Compendium of Recycling and Destruction Technologies for Waste Oils

UNEP

United Nations Environment Programme

Acknowledgement

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EXECUTIVE SUMMARY

Oils, whether mineral-derived or synthetic, are essential in a broad spectrum of processes, finding use as metalworking fluids, engine coolants, gear oils, and transformer oils, among a great many other applications.

The hazardous nature of waste oils (used oils) makes their proper handling, treatment, and disposal imperative. Increases in the number of motor vehicles and the spread of various types of industrial processes to a greater number of communities necessitate wider dissemination of accurate and practical knowledge regarding their recycling and disposal.

Recycling and recovery, which are possible for a sizeable range of waste oils, not only avoid the negative impacts on human health and the environment associated with improper waste oil disposal but also help to conserve finite resources. At the same time, the recycling/recovery process often yields substantial economic benefits through the creation of highly saleable end-products. Thus there is ample scope for persuading governments, private industry, and the general public of the imperative nature of introducing or improving upon their recycling and recovery practices and for implementing environmentally-sound disposal practices when recycling and recovery are impossible.

This Compendium overviews the state of oil usage and waste oil management in selected countries and includes examples of both policy approaches and recycling/destruction technologies currently in use. It then provides a step-by-step guide for assessing technologies both strategically and operationally in ways that are highly participatory and closely tied in with local community needs. In this way, this Compendium helps to bridge various gaps in the knowledge base faced by many communities, local governments and other entities in this area.

The Compendium starts with a review of data on lubricating oils supply and demand and generation of waste oils, outlines its constituents, and assesses health and environmental impacts of improper disposal practices. It also looks at legislative and regulatory frameworks addressing waste oils as well as prevailing management practices. Key common themes include the importance of minimising waste generation and then prioritising waste reuse, recovery and recycling over disposal; the importance of monitoring/auditing the collection, treatment and disposal of waste oils; the importance of generating awareness and support and of facilitating participation within the private sector and the general public; and the ongoing need to find ways to increase both the percentage of waste oils that is collectable and the percentage that is actually collected.

A step-by-step methodology for developing data inventory (baseline data) is also provided, enabling communities to take the first step in addressing waste oil by identifying and assessing their own sources of waste oil generation, the quantities of different types of waste oils they generate, and their current methods for reuse/disposal.

Oils are often discarded as a result of contamination or degradation. However, it has been estimated that 85 to 90% of dehydrated waste oils can be converted into useful products, including lubricating base oils and fuel. Moreover, unlike re-refined oils of the past, technological improvements have made recycled lube oils essentially equivalent to virgin oils in their lubricating properties.

The next chapter overviews the seven principal drivers enabling a re-refining technology to meet market, industry and environmental demands. It then discusses numerous recycling technologies, including generic technologies as well as specific technologies already commercially available or still in the research and development stage. It also covers burning technologies, first in generic terms and then in the context of various companies' specific applications of technologies. The chapter also assesses socio-economic implications of treating waste oils, including employment opportunities. Cognizant of the fact that recycling and destruction of waste oil can result in discharge of pollutants, the chapter describes various types of air pollution control devices and other necessary equipment and provides general background on disposal of hazardous wastes in secured landfills.

The need to promote Environmentally Sound Technologies (ESTs) in the context of sustainability is a critical consideration, and indeed often the primary consideration, in investment projects. It is imperative to undertake an accurate assessment of technologies in a way that incorporates participatory decision making and takes into account specific local needs.

In response to the need for such assessments, the International Environmental Technology Centre of the United Nations Environment Program (IETC-UNEP) has developed a methodology known as Sustainability Assessment of Technologies (SAT). The SAT methodology, which has received commendation internationally, is overviewed in Chapter 3. Among the elements that set the SAT methodology apart are its consultative and decision-making processes that involve not only direct but also indirect stakeholders; its ability to customise criteria and indicators in keeping with local conditions; its efficiency in not requiring exhaustive data collection for all technology systems under consideration; and its ability to bring groups to consensus in the process of decision-making.

In applying the SAT methodology to the issue of waste oils in particular, there are certain issues and aspects that must be considered during the screening and scoping processes. Chapter 4 covers these issues and provides concrete examples of how the SAT methodology can be applied to this particular area.

It is hoped that the Compendium will assist national and local governments, environmental organizations and other stakeholders, especially in developing countries, in assessing and selecting appropriate technologies for the recycling and/or destruction of waste oils.

