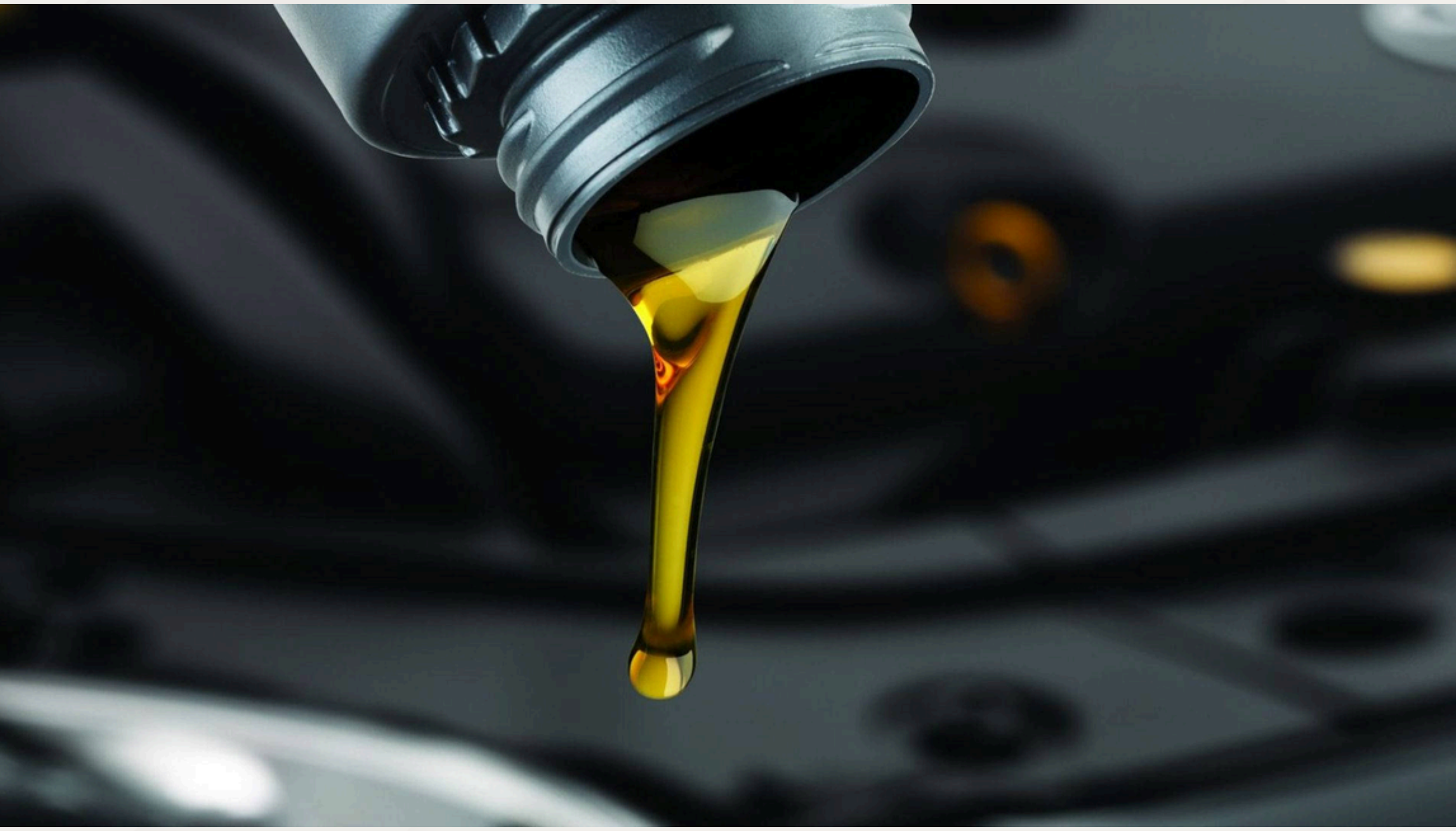
GLOBAL TUNIKARA SDN BHD
"Infinite Possibilities"

PRODUCT CARBON FOOTPRINT REPORT

DEVELOPMENT OF PRODUCT CARBON FOOTPRINT FOR BASE OIL (SN 150)



RENGKAS MAJU (M) SDN BHD

TABLE OF CONTENT

1.0 INTRODUCTION TO PRODUCT CARBON FOOTPRINT

Product Carbon Footprint (PCF) is defined as the **total amount of greenhouse gases (GHG) emitted throughout the lifecycle of a product**, expressed in carbon dioxide equivalents (CO_2e). This product cycle encompasses various stages such as raw material extraction, production/manufacturing, transportation and distribution, usage phase and disposal.

