NISTIR 7423

BEES® 4.0

Building for **E**nvironmental and **E**conomic **S**ustainability Technical Manual and User Guide

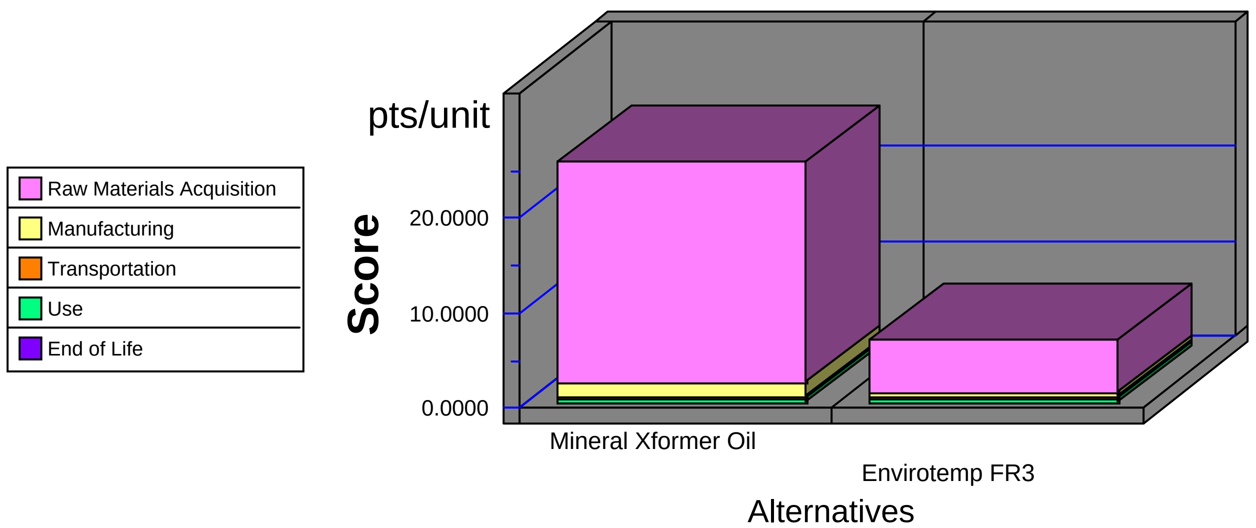
Barbara C. Lippiatt
Office of Applied Economics
Building and Fire Research Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8603

Sponsored by:
National Institute of Standards and Technology
Building and Fire Research Laboratory