GLOSSARY OF TERMS

AHP	Analytic Hierarchy Process
API	American Petroleum Institute (USA)
AN	Alkylated Naphthalene
BCUOMA	British Columbia Used Oil Management Association (Canada)
BERC	Bartlesville Energy Research Centre (USA)
CATOR	Catalana de Tractament d'Olis Residuals (Spain)
cSt	Centistokes
DCH	Direct Contact Hydrogenation
DG	Diesel Generator
ECD	Electron Capture Detector
EIO	Engine Oils
EnTA	Environmental Technology Assessment
EOPT	Environmental Oil Processing Technology
EPA	Environmental Protection Agency (USA)
ESCO	Energy Services Company
ESTs	Environmentally Sound Technologies
EU	European Union
GLC	Gas Liquid Chromatography
GNP	Great Northern Processing Inc
HF	Hydraulic Fluids
HSD	High Speed Diesel
IETC	International Environmental Technology Centre
IOOI	Input-Output-Outcome-Impact
KMPL	Kilometers per Liter
Kms.	Kilometers
KTI	Kinetics Technology International (USA)
MDO	Marine Diesel Oil
MMT	Million Metric Tonnes
MMTA	Million Metric Tonnes per Annum
MoEF	Ministry of Environment and Forests (India)
MWF	Metalworking Fluids
NIPER	National Institute for Petroleum and Energy Research (USA)
NOAA	National Oceanic and Atmospheric Administration (USA)
OEMs	Original Equipment Manufacturer
PAG	Polyalkylene Glycol
PAHs	Polycyclic Aromatic Hydrocarbons
PAO	Polyalphaolefin
PCBs	Polychlorinated Biphenyls
PPM	Parts per Million
SAT	Sustainability Assessment of Technologies
SOC	Springs Oil Conversion
STOU	Super Tractor Oil Universal

SUS	Saybolt Universal Seconds
UNCED	United Nations Conference on Environment & Development
UNEP	United Nations Environment Programme
UOP	Universal Oil Product
UTTO	Universal Tractor Transmission Oil
VGO	Vacuum Gas Oil
Vol %	Percentage by Volume
WCO	Waste Crankcase Oils
WOGF	Waste Oil Generation Factor
WOI	Waste Oil Index

PURPOSE OF THE COMPENDIUM

Management of waste oils is an issue of growing concern, particularly in industrial and urban areas. Generation of waste oils is closely linked with increases in the numbers of automobiles and industries. Most of these oils contain degraded additives which, along with other contaminants, render them hazardous. In many developing countries, some of these waste oils are recycled by means of primitive and obsolete technologies such as open boiling, the acid-clay method and so on, not only giving rise to toxic air emissions but also resulting in hazardous solid wastes. The market for low-grade recycled oils is usually limited and the remaining waste oils are either burnt in the open or indiscriminately disposed of, causing serious threats to both human health and the environment. Guidelines for management of waste oils have been prepared by entities such as the Secretariat of the Basel Convention. However, these guidelines provide information on management of wastes in general and contain, at best, a generic description of destruction technologies. Local authorities and industry managers are increasingly in need of reliable information on various technology options for the safe treatment and disposal of waste oils.

Technologies for recycling, reprocessing and destroying waste oils are not widely available in developing countries. As a result, technology choices, when they are made, may not be well-informed, resulting in poor or uneconomic outcomes. The use of obsolete or inappropriate technologies also results in serious environmental issues due to toxic air emissions and discharges of hazardous solid wastes.

Chapter 1 of this compendium reviews data on the generation of waste oils, outlines its constituents and delves into waste oil management practices. Chapter 2 addresses technologies for waste oil recycling, elaborating upon the technologies by examining various treatment processes, including their advantages and disadvantages. It also provides details on specific treatment technologies for recycling waste oils as well as the handling and treatment of hazardous components. Chapters 3 and 4 cover sustainability aspects of these technologies.

Along with the compendium, interactive software has also been developed to facilitate users' identification and selection of particular technologies appropriate to their own specific requirements.

A training manual has also been prepared to facilitate trainers in the provision of training on waste oil destruction technologies, using this compendium as the base document.

The compendium is thus intended to assist national and local governments, environmental organisations and other stakeholders, especially in developing countries, in assessing and selecting appropriate technologies for the recycling and/or destruction of waste oils.

CHAPTER 1: REVIEW OF DATA ON WASTE OILS

1.1 Introduction

Oils, whether extracted from crude oil or manufactured as synthetic oils, are used for a wide variety of purposes ranging from lubrication to heat and power transfer, metal cutting and so on. Depending upon the application and operating environment, these oils become contaminated and/or degraded and thus need to be discarded, resulting in the generation of waste oils (used oils).[1] Such waste oils are classified as hazardous waste[1] and under the Basel Convention fall under categories Y8 and Y9.

The management of waste oils is particularly important because of the large quantities generated globally through transport and industrial activities. These waste oils may have a detrimental effect on the environment if not properly handled, treated or disposed of.

A large range of waste oils can be recycled and recovered in a variety of ways, either directly or after some form of separation and refinement. In keeping with the waste management hierarchy, the first option is to conserve the original properties of the oil, allowing for direct reuse. Other options include recovering its heating value and/or using in other lower-level applications. Certain types of waste oils, lubricants in particular, can be reprocessed, allowing for their direct reuse. After treatment, waste oils can be used either as a lube base stock comparable to refined virgin base oil or as clean burning fuel. Waste oils and residues from recycling processes which cannot be reused in any way need to be disposed of in an environmentally sound manner.