The PCF is important for organizations for following key reasons:

Compliance with Regulation & Standard

Many countries have implemented regulations mandating companies to report their carbon emissions. For instance, the EU's Corporate Sustainability Reporting Directive (CSRD) and carbon pricing policies compel businesses to monitor and disclose their emissions.

Transparency & Accountability

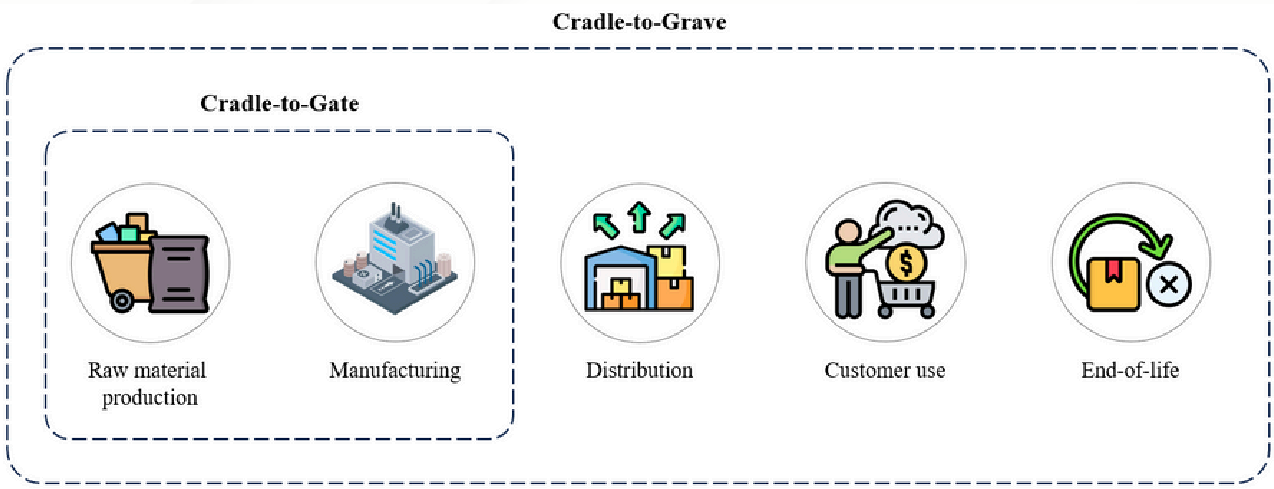
Reporting PCF showcases a company's transparency about its products' environmental impact, enabling stakeholders like investors, customers, and regulators to ensure accountability and promote sustainable practices.

Responding to Consumer Demand

As consumers increasingly prioritize sustainability, reporting PCF allows companies to share transparent information, gain trust from eco-conscious buyers, and enhance brand reputation by promoting low-carbon products.

In ISO 14067, the system boundaries for a product's life cycle are defined as cradle-to-grave or cradle-to-gate:

- Cradle-to-grave: Includes all emissions and removals throughout the product's life cycle
- Cradle-to-gate: Includes emissions and removals up to the point where the product leaves the organization



2.0 ABOUT RENGKAS MAJU (M) SDN BHD

Rengkas Maju (M) Sdn Bhd established on 26 February 2005 and the first integrated Scheduled Waste Management plant has been built at Kawasan Perindustrian Sri Gading, Batu Pahat. Since 2005, RMSB are distributor for waste oil recycling processing, manufacturing and trading. They also hold the licensed to handle 7 categories listed under Environment Quality (Scheduled Waste) Regulation 2005. RMSB markets own lubricant oil brand in Malaysia and other Asian coutries.

Environmental solutions provided by Rengkas Maju include the collection and recovery of waste materials such as engine oil, lubricants, petroleum products, and related substances. These materials are processed in an established laboratory into reusable fuel oil, contributing to resource circularity and reducing environmental impact.

3.0 OBJECTIVES

The aim of this assessment is to establish the product carbon footprint of re-refined base oil (SN 150) based on the plant located at RMM Technology Sdn. Bhd, Masjid Tanah Melaka.

4.0 PRODUCT OVERVIEW

RMM refine base oil, which produced from waste oils and primarily used lubricants. The re-refining process involves several advanced techniques designed to remove impurities such as water, dirt, and other contaminants from the waste oil. This transformation not only recycles valuable resources but also significantly reduces environmental impact compared to producing virgin base oils from crude oil.

Re-refined base oils are employed in numerous applications due to their comparable performance characteristics to virgin oils. Key uses include:

1. Automotive Lubricants: RRBO is commonly blended with virgin base oils to produce motor oils and transmission fluids.
2. Industrial Applications: These oils serve as lubricants in machinery, hydraulic systems, and gear oils.