August 2007

http://www.bfrl.nist.gov/oae/software/bees/bees_USDA.html

Environmental Performance by Life-Cycle Stage*



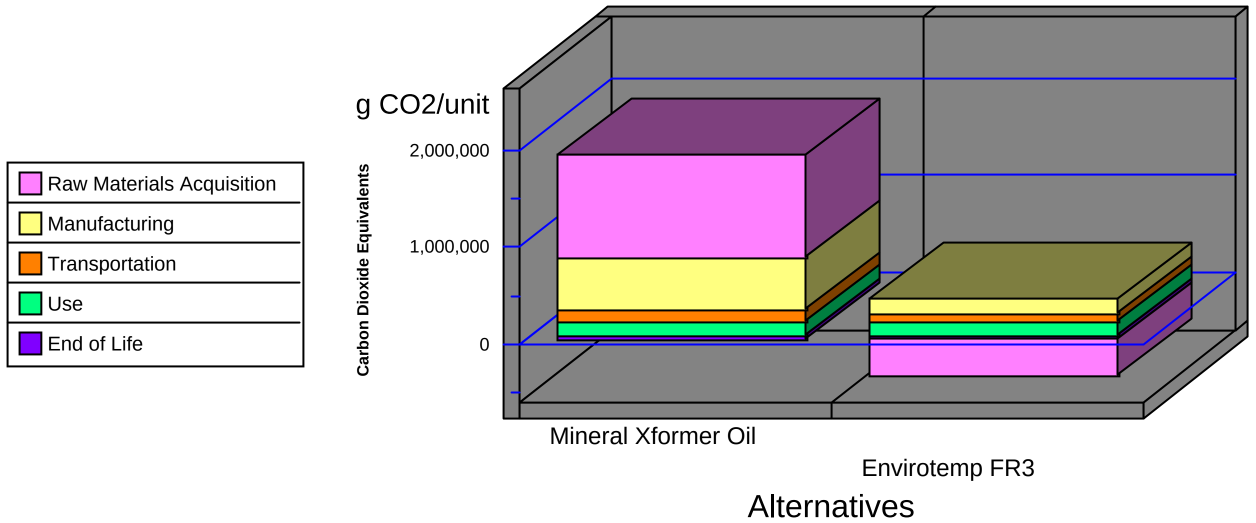
Note: Lower values are better

Category	MineralOil	Envirotemp
1. Raw Materials	23.1704	5.5222
2. Manufacturing	1.4394	0.4708
3. Transportation	0.3461	0.2020
4. Use	0.4075	0.4058
5. End of Life	0.0815	0.0812
Sum	25.4449	6.6820

*Summed environmental performance scores by life-cycle stage and by impact may differ slightly due to rounding.

1 unit = 1 1000-kVA transformer containing 500 gallons of fluid having a 30-year life.

Global Warming by Life-Cycle Stage



Note: Lower values are better

Category	MineralOil	Envirotemp
1. Raw Materials	1048184	-381590
2. Manufacturing	544363	160212
3. Transportation	122478	71498
4. Use	154124	153450
5. End of Life	30825	30690
Sum	1899973	34260

NISTIR 7423

BEES® 4.0

Building for **E**nvironmental and **E**conomic **S**ustainability
Technical Manual and User Guide

Barbara C. Lippiatt

NIST
National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

3.18 Transformer Oil

3.18.1 Generic Mineral Transformer Oil

Mineral oil-based transformer oil can be made from either naphtha or paraffin. Since the naphthenic-based mineral oil carries a larger market share, it is used as the mineral oil base for the product in BEES.[185] The detailed environmental performance data for this product may be viewed by opening the file G4010B.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The figure below shows the elements of mineral oil-based transformer oil production.