General Definitions

i. The Basel Convention defines waste oil as, "oil from industrial and non-industrial sources which has been used for lubricating or other purposes and has become unsuitable for its original purpose due to the presence of contaminants or impurities or the loss of original properties (e.g. lubricating oils, hydraulic fluids, metal working fluids, electrical (dielectric) or heat transfer fluid, insulating fluid)." [2]

ii. The U.S. EPA defines used oil as, "any oil that has been refined from crude oil or any synthetic oil that has been used and as a result of such use is contaminated by physical or chemical impurities. Simply put, used oil is exactly what its name implies—any petroleum-based or synthetic oil that has been used. During normal use, impurities such as dirt, metal scrapings, water, or chemicals can get mixed in with the oil, so that in time the oil no longer performs well."[3]

iii. Engineering firm Mueller Associates defines "used (waste) oil" as "petroleum or synthetically derived oil whose physical and chemical properties have changed such that it cannot be used for its original purposes. Waste oil is defined as oil which

[1] Basel Convention, Technical Guidelines on Used Oil Re-Refining of Other Re-Uses of Previously Used Oil, series/SBC No. 02/05, reprinted November 2002 ISBN: 92-1-158605-4
[2] ibid.
[3] EPA, EPA Publication Number 905-R Adopted from http://www.epa.gov/osw/conserve/materials/used oil/usedoil.htm (24.08.2011)

becomes contaminated during storage, handling and use. It is made up of both used and unused waste oils."[4]

iv. The California Hazardous Waste Fee Health and Safety Code (Health and Safety Code 25250.1) defines "used oil" as, "oil that has been refined from crude oil, or any synthetic oil, that has been used, and, as a result of use or as a consequence of extended storage, or spillage, has been contaminated with physical or chemical impurities."[5]

1.2 Impact of Waste Oils on Health and the Environment

The contaminants in waste oils have adverse impacts on both human health and the environment. Irwin et al.[6] state that the presence of degraded additives, contaminants and by-products of degradation render waste oils more toxic and harmful to human health and the environment than virgin base oils. Oil concentrations as low as 1 ppm can contaminate drinking water. For mammals and birds, harmful impacts include toxic contamination, destruction of food resources and habitats and impaired reproductive capability. In addition, oil vapors are toxic for some species and may damage their central nervous systems, lungs, and livers. Ingesting oil may also adversely impact the ability of animals to digest food and furthermore damage their intestinal tract. Oil reduces the insulating capacity of furs and the water repellency of feathers, which places some animals at the risk of freezing or drowning.[7]

As compared to fresh oils, waste oils contain more metals and heavy polycyclic aromatic hydrocarbons (PAHs) that contribute to chronic hazards including carcinogenicity. Waste oils have been shown to be mutagenic and teratogenic. Cases of immunological, reproductive, fetotoxic and genotoxic effects have also been reported. Used engine oil is a contaminant of concern, with large volumes entering aquatic ecosystems through water runoff. Improper disposal of used motor oil is a significant source of its entry into the water system. The oil spilled on soil migrates downward by gravity through soil, possibly reaching groundwater, and spreads laterally due to capillary forces and soil heterogeneity. Uncontrolled burning of waste oils leads to emissions of metals and PAHs that are generally adsorbed by air-borne particulate matter which ultimately gets deposited in soil and water. Under controlled combustion conditions, e.g. in commercial incinerators, most organic compounds are destroyed but metals are still emitted as residues of burning in the form of ash. More worrisome are the emissions of dioxins and furans, which are highly carcinogenic.[8]

Hydrocarbons from oil can move to the atmosphere or settle through water into bottom sediments, where they may persist for years. Metals from oil may build up in various media. The major source of petroleum contamination in urbanised estuaries comes from waste oil (crankcase oil). PAHs, heavy metals, additives and antioxidants, trace levels of chlorinated solvents, and polychlorinated biphenyls (PCBs) have been detected in used engine oil. In

[4] Mueller Associates (Baltimore, MD, USA) William Andrew, Waste oil reclaiming technology, utilization, and disposal, 1989
[5] Denton, J.E., Used oil in bunker fuel: A review of potential human health implications, December 2004
[6] Irwin, R.J. et al., Environmental Contaminants Encyclopaedia, February 1998
[7] Nixon, H. et al., Used Oil Policies to Protect the Environment: An Overview of Canadian Experience, exfrom http://www.uctc.net/papers/666.pdf, 05.09.2011

rural areas, a considerable portion of the PAHs in streams comes from water streams from highways. While the amount of waste crankcase oils (WCOs) lost by runoff varies, estimates range from 3 to 5% to 20% or greater. In general, high runoff rates are expected when roads are made of nonporous materials such as clay, when roads are in poor condition and following periods of heavy rainfall. Compounds in WCO runoff may be in the water-soluble fraction or may be adsorbed to particles in the runoff. [8]

Another source of WCOs entering the aquatic environment is through improper disposal of used motor oil. Many people change their own car motor oil instead of having it done professionally. While shops that perform oil changes have special receptacles for used motor oil, many individuals do not dispose of their waste oil properly. For example, some people pour waste oil over their gravel/dirt driveways to keep the dust down, let it sit in their garage or backyard for extended periods of time, or illegally pour it down storm drains, causing grave environmental damage.