5.0 METHODOLOGY

To determine the product carbon footprint, the following steps shall be taken:

- Boundaries identification
- Data collection
- Product carbon footprint calculation and analysis
- Reporting

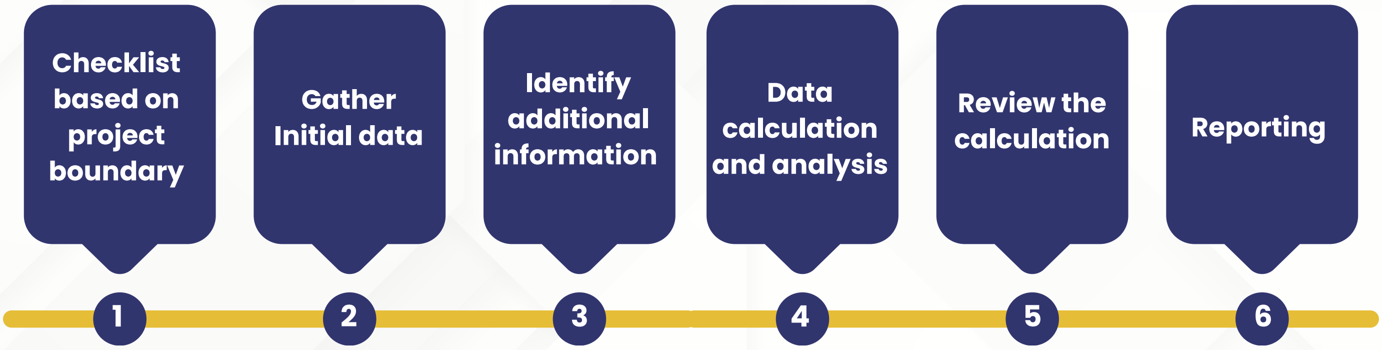


Figure 1. Process flow of PCF.

5.1 Boundaries Identification

The product carbon footprint detailed in this report is based on **Cradle-to-Gate** approach. The boundaries considered in this assessment includes from the transport of waste oil from the supplier, transport of chemical additives, the manufacturing process and packaging of final product. The details are as depicts in Figure 2.

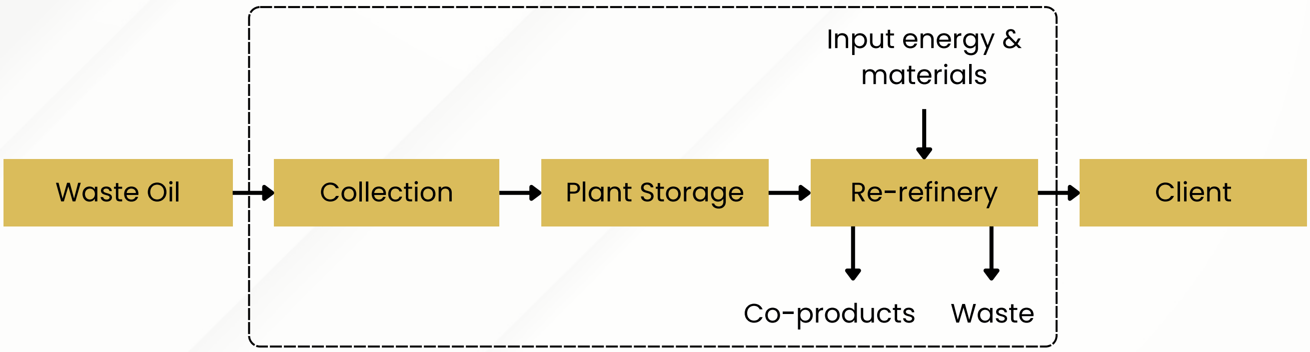


Figure 2. Boundary for PCF Assessment.

5.2 Scope Definition

5.2.1 Functional Unit

The functional unit for this study is defined as the production of 1 kg of SN150 base oil, derived from processing waste oil through distillation at a capacity of 40,000 tons per year.

5.2.2 Cut-Off Criteria

Cut-off criteria are not applied in this assessment because sufficient primary and secondary data attributed to the re-refined base oil processes are provided.

5.3 Data Collection and Assumptions

Data was gathered from primary, secondary source and journal. GTS provided initial checklist on the information required for the PCF assessment. Primary data was provided by RMM based on the plant pre-operating data. The secondary data was gathered from similar re-refining operation and other technology. Included in the reference are also scientific journal and standard for the industry norms and emission factor. In addition to these, discussion and meeting were held between both parties to understand the plant operation and the data points.