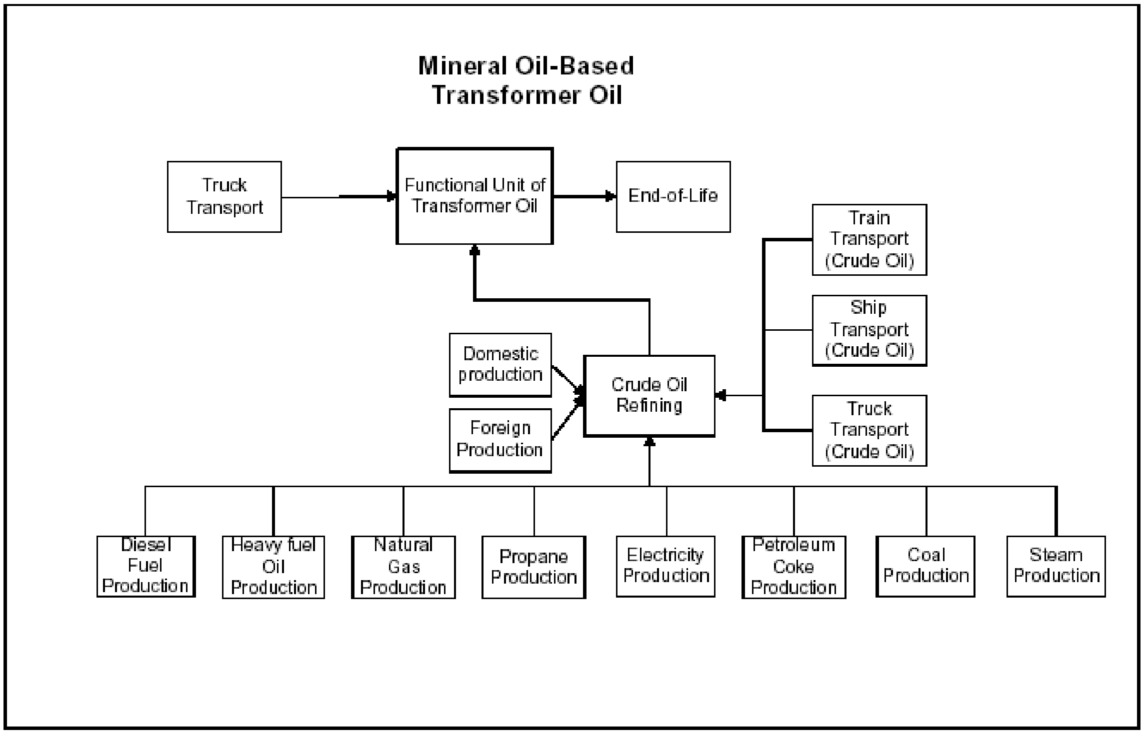


Figure 3.56: Mineral Oil-Based Transformer Oil System Boundaries

Raw Materials

Mineral-oil based transformer oil is composed of the materials listed in the Table below. The density of the oil is assumed to be 0.864 kg/L.[186]

---

[185] 2001 telephone conversation with United Power Services, an independent transformer oil testing laboratory.

[186] From http://www.shell-lubricants.com/Electrical/diala_hfx.html and http://www.camd.lsu.edu/msds/t/transformer_oil.htm.

Table 3.131. Mineral-Oil Based Transformer Oil Constituents

Constituent	***Mass (kg/kg oil)***
Naphtha	98 %
Pour-point depressives and other additives	2 %

The production of naphtha requires extraction of crude oil and crude oil refining; since naphtha is just one of many oil refinery products, only a portion of the inputs and outputs to these processes is allocated to naphtha production. Data for these inputs and outputs is based on the SimaPro and U.S. LCI Databases, as detailed below.

Crude Oil Extraction. This production component includes process flows associated with the extraction of crude oil from the ground. U.S. LCI Database data used to represent extraction from onshore and offshore wells range from the late 1990s to early 2000s.

Crude Oil Refining into Naphtha. Crude oil refining involves raw material and energy use as well as emissions. Crude oil refining is based on an average U.S. refinery. It is assumed that the material required by the refinery includes crude oil and other petroleum-based feedstocks, purchased energy inputs, and process catalysts.

Crude oil refineries draw much of their energy requirements from the crude oil stream in the form of still gas and catalyst coke as shown in the Table below. Additional energy requirements and process needs are fulfilled by the other inputs listed in the Table.[187]

Table 3.132. U.S. Average Refinery Energy Use

Energy Carrier	***Annual Quantity (MJ)***
Still Gas	1.52E+12
Catalyst Coke	5.14E+11
Natural Gas	7.66E+11
Coal	3.27E+09
Steam	3.8E+10
Electricity	1.43E+11
Propane (C3H8, kg)	6.21E+10
Diesel Oil (kg)	3.16E+09
Heavy Fuel Oil	6.13E+10
Coke	1.77E+10
Other	8.8E+09

The emissions and energy requirements associated with the production of these fuels are accounted for. Emissions are based on U.S. Environmental Protection Agency AP-42 emission factors.

[187] Energy Information Administration, *Petroleum Supply Annual 1994*, Report No. DOE/EIA-0340(94)/1, May 1995.