1.2.1 General Hazard/Toxicity

Considerable amount of research has been carried out regarding the health hazards of waste mineral oils. Some experiments and studies[9] have proven a positive correlation to some of the hazards, while in other areas, correlations are not yet clear but suggest that waste oils do impact upon various areas of health of both humans and animals.

New motor oil contains fresh and lighter hydrocarbons that are more of a concern for short-term (acute) toxicity to aquatic organisms, whereas used motor oil contains more metals and heavy PAHs that contribute to chronic (long-term) hazards, including carcinogenicity. These metals include lead and, to a lesser degree, zinc, chromium, barium and arsenic.

Waste crankcase oil contains several toxic components, including up to 30% aromatic hydrocarbons, with as much as 22 ppm benzo[a]pyrene, which is a PAH.[9] Used motor oil typically has much higher concentrations of PAHs than new motor oil. Aromatics are considered to be the most acutely toxic component of petroleum products, and are also associated with chronic and carcinogenic effects.

Chronic effects of naphthalene, a constituent in used motor oil, include changes to the liver and harmful effects on the kidneys, heart, lungs and nervous system. Due to their relative persistence and potential for various chronic effects (like carcinogenicity), PAHs (particularly the alkyl PAHs) can contribute to long-term (chronic) hazards. PAHs in used motor oil occur in complex mixtures rather than alone. All the known human health issues related to used mineral based crankcase oil have been summarised by the Agency for Toxic Substances and Disease Registry (ATSDR).[9]

1.2.2 Carcinogenicity/Cancer Effects

[8] Mahaney P.A., Effects of freshwater petroleum contamination on amphibian hatching and metamorphosis, Environmental Toxicology and Chemistry, Volume 13, Issue 2, February 1994
[9] ATSDR, Toxicological profile for used mineral based crankcase oil, September 1997

Crankcase oil breaks down to give a wide variety of oxygenated aromatic hydrocarbons and some heavy metals having toxic effects. This oil has been shown to be mutagenic and teratogenic. Combustion products, too, have PAHs which are mutagenic and carcinogenic. While there is an ongoing global debate on the subject, the 4- to 7-ring PAHs have been found to have carcinogenic effects.[9]

1.2.3 Developmental, Reproductive, Endocrine, and Genotoxicity

While studies offer mixed results, some immunological, reproductive, fetotoxic, and genotoxic effects have been associated with a few of the compounds found in used motor oil. Further, exposure to used crankcase oil has been shown to produce an induction of EROD enzymes in the livers of fish. Crankcase oil has also demonstrated some effects on amphibian reproduction.[8]

1.3 Types of Facilities that Generate Waste Oils

Various types of facilities, such as automotive, industry, aviation, marine and so on, generate different types of waste oils. A brief description of major waste oil generating facilities is given below.

1.3.1 Automotive Sector

Waste oils are generated in service stations, garages, new car dealer showrooms, other retail establishments and automotive fleet service areas. The waste oils consist primarily of crankcase oil, waste transmission fluids, gear lubricants, hydraulic oils, and minor amounts of solvents used in the service areas. Such waste oils are flammable and contain toxic ingredients.[10]

In highly industrialised regions, considerable amounts of waste oils are generated from trucking, transportation, and construction company fleets. In the organised sectors such as mass public transportation organisations, public works departments of various states, state transport corporations, defense services, airports, ports, mining facilities and large industries, enormous quantities of waste oils are generated, but they are easier to manage. Nevertheless, automobile service centers and commercial vehicle fleets constitute the largest sources of waste oils that are relatively uniform.

1.3.2 Industrial Sector

Industrial waste oils may be either lubricating or non-lubricating and include turbine oils, gas engine oils, refrigeration oils, heat transfer oils, compressor oils, hydraulic oils and metal cutting oils, among others. The waste oils generated at industrial plants are generally

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[10] Andrews, E. Waste Oil and other automotive products, publication no. G3456 (Extracted from report on *Toxicants in consumer products* by S. Ridgely, August 1982)

mixtures of various oils and greases and may be mixed with synthetic oils, solvents and cutting oils. Typical impurities include the products of oxidation and decomposition as well as fine suspended dust and metal particles.[11]

1.3.3 Marine Sector

Ocean-going ships and vessels use huge quantities of lubricating oils and greases. They are equipped with collection tanks to retain the waste oils, spent lubrication greases, contaminated fuel oils, and diesel engine crankcase drainings accumulated during their operation. The contents of these retention tanks are discharged during port calls. A huge quantity of waste oil may occasionally be generated upon leakage/spillage from tankers or damage to vessels near the harbor.