Tables 1 and 2 summarize the activity data sources and emission factors used to develop the life cycle emissions inventory for re-refined base oil.

Table 1. Emission sources from each process.

Process	Emission Sources	Data Needed
Waste oil sourcing	Raw material	Waste oil processes by facility
Material transportation (i.e raw material, chemical, packaging, diesel)	Truck delivery	Fuel type and usage Travel distance and frequency Number of trucks
Plant operation	Electricity Water	Energy consumption Water usage
Fuel usage within the plant (i.e forklift)	Fuel	Transportation type Fuel usage
Product packaging	Packaging material	Type of packaging Number of packaging

Table 2. Emission factors used and reference.

Category	Emission Factor	Reference
Fuel - Diesel B10	2.41 $kgCO_2$/liter	UK DEFRA 2024
Electricity	0.774 $kgCO_2$/kW	Malaysia Energy Commission, 2021
Water	0.562 $kgCO_2/m^3$	Air Selangor 2023
Sea Freight	0.0103 $kgCO_2e$/ton.km	UK DEFRA 2024
Packaging - Flexibag	157.62 $kgCO_2$/pc	Reusable Industrial Packaging Association, 2015
IBC	22.86 $kgCO_2$/pc	
NMP	3.72 $kgCO_2$/kg	Pastore, B., M. et al. 2016

RMM has a total of 7 supplier of waste oil, which ranging 30 – 275 km from the processing facility in Masjid Tanah, Melaka. Table 3 shows the full list of waste oils supplier with their distance to processing.

Table 3. Waste oil supplier details.

Collection Point	Distance (km)
Point A	30
Point B	181
Point C	101
Point D	106
Point E	176
Point F	127
Point G	275

Table 4 summarizes the assumptions used in this study for the unavailable data based on the publicly available documents, journal and databases.

Table 4. Data assumptions.

Process	Assumptions
Waste oil	Waste oil is delivered by suppliers using a 30-ton capacity tanker per trip.
NMP	The distance for the ship is calculated as one-way since the ship returns with goods, whereas the vehicle returns empty.
Packaging	The lorry used for transporting packaging to the plant has a capacity of 10 tons and dimensions of 6.9m x 3.5m x 2.4m.
Diesel	A 1,000-liter diesel load is transported in an IBC tank using a 3.5L 4WD vehicle.
Packaging	The packaging purchased is from recondition packaging Base oil only use flexibag and IBC for product packaging

6.0 RESULTS AND DISCUSSIONS

This cradle-to-gate assessment focuses on emissions from the raw material production through to the final base oil (SN150) processing stage.

6.1 Transportation of Input Material

For this assessment it will include the transportation of feedstock, NMP, B10 diesel fuel and packaging material.

6.1.1 Waste Oil (WO)

The waste oil (WO) is sourced from selected workshops listed in Table 3. The suppliers are located within Peninsular Malaysia, and the waste oil is transported to the factory in Masjid Tanah, Melaka. The tanker, with an assumed capacity of 30 tons per trip, is expected to return empty after delivery.

Based on the International Council on Clean Transportation, the fuel efficiency for 40-footer truck is expected to be 2.6 km/liters. The fuel used is B10 diesel and the emission factor used is 2.41 kgCO_2e/liter, (UK DEFRA 2024). The emission for raw material transportation from each location are detailed out below.

a. Point A

The waste oil transported from the supplier at Point A is at 15,000 ton per year with total distance of 60 km, which require two trips per day using a 30-ton truck. This transportation generates emissions of 33,369.23 kgCO_2e annually. Table 5 shows the summary of carbon emissions from raw material transportation.

Table 5. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	60
Frequency (trip/day)	2
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor (kgCO_2e/litre)	2.41
Emission (kgCO_2e/year)	33,369.23

b. Point B

The waste oil transported from the supplier at Point B is at 5,000 ton per year with total distance of 362 km, which require two trips per 3 days using a 30-ton truck. This transportation generates emissions of 67,109.23 kgCO_2e annually. Table 6 shows the summary of carbon emissions from raw material transportation.

Table 6. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	362
Frequency (trip/day)	2 trips per 3 day
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor (kgCO_2e/litre)	2.41
Emission (kgCO_2e/year)	67,109.23

c. Point C

The waste oil transported from the supplier at Point C is at 5,000 ton per year with total distance of 202 km, which require two trips per 3 days using a 30-ton truck. This transportation generates emissions of 37,447.69 kgCO_2e annually. Table 7 shows the summary of carbon emissions from raw material transportation.

