Considered the baseline product for this analysis because it currently represents a large market share of transformer oils in Europe. The process “base oil production, petroleum refinery operation | base oil | Cutoff, S – Europe without Switzerland” from ecoinvent 3.9.1 is used as a proxy to represent base oil production from cradle-to-gate.

#### 7.7 cSt Naphthenic Transformer Oil

Also modeled using the same ecoinvent 3.9.1 process

#### 3.7 cSt Biobased Hydrocarbon

A transformer oil that is comprised of a bio-waste product. According to the cut-off criteria employed in this LCA, this bio-waste founded product is available “burden-free” to the product system. The bio-waste oil is hydrotreated, which is a process that uses heat and hydrogen to convert the molecular structure of the waste oil to the desired transformer oil.

#### 9 cSt Naphthenic Re-refined Transformer Oil

A re-refined transformer oil that is produced from EoL transformer oil which at the origin categorizes as waste (from a primary lifecycle), hence also available burden free. As such, “Waste Transformer Oil”

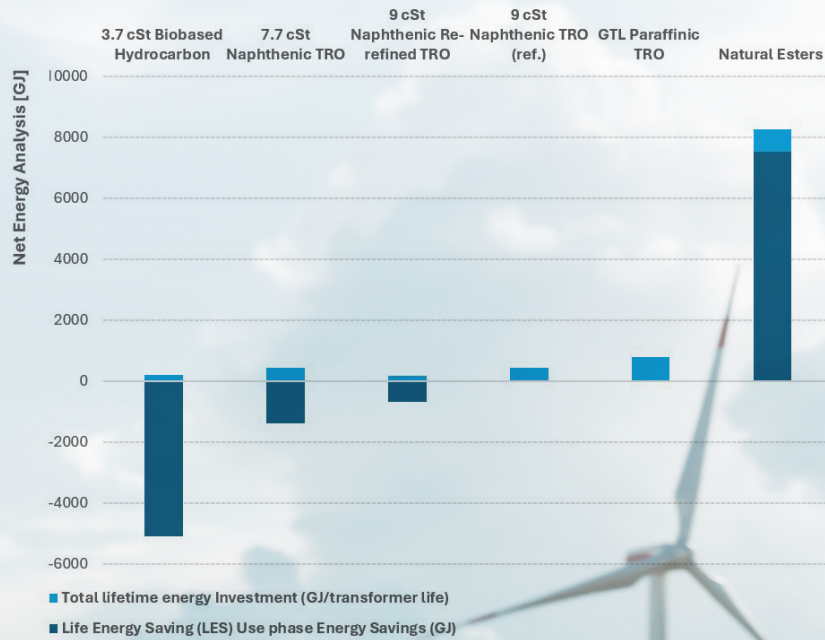


Figure 3. Lifetime energy savings (or costs) for transformer oils compared with common alternatives. 9 cSt Naphthenic Transformer Oil and GTL Paraffinic used as baseline comparison. Natural ester produced from soybean oil. Assumptions: 35-year lifetime, 50% average load, average load losses and no-load losses from Sacotte (ND), Jorge et al., and ABB. Reduction in losses from Wolmarans et al. (2021), and FEA calculations based on viscosity.

is included in the life cycle model without any upstream processes or burdens. The “Waste Transformer Oil” is hydrotreated to a virgin state. Heavy fuel oil is presumed to be used as the heat-energy source for the hydrotreatment process.

**Paraffinic Oils produced by Gas-To-Liquids (GTL) Facility**

Theecoinvent 3.9.1 database does not have adequate processes to represent the gas-to-liquids operation. Price Waterhouse Cooper (2003), however, completed an entire LCA of a gas-to-liquids (GTL) facility, comparing it with an average oil refinery from Europe. The comparative values indicate that the GTL facility requires 2.15 times

more energy per unit of base oil than the average European petroleum refinery (Appendix B). The energy cost of GTL transformer oil is hence scaled by multiplying the CtG energy investment of the average European base oil production

Similarly, PWC reports the carbon emissions for both the GTL process and the conventional refinery. Base oil production in the conventional refinery produced 535 tonnes of GHG emissions per 880 tonnes of oil while emissions associated with that level of production in the GTL facility was 1,210 tonnes. The GHG intensity of the GTL process is calculated from these values to be 2.26 times greater than that from an average

European petroleum refinery. Using this data on energy costs, the GWP of GTL transformer oil is scaled by multiplying the GHG emissions of benchline product by 2.26.

There is a high likelihood that there are other non-carbon GHG emissions in the GTL process, and by only including carbon emissions our estimates should be considered conservative.

**Natural Ester**

Natural esters are produced from vegetable oils. Soy is often used as a source product for natural esters. In this product category, we modeled soy production as the agricultural product for a natural ester.

## The use-phase energy savings were driven mostly by increases in cooling efficiency because of lower viscosity – i.e. lower waste heat losses when transforming power.

Much of the modeling framework and processes for this use-case were derived from William-Olsson (2020), who produced a comparative LCA for bio- and petroleum-based lubricants, which includes a detailed accounting of the esterification process. The esterification process in the model was produced using quantities from William-Olsson (2020) and connected to the appropriate upstream inputs from the ecoinvent 3.9.1 database.

### Use-Phase Net Energy Assessment

The use-phase assessment begins by calculating both the load and no-load losses of a 40 MVA transformer. Based on data presented by Sacotte Partners' TCO Report on the 3.7 cSt biobased hydrocarbon, a regression model was developed to calculate both no-load losses and load-losses for a 40 MVA transformer. The no-load losses were 27,224 W and the load losses were 178,788 W. The transformer was assumed to have a lifetime average load of 50%, which was in accordance with other similar models. The baseline model for the transformer assumed a 35-year life

and used the STEPS grid model, which means that each kWh of electricity is equivalent to 5.12 MJ of primary energy.

In addition to the above information provided by Sacotte, two other references were found for no-load and load losses for 40 MVA transformers: Jorge et al. (2012) and ABB Product Declaration (2003). The ABB Product Declaration provides losses for both Oil Natural Air Natural (ONAN) and Oil Natural Air Forced (ONAF) transformers, and both were included in this analysis as separate estimates. Using all four estimates for no-load and load losses, total lifetime energy losses for a transformer were calculated using the average value of those four results.

### Results

All low viscosity Transformer Oils provide energy and GWP100 savings for society compared to the paraffinic and natural ester product. The LES (Lifetime Energy Saving) for transformer oils range from 5,690 GJ per transformer for the "3.7 Biobased Hydrocarbon" to a cost of 7,520 GJ

per transformer for the natural ester oil. Most of the energy and GHG savings occur during the use-phase.

The CtG energy savings, compared to GTL having the highest CtG impact, of transformer oils range from 619 GJ for the "9 cSt Circular Re-refined transformer oil" to 47 GJ for the natural ester. The CtG savings for the circular TRO are driven mostly by the lower energy investments required to produce the oil compared with that for the paraffinic oil which served as the baseline for this product category (60.2 GJ).

The use phase energy savings range from 3,696 GJ for the "3.7 cSt Biobased Hydrocarbon" and 1408 GJ for the "7.7 cSt Naphthenic Transformer Oil", to a cost of 7568 GJ for the Natural Ester both compared to benchmark "9 cSt Naphthenic Transformer Oil" and "GTL Paraffinic" (which both have comparable viscosities). The use-phase energy savings were driven mostly by increases in cooling efficiency because of lower viscosity – i.e. lower waste heat losses when transforming power.



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