Accidental or deliberate operational discharges and spills of waste oil from ships, especially tankers, offshore platforms and pipelines are the most obvious and visible cause of oil pollution of the marine environment. As summarised by the National Oceanic and Atmospheric Administration (NOAA), "The kind of oil spill we usually think about is the accidental or intentional release of petroleum products into the environment as [a] result of human activity (drilling, manufacturing, storing, transporting, waste management)."[12]

Box 1:
Typical set up of a power distribution circuit and the transformers catering to that load

Estimation of used transformer oil

In a typical power distribution circuit catering to a population of about 2,500 MW of power needs, the total number of transformers installed is 36,157 with a total rating of the order of 8,620 MVA.

In this case, the distribution system generates a total of about 240,000 litres of transformer oil annually. The details of various transformers in the circuit are provided in the table below.

On the main HT power transmission side, a dialogue with the agency in charge revealed that in a 400 MVA transformer, they had changed 250 KL of transformer oil only once in 25 years, and that this was because of a major burn out. The generation of waste transformer oil from the transmission circuits is negligible as compared to the waste oil from the distribution circuits.

KVA rating of the distribution transformers	Number installed
16	92
25	89
25	29776
100	925
400	1520
500	22
630	2346
750	23
990	930
990	223
300	5
315	5
Total	**35,956**
MVA rating of transmission transformers	**Number**
3	1
5	2
10	1
16	35
20	57
20	65
25	6
25	14
50	20
Total	**201**

Data constructed from BSES Rajdhani Power Limited, New Delhi, India

1.3.4 Power Sector

Transformers are an intrinsic type of apparatus throughout the power generation, transmission and distribution

[11] Bourgeois, M. (n.d.) Used Oil Management: International Experiences and Approach for Colombia, www.bvsde.paho.org/bvsacd/acodal/xxiii.pdf

[12] UNEP, Global Marine Oil Pollution Information Gateway, http://oils.gpa.unep.org/facts/sources.htm, 20.08.2011

sector. Therefore their reliability and proper operation are important in ensuring their effective performance.[13]

Power transmission companies use only a small number of very large rating transformers while distribution companies use a large number of small transformers to distribute megawatts of power around the world. The majority of transformers use oil as an internal coolant which also gives added insulation and protection against arcing. Transformer oils have to be periodically tested to ascertain their basic electrical properties. If found unfit, the oils are replaced, thus generating waste oils.

Transformer oils are subject to electrical and mechanical stresses while a transformer is in operation. In addition there is contamination due to chemical interactions with windings and other solid insulation, catalysed by high operating temperatures. As a result, the original chemical properties of the transformer oils change gradually, rendering the oils ineffective for their intended purpose over a period of time. Transformer oils are a major source of PCBs, which are added to increase the oxidation stability of the oils. Hence transformer oils have to be periodically tested to ascertain its basic electrical properties and ensure its suitability for further use. The configuration of transformers in a typical power distribution network is represented in Box 1.

1.3.5 Other Sources

The other major sources of waste oil are railways, airlines, and mining operations and similar activities. A consolidated picture of various facilities that generate waste oils is shown in Figure 1.3.5.

[13] EL-Sayed M.M. et al., Prediction of the Characteristics of Transformer Oil under Different Operation Conditions, World Academy of Science, Engineering and Technology, Issue 53, May 2009