Table 7. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	202
Frequency (trip/day)	2 trips per 3 day
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor (kgCO_2e/litre)	2.41
Emission (kgCO_2e/year)	37,447.69

d. Point D

The waste oil transported from the supplier is at Point D at 5,000 ton per year with total distance of 106 km, which require two trips per 3 days using a 30-ton truck. This transportation generates emissions of 19,650.77 $kgCO_2e$ annually. Table 8 shows the summary of carbon emissions from raw material transportation.

Table 8. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	106
Frequency (trip/day)	2 trips per 3 day
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	19,650.77

e. Point E

The waste oil transported from the supplier at Point E is at 3,000 ton per year with total distance of 176 km, which require only one trip per 3 days using a 30-ton truck. This transportation generates emissions of 16,313.85 $kgCO_2e$ annually. Table 9 shows the summary of carbon emissions from raw material transportation.

Table 9. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	176
Frequency (trip/day)	1 trip per 3 day
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	16,313.85

f. Point F

The waste oil transported from the supplier at Point F is at 2,000 ton per year with total distance of 254 km, which require one trip per 4 days using a 30-ton truck. This transportation generates emissions of 17,657.88 $kgCO_2e$ annually. Table 10 shows the summary of carbon emissions from raw material transportation.

Table 10. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	254
Frequency (trip/day)	1 trip per 4 day
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	17,657.88

g. Point G

The waste oil transported from the supplier at Point G is at 5,000 ton per year with total distance of 176 km, which require two trips per 3 days using a 30-ton truck. This transportation generates emissions of 101,961.54 $kgCO_2e$ annually. Table 11 shows the summary of carbon emissions from raw material transportation.

Table 11. Emission from raw material transportation.

Parameter	Data
Vehicle Type	30 ton truck
Distance travelled (km/trip)	550
Frequency (trip/day)	2 trips per 3 day
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	101,961.54

6.1.2 N-Methylpyrrolidone (NMP)

NMP plays a crucial role in enhancing the recovery and purification processes. NMP is being transported from Qingdao, China to Port Klang, Malaysia by chemical tanker for 5,998.63 km (Fluent Cargo, 2024). The solvent was then transported to the processing facility in Melaka by tanker for 115.62 km. This solvent will be purchased once a year for amount of 12,000 kg. The total emission for NMP transportation is at 1,020.06 $kgCO_2e$ annually. Table 12 shows the summary of carbon emissions from NMP transportation by sea and land transportation.

Table 12. Sea transportation of NMP by chemical tanker.

Parameter	Data
Transportation mode	Sea
Distance travelled (km/trip)	5998.63
Frequency (trip/year)	1
Operating days	300
Emission factor ($kgCO_2e$/ton.km)	0.0103
Emission ($kgCO_2e$/year)	741.43

Table 13. Land transportation of NMP by tanker.

Parameter	Data
Vehicle Type	Truck
Distance travelled (km/trip)	300.6
Operating days	300
Fuel efficiency (km/l)	2.6
Fuel type	B10
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	278.63

6.1.3 Product Packaging

The packaging material to transport the base oil is depends on customer request, ranging from flexibag, drum, IBC or in pail. As information provided from the checklist, the packaging material will be delivered by using a 10 ton truck. The distance from the packaging supplier to the facility is varies depending on the supplier location.

Within the defined boundary, the calculation of product packaging emissions is limited to base oil packaging, assumed to use flexibags and intermediate bulk containers (IBCs). The total emission for both packaging transported is at 8691.76 $kgCO_2e$/year. The table below summarizes the emissions associated with each type of packaging supplied.

Table 14. Flexibag transportation emission.

Parameter	Data
Packaging dimension (mm)	5900 x 2400 x 1700
Quantity (unit/month)	100
Supplier location	Batu Pahat, Johor
Distance travelled (km/trip)	304.6
Frequency (trip/year)	5
Operating days	300
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	1,411.70

Table 15. IBC transportation emission.

Parameter	Data
Packaging dimension (mm)	200 x 1000 x 1160
Quantity (unit/month)	100
Supplier location	Shah Alam, Selangor
Distance travelled (km/trip)	261.8
Frequency (trip/year)	30
Operating days	300
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	7,280.05

6.1.4 Diesel

Diesel purchased is amount at 1000 litre/month for operational use. The diesel is assumed to be transported in IBC tank on a 3.5L 4WD from RMM Batu Pahat to Melaka. This transportation generates emissions of 17,657.88 $kgCO_2e$ annually. Table 16 shows the summary of carbon emissions from raw material transportation.

Table 16. Diesel transportation emission.