Allocation. Crude oil refineries produce a number of different petroleum products from crude oil. The method for allocating total refinery energy use and total refinery emissions to the production of naphtha is complicated by the fact that the refinery product mix is variable, both among refineries and even with time for a given integrated refinery. The following method is used to allocate refinery flows to naphtha production:

1. Calculate the percentage of total refinery energy use by refinery process.
2. Calculate naphtha's share of each process's energy consumption.
3. For each refinery process, multiply the corresponding results from steps 1 and 2 to get the percentage of total refinery energy use allocated to naphtha refining

Manufacturing

Energy Requirements

After producing naphtha, pour-point depressives and other additives such as antioxidants are added to give the transformer oil the properties it needs. The specifics for these additives can not be reported because they are confidential, but their production data come from the SimaPro database. The assumed energy requirement for producing the transformer oil is given in the Table below.[188]

Table 3.133. Energy Requirement for Mineral-Oil Based Transformer Oil Production

Requirement	***Quantity (per kg oil)***
Production Energy	1.6 MJ (0.44 kWh)

Transportation

Trucking is the mode of transport representing transportation from the transformer oil production plant to the transformer to be filled at the point of use. The transportation distance is modeled as a variable of the BEES system. Only trucking is modeled, and not pipeline transportation, since transformer oil is a specialty petroleum product with a tiny market as compared to other petroleum products. As a result, pipeline transportation burdens allocated to transformer oil are assumed to be insignificant.

Use

The amount of oil used in a transformer depends on the size of the transformer. A relatively small-sized (1 000 kV·A) transformer is assumed, which requires about 1.89 m^3 (500 gal) of fluid to cool. It is assumed that the use phase of the transformer oil lasts the lifetime of the transformer, approximately 30 years. Included in the modeling is the

[188] This data is based on confidential energy requirement data gathered for biobased transformer oil production (summer 2005). It is used in the absence of more representative manufacturing energy information for this product.

electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[189]
With periodic reconditioning of transformer oil during the 30-year life of the transformer, the oil can be further reconditioned and reused in another transformer at end of life. This is assumed to be the case; none of the product is landfilled.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

[189] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR) website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist_pub.html. Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.

3.18.3 Cooper Envirotemp FR3

Envirotemp FR3 Dielectric Coolant is a soy oil-based transformer fluid. A relatively small-sized (1 000 kV·A) transformer is assumed for BEES, which requires about 1.89 m^3 (500 gal) of fluid to cool. The functional unit for Envirotemp FR3, as for all BEES transformer oils, is the use of 1.89 m^3 (500 gal) of transformer fluid to cool a 1 000 kV·A transformer for a period of 30 years.

The detailed environmental performance data for this product may be viewed by opening the file G4010D.DBF under the File/Open menu item in the BEES software.

Flow Diagram

The flow diagram below shows the major elements of the production of this product, as it is currently modeled for BEES.

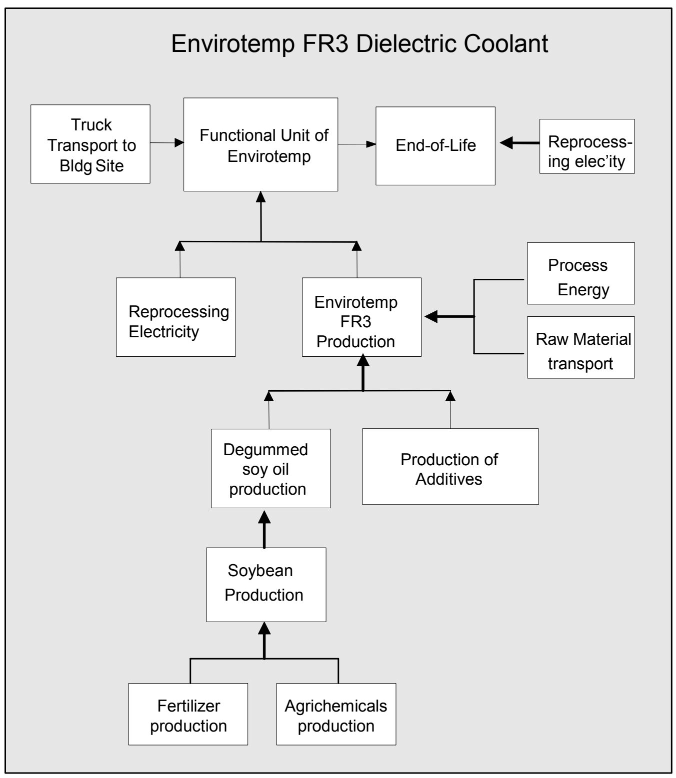


Figure 3.58: Envirotemp FR3 Dielectric Coolant System Boundaries

Raw Materials

The main constituent of Envirotemp FR3 is degummed soybean oil, and it contains small amounts of other additives, shown in the Table below.