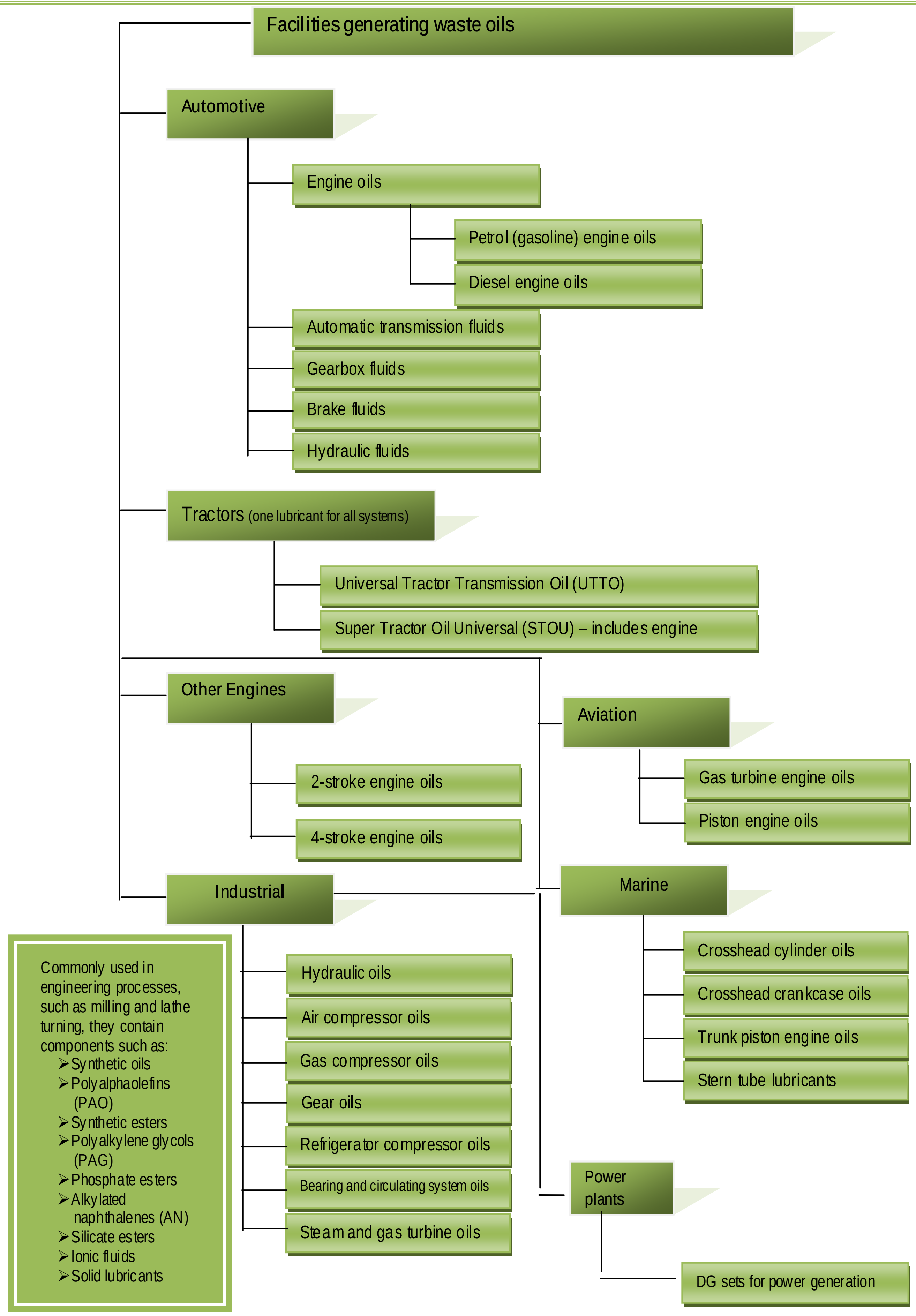
Facilities generating waste oils
Automotive
Engine oils
Petrol (gasoline) engine oils
Diesel engine oils
Automatic transmission fluids
Gearbox fluids
Brake fluids
Hydraulic fluids
Tractors (one lubricant for all systems)
Universal Tractor Transmission Oil (UTTO)
Super Tractor Oil Universal (STOU) – includes engine
Other Engines
2-stroke engine oils
4-stroke engine oils
Aviation
Gas turbine engine oils
Piston engine oils
Industrial
Marine
Crosshead cylinder oils
Crosshead crankcase oils
Trunk piston engine oils
Stern tube lubricants
Hydraulic oils
Air compressor oils
Gas compressor oils
Gear oils
Refrigerator compressor oils
Bearing and circulating system oils
Steam and gas turbine oils
Power plants
DG sets for power generation
Commonly used in engineering processes, such as milling and lathe turning, they contain components such as:
➢Synthetic oils
➢Polyalphaolefins (PAO)
➢Synthetic esters
➢Polyalkylene glycols (PAG)
➢Phosphate esters
➢Alkylated naphthalenes (AN)
➢Silicate esters
➢Ionic fluids
➢Solid lubricants

Figure 1.3.5: Facilities generating waste oils

1.4 Estimation of Waste Oils Generated

As the major share of waste oils generated comes from the automotive sector, which uses a considerable quantity of lubricating oil, it would be prudent to estimate the demand and supply of the same.

1.4.1 Global Supply/Demand of Lubricating Oils

World demand for lubricants was forecast to advance 2.3% per year beginning in 2000, reaching 41.7 million metric tonnes (MMT) in 2010. The expected growth was primarily linked to the increasing rates of motor vehicle production worldwide coupled with the rising number of kilometres travelled per vehicle due to expanding cities and towns. The growth in worldwide manufacturing activity was also expected to boost demand for industrial lubricants such as process oils and hydraulic fluids.[14] However, production of lubricant globally is expected to decline to 40.5 MMT in 2012.[15] The drop in the estimates for 2012 vis-à-vis 2010 is primarily associated with the expected global recession from 2008 to 2011. A small fraction of the decline may be due to efficiency gains in operations across all sectors.

As economies around the world, especially in Asia, are showing a trend towards growth, the global demand for lubricants has been estimated at a level of about 45 MMT by the year 2015. The current trend also suggests that demand will be stronger in the Asia-Pacific, Africa/Mideast and Latin American regions due to ongoing rapid industrialisation and rising car ownership rates. Engine oils will remain the largest segment, while the portion of process oils will grow at the fastest rate.