Parameter	Data
Distance travelled (km/trip)	336
Frequency (trip/year)	10
Operating days	300
Emission factor ($kgCO_2e$/litre)	2.41
Emission ($kgCO_2e$/year)	1,208.60

Overall, the transportation emission associated in a year for these 4 input materials are at 304,430.61 $kgCO_2e$/year.

6.2 Product Packaging

RMM used 4 types of packaging which are flexibag, drum, IBC and pail depending on the customer request. Table below shows the number of packaging used by RMM monthly.

Table 17. Product packaging used by RMM.

Packaging Type	Quantity (unit/month)
Flexibag	100
Drum	600
IBC	100
Pail/Jerry can	600

Flexibags and Intermediate Bulk Containers (IBCs) are efficient packaging solutions for base oil storage and transport. Flexibags, made from polyethylene and polypropylene, are lightweight, cost-effective, and suitable for non-hazardous liquids. IBCs, constructed from durable materials like steel and plastic, are reusable, stackable, and ideal for both liquids and solids. Both options enhance logistical efficiency, reduce handling requirements, and support operational sustainability while maintaining product integrity.

6.2.1 Flexibag

Flexibag are the easiest way to transport non-hazardous cargo like chemicals and food items in bulk. Each container can be just placed in a 20ft international standard container with a volume of 14-25 cubic meters, and can store and transport up to 25,000 liters of liquid.

The flexibag used by RMM is estimated at 100 pieces per month. Flexibag is supplied for 100 unit per month with capacity of 24,000 liters with weight of 28.88 kg per unit. The emissions associated with the packaging are calculated based on the study by FGN Global Logistics, 2024. The associated emission of flexibag usage is at 157,620 $kgCO_2e$/year.

Table 18. Flexibag packaging emission.

Parameter	Data
Packaging dimension (mm)	5900 x 2400 x 1700
Quantity (unit/month)	100
Operating days	300
Emission factor ($kgCO_2e$/pc)	157.62
Emission ($kgCO_2e$/year)	157,620

6.2.2 IBC

Intermediate Bulk Container (IBC) is a reusable industrial container designed for storing and transporting large quantities of liquids, typically with capacities ranging from 300 to 2,000 liters. Constructed from materials like high-density polyethylene (HDPE) or stainless steel, IBCs are durable and corrosion-resistant.

In this study, RMM uses IBC with capacity of 1000 liters with weight of 60 kg per unit. The emissions associated with the packaging are calculated based on the report published by Reusable Industrial Packaging in 2015 entitled Life Cycle Assessment of Newly Manufactured and Reconditioned Industrial Packaging. The annual emissions are estimated at 22,860 $kgCO_2e$ per year.

Table 19. IBC packaging emission.

Parameter	Data
Packaging dimension (mm)	200 x 1000 x 1160
Quantity (unit/month)	100
Operating days	300
Emission factor ($kgCO_2e$/pc)	22.86
Emission ($kgCO_2e$/year)	22,860

6.3 Operation Emission

6.3.1 Forklift

A total 4 unit of forklift being used in the plant for day-to-day operation. The forklift usage for RMM operations consist of 3 unit of 3-ton forklift and 1 unit of 4.5-ton forklift. According to the Toyota catalogue for engine powered forklift, the fuel consumption of both forklift is at 3.4 l/h and 4.4 l/h, respectively. The emission for both forklift usage shown in Table 20.

Table 20. Forklift emission.

Parameter	Data	
Capacity (ton)	3	4.5
No of forklift (unit)	3	1
Operating hour (h/d)	2.5	2.5
Fuel consumption (l/h)	3.4	4.4
Operation day (days/year)	300	
Emission factor ($kgCO_2e$/litre)	2.41	
Emission ($kgCO_2e$/year)	18,436.5	7,953

6.3.2 Electricity usage

The energy consumption for the processing facility estimated in range of 700 A/hr to 900 A/hr and operated alternately based on the data collection from the RMM team. It is estimated that electricity consumption in kW, ranging from 290.5 to 373.5 which amounted to 6972 to 8964 kW per day for 24 hours operational hour. In a year, the facility will use up to 2,689,200 kw for 300 operational days. As such the emissions for operational usage is 77,090,400 $kgCO_2e$/year.

Table 21. Electricity emission.

Parameter	Data			
	Line A		Line B	
	Min	Max	Min	Max
Usage	700	900	700	900
Operation time (days/year)	150	150	150	150
Emission factor ($kgCO_2e$/kWh)	0.774			
Emission ($kgCO_2e$/year)	33,727,050	43,363,350	33,727,050	43,363,350
Average emission ($kgCO_2e$/year)	38,545,200		38,545,200	

6.3.3 Water usage

The daily total water consumption for operational use is at 102,360 litre/day based on the process flow provided by RMM. In a year, the facility will use up to 30,708,000 for 300 operational days. The emissions from water usage are 17,257,896 $kgCO_2e$/year.