Table 1: Envirotemp® FR™ Constituents	
Constituent	***Mass Fraction (%)***
Degummed soybean oil	95
Additives	5

Data for soybean production comes from the U.S. LCI database. Production data for soybean oil comes from the National Renewable Energy Laboratory LCA study on biodiesel use in an urban bus,[194] in which degummed soy oil is modeled as the predecessor to soy-based biodiesel. Additives used in Envirotemp FR3 include a blend of natural esters and methacrylate resins, phenol compounds, and coloring. These additives are not specified due to confidentiality concerns, but they are included in the model and life cycle data for their production comes from the general contents of the SimaPro LCA database.

Manufacturing

Energy Requirements and Emissions. Steam from natural gas and electricity are used to heat and blend a 22.71 m3 (6 000 gal) batch of Envirotemp FR3. The Table below presents the quantities of each type of energy per gal of product (1 gal weighs 3.2 kg).

Table 3.135: Envirotemp FR3 Manufacturing Energy

Energy Carrier	***Quantity per gal***
Electricity	0.216 MJ (0.06 kWh)
Natural gas	4.43 MJ (4 200 BTU)

Electricity and natural gas are modeled using the U.S. average electric grid from the U.S. LCI Database.

Transportation. Soybean oil is assumed to be transported 322 km (200 mi) to the production site. Transportation of additives is assumed to cover 800 km (500 mi) by truck to the Envirotemp facility. Transportation data is based on the U.S. LCI Database.

Transportation

Heavy-duty truck transportation is used to represent transportation from the Envirotemp facility to the transformer to be filled at the point of use. The distance traveled is modeled as a variable of the BEES system.

Use

For BEES, Envirotemp FR3 Dielectric Fluid is used in a transformer with a capacity of 1.89 m^3 (500 gal). Any type of transformer oil needs to be reconditioned or reclaimed over the life of the transformer: transformer aging, thermal problems, or electrical

[194] Sheehan, J. et al., NREL/SR-580-24089 (Washington, DC: US Department of Agriculture and US Department of Energy, May 1998).

problems can generate dissolved gas, which results in deterioration or contamination of the fluid. Included in the BEES use phase modeling is the electricity required to recondition the oil when dissolved gas analysis tests indicate the need. Reconditioning is assumed to occur every five years.[195] The transformer itself is assumed to have a lifetime of 30 years.

End of Life

At the end of the 30-year life of the transformer, Envirotemp FR3 is modeled the same as most all other transformer oils in BEES: at year 30, Envirotemp is assumed to be further reconditioned and reused in another transformer. Included in the end-of-life modeling is the electricity required to recondition the oil.

References

Life Cycle Data

National Renewable Energy Laboratory (NREL): *U.S. Life-Cycle Inventory Database*. 2005. Golden, CO. Found at: http://www.nrel.gov/lci/database.

PRé Consultants: *SimaPro 6.0 LCA Software*. 2005. The Netherlands.

Sheehan, J. et al., *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus,* NREL/SR-580-24089 (Washington, DC: U.S. Department of Agriculture and U.S. Department of Energy, May 1998).

Industry Contacts

Patrick McShane, Cooper Power Systems (February 2005)

[195] Information on dissolved gas analysis testing can be found in the U.S. Bureau of Reclamation (USBR) website's Facilities Instructions Standards and Techniques (FIST) document, http://www.usbr.gov/power/data/fist/fist3-30. Energy information on reconditioning was provided during telephone conversations with S.D. Myers, a transformer and transformer fluid contractor, November 2001.