Slightly different figures for global demand emerged through the latest study undertaken by the Freedonia Group, which has forecasted world lubricant demand to amount to 41.7 MMT in 2015. This is based on various approaches, including formulation (e.g. petroleum, synthetic, re-refined, vegetable-based), product (e.g. engine oils, process oils, hydraulic fluids, metal working fluids), and market (e.g. motor vehicle aftermarket, manufacturing) trends.[15]

The report provides market estimates and projections for different countries including the United States, Canada and Japan as well as for major geographic regions, such as Europe, Asia, the Pacific, the Middle East, and Latin America based on data available in open literature.

(a) Worldwide Lube Oil Production

[14] Researchwikis, Lubricants Marketing Research (http://researchwikis.com/Lubricants_Marketing_Research, 21.06.2011)
[15] Freedonia Industry Study. World lubricants, industry study with forecasts for 2012 to 2017, Study #2454, February 2009

Worldwide production of lubricating oil for 2003 was estimated at 41.1 MMT. Table 1.4.1.a shows the approximate breakdown by region. Demand projections for the year 2015 are almost the same as those for 2003.

Table 1.4.1.a: Worldwide production of lubricating oils (2003)

Region	Estimated lubricant market, 2003, in million metric tonnes
North America	8.9
Central and South America	3.2
Western Europe	5.1
Central/Eastern Europe	4.9
Near/Middle East	2.0
Africa	1.8
Asia Pacific	11.2
Total	41.1

(b) Worldwide Lube Oil Consumption

Although the data in Figure 1.4.1.a below pertains to a past period (1997 to 1999), it is useful in that it indicates that the demand trend for lube oils in various countries over these three years did not show any significant increases or decreases. Various references in the literature also indicate this phenomenon across a range of countries, even at present.[16]

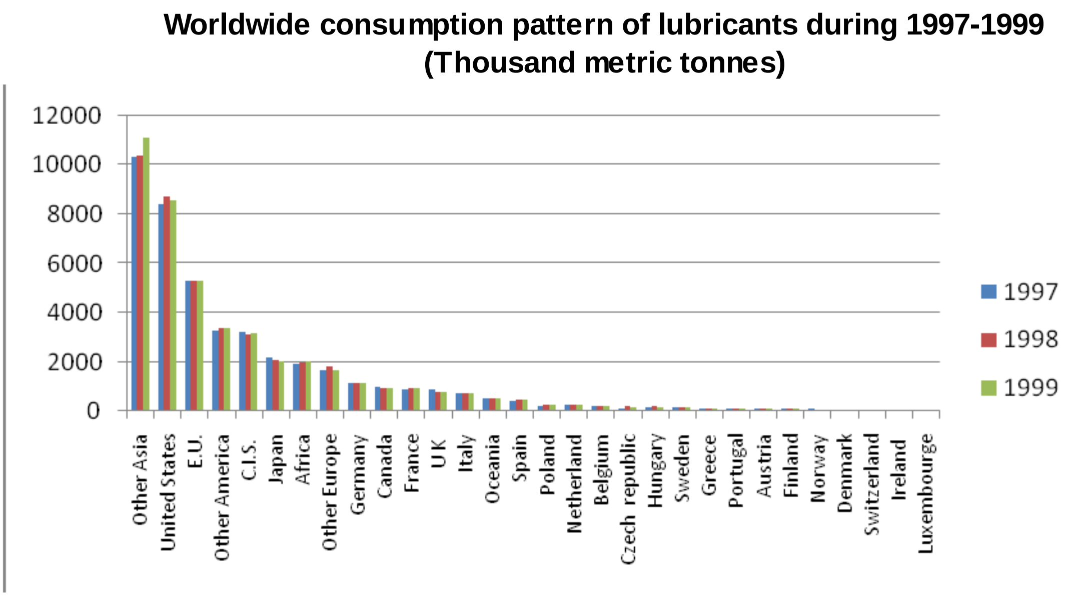

Figure 1.4.1.a: Worldwide consumption pattern of lubricants, 1997-1999 (cf. Annex 1)
Source: Compendium of used oil regeneration technologies[16]

[16]Khelifi, O. et al., Decision support tool for used oil regeneration technologies assessment and selection, International Centre for Science and High Technology, UNIDO, Trieste, 2003.

Table 1.4.1.b depicts regional demand for lubricants during the two years 2004 and 2005.

Table 1.4.1.b: Regional and global demand for lubricants, 2004-2005[14]

	Year	
Region	2004	2005
North America	8170	8130
Latin America	3215	3295
Western Europe	4705	4635
Central/Eastern Europe	4835	4905
Middle East	1775	1870
Asia Pacific	11580	11870
World	36130	36500

(Quantities in thousand metric tonnes)

From the table it can be concluded that:

- North America accounts for nearly 22% of total worldwide demand and its per capita lube oil demands far exceed other regions (due to widespread use of automobiles compared to other regions).
- Western Europe accounts only for 13% of total worldwide demand, probably due to efficient mass transit infrastructure and consequently lesser dependency on personal automobiles as compared to that in North America.