Table 22. Water usage emission.

Parameter	Data
Water usage (litre/day)	102,360
Operating days (days/year)	300
Emission factor ($kgCO_2e/m^3$)	0.562
Emission ($kgCO_2e$/year)	17,257,896

6.3.4 Waste oil

The emission for waste oil has been considered zero as waste oil is deemed as oil that has been contaminated and can no longer be used for its original purpose.

6.3.5 NMP

N-methylpyrrolidone (NMP) is commonly used in lubricant oil refining due to its selective solubility. It effectively dissolves impurities and heavy components (multi-ring hydrocarbons with short side chains) while exhibiting low solubility for lighter components (fewer rings with long side chains). In the refining process, NMP is mixed with crude oil fractions in a centrifugal extractor, where high-speed mixing facilitates the transfer of heavy components to the solvent. The mixed phase is then separated in a centrifugal drum, using differences in specific gravity and centrifugal force to isolate base oil (light component) from the solvent containing heavy components. This process enhances the viscosity-temperature performance, reduces residual carbon, improves oil color, and increases antioxidant stability.

The emission factor is estimated at 3.72 $kgCO_2e$/kg of NMP. The emissions from the NMP are 44,640 $kgCO_2e$/year. Table 23 shows the summary of carbon emissions from the NMP.

Table 23. NMP usage emission.

Parameter	Data
NMP usage (kg/day)	40
Operating days (days/year)	300
Emission factor ($kgCO_2e$/kg)	3.72
Emission ($kgCO_2e$/year)	44,640

6.4 Product Carbon Footprint Summary

The sum of the calculation from 6.1, 6.2 and 6.3 will be total up to derive the product carbon footprint of base oil. The emission from Table 24 below shows the summary of emissions from each process and facility.

Table 24. Product carbon footprint summary.

Process	Emissions ($kgCO_2e$/year)	
Transportation		
1. Waste oil	293,510.19	
a. Point A		33,369.23
b. Point B		67,109.23
c. Point C		37,447.69
d. Point D		19,650.77
e. Point E		16,313.85
f. Point F		17,657.88
g. Point G		101,961.54
2. NMP	1,020.06	
3. Product packaging	8,691.76	
4. Diesel	1,208.60	
Packaging		
1. Flexibag	157,620	
2. IBC	22,860	
Operation		
1. Forklift	26,389.50	
2. Electricity	77,090,400	
3. Water	17,257,896	
4. Waste oil (feedstock)	0	
5. NMP	44,640	
Total	**94,904,236.11**	

The total emissions associated with the production of **27,200,000 kg of base oil** are calculated at **94,904,236.11 $kgCO_2e$/year**, assuming 300 operational days. Based on these figures, the carbon emissions per unit of product are calculated at **3.49 $kgCO_2e$/kg of base oil**.

Product Carbon Footprint Benchmarking

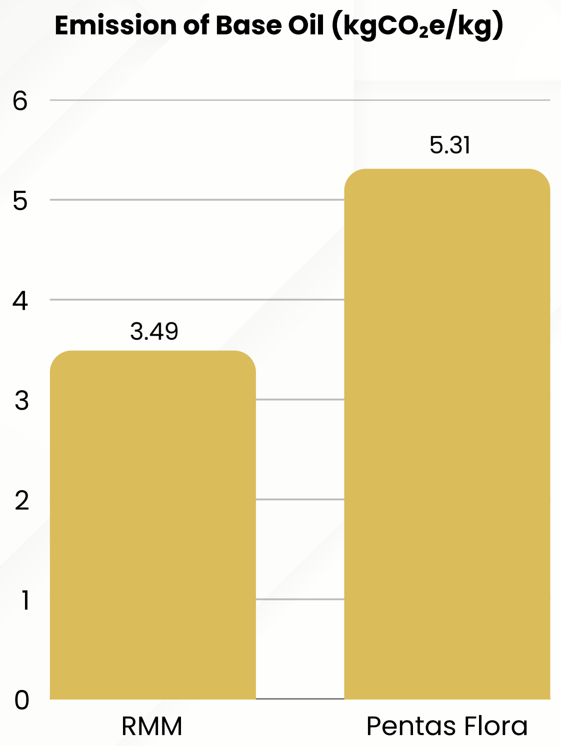
For this assessment, the carbon emission reduction potential of re-refined base oil was benchmarked against conventional crude-derived base oil. Based on literature and industry sources, re-refined base oil generally achieves a 70% to 80% reduction in carbon emissions compared to crude oil.

Using this range, the estimated carbon emissions for crude oil are approximately 6.13 kgCO_2e/kg, which would correspond to re-refined oil emissions in the range of:

- 5.72 kgCO_2e/kg (75% reduction),
- 5.36 kgCO_2e/kg (80% reduction),
- and lower at higher efficiencies.

According to Pentas Flora's data, their re-refined base oil achieves an 81% emission reduction, resulting in a total carbon footprint of **5.31 kgCO_2e/kg**.

For conversion purposes, it is assumed that 1 litre of base oil is equivalent to 0.85 kg.



References

1. Grice, L.N., Nobel, C.E., Longshore, L., Huntley, R., & DeVierno, A. (2014). Life Cycle Carbon Footprint of Re-Refined versus Base Oil That Is Not Re-Refined. ACS Sustainable Chemistry & Engineering, 2, 158-164.
2. American Petroleum Institute. (2023). Lubricants Life Cycle Assessment and Carbon Footprinting—Methodology and Best Practice. API Technical Report 1533.
3. Pastore, B.M., Savelski, M.J., Slater, C.S. et al. Life cycle assessment of N-methyl-2-pyrrolidone reduction strategies in the manufacture of resin precursors. Clean Techn Environ Policy 18, 2635–2647 (2016). https://doi.org/10.1007/s10098-016-1180-5
4. Abdalla, N., & Fehrenbach, H. (2018). LCA for regeneration of waste oil to base oil. Institut für Energie- und Umweltforschung Heidelberg GmbH Wilckensstr. 3, D-69120 Heidelberg, Germany.
5. Botas, J. A., Moreno, J., Espada, J. J., Serrano, D. P., & Dufour, J. (2017). Recycling of used lubricating oil: Evaluation of environmental and energy performance by LCA. Resources, Conservation and Recycling, 125, 315-323. https://doi.org/10.1016/j.resconrec.2017.07.010
6. Ishizaki, Keita & Nakano, Masaru. (2018). Reduction of CO2 Emissions and Cost Analysis of Ultra-Low Viscosity Engine Oil. Lubricants. 6. 102. 10.3390/lubricants6040102.
7. Gadalla, M., Olujić, Ž., Jobson, M., & Smith, R. (2006). Estimation and reduction of CO2 emissions from crude oil distillation units. Energy, 31(13), 2398-2408. https://doi.org/10.1016/j.energy.2005.10.030
8. Environment of Australia. (1999). Emission Estimation Technique Manual for Oil Recycling. National Pollutant Inventory.
9. Jamaludin, N. F., Shuhaimi, N. A., Mohamed, O. Y., & Hadipornama, M. F. (2023). Quantification of Carbon Footprint in Petroleum Refinery Process. Chemical Engineering Transactions, 106, 97-102. https://doi.org/10.3303/CET23106017.
10. Shanbhag, Sharad & Ramani, Swapnil & Naik, Sanjeel. (2020). Refining of used Engine Oil. International Journal of Engineering Research and. V9. 10.17577/IJERTV9IS050510.
11. Khan, A., H., Batool, N., & Aziz, A. (2023). Recovery of Base Oil from Used Oil through Solvent Extraction Followed by Adsorption: A Review. Environmental Protection Research, Volume 3 Issue 2.
12. Ahmed, D. J. ., Al-Nidawi, M. R., Chali, M. ., & Bahjat , A. . (2024). Purification of Used Lubricating Oils Using Vacuum Distillation. Journal of Petroleum Research and Studies, 14(1), 111-130. https://doi.org/10.52716/jprs.v14i1.766.
13. Islam Sazzad, M. R., Rahman, M. M., Hassan, T., Al Rifat, A., Al Mamun, A., Adib, A. R., Meraz, R. M., & Ahmed, M. (2024). Advancing sustainable lubricating oil management: Re-refining techniques, market insights, innovative enhancements, and conversion to fuel. Heliyon, 10(20), e39248. https://doi.org/10.1016/j.heliyon.2024.e39248
14. Hassanain, E.M., Yacout, D.M.M., Metwally, M.A. et al. Life cycle assessment of waste strategies for used lubricating oil. Int J Life Cycle Assess 22, 1232–1240 (2017). https://doi.org/10.1007/s11367-016-1255-x
15. Winberg, H. & Kopp, M. & Norrby, Thomas. (2004). LCA for production of re-refined base oil. 523-531.

RENGKAS MAJU (M) SDN BHD