The overall pattern of consumption of various types of oils and lubricants is shown in Figure 1.4.1.b. On a global basis, the same trend can be seen as follows.

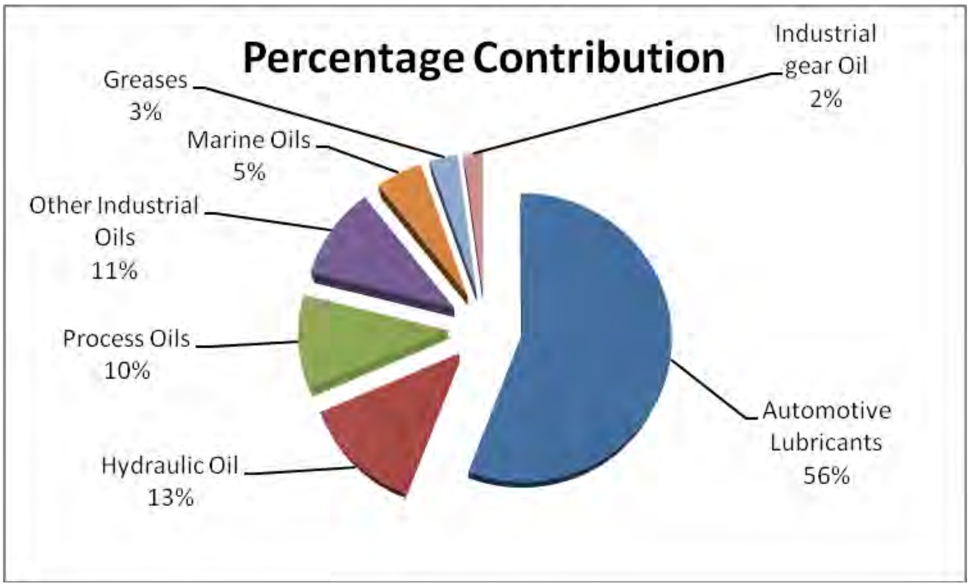

Figure 1.4.1b: Global share of different lubricants

Source: Bharat Petroleum Corporation (India), n.d.

1.4.2 Estimation of Waste Oil Generation Globally

While total worldwide production of lubricants can be estimated with comparative ease in a manner that closely approximates actual production figures, a similar estimation is difficult in the case of total waste oils generated, as users and recyclers either do not collect, or do not share, data. Waste oil generation is therefore estimated based on the following assumptions:

(i) The total amount of lubricants and industrial oils produced is consumed completely, and
(ii) Waste oils are always a mix of various grades of different oils, such as engine oils, greases, brake oils, sediments, moisture, industrial oils, metal cutting fluids etc.

Further, an "Unaccounted Used Oil Study" report compiled by the British Columbia Used Oil Management Association (BCUOMA) indicates that approximately 50% of oil consumed is later collected as waste oils.[17] This figure is comprised mainly of used engine oils. Out of the collectable amount of waste oil, about 25% is estimated to end up either dumped or in land filling. Thus a maximum of 75% (on average) of collectable waste oil is available for recycling.

Current global demand for virgin lube oil, as reported earlier, currently stands at roughly 41.7 MMT. This should yield about 21 MMT of collectable waste oil. Deducting another 25% that consists of uncollected oil that is burnt as fuel and dumped and/or land filled, the total comes to about 15.75 MMT. Assuming that actual collection will invariably be less than this amount, the figure of 15.75 MMT can be taken as the maximum quantity of oil that could be available for recycling.

1.4.3 Waste Oil Generation Rates by Major Regions/Countries

The generation of waste oils in some of the major regions and countries of the world is reported below.

(a) United States[18]

The demand for lubricants has been forecast to expand 1.3% annually, to 8.48 MMT in 2014. However, with the present sluggishness in the market, this may not be realised.

[17] Spence, R., Unaccounted Used Oil Study (Draft) Report, BCUOMA, April 2006
[18] U.S. Department of Energy (Office of Oil and Natural Gas, Office of Fossil Energy), July 2006. Used oil re-refining study to address energy policy act of 2005, Section 1838

Table 1.4.3: U.S. lubricating oil demand by type

Lubricating oil type	Demand, in million metric tonnes/year	%	Typical applications
Automotive fluids	5.04	59.44	Motor oils, automotive transmission fluids
Industrial oils	1.81	21.29	Hydraulics, turbines, gear oils, heavy duty equipment and metalworking fluids
Process oils	1.46	17.27	Rubber, transformers, white and agricultural spray oils
Greases	0.17	2.01	Automotive and industrial applications
Total	8.48	100	-

Source: U.S. Department of Energy (Office of Oil and Natural Gas, Office of Fossil Energy), July 2006. Used oil re-refining study to address energy policy act of 2005, Section 1838
(1 US gallon = 3.785 litres; average density of the lube oils = 0.9).

In the general lubricating oils categories, Figure 1.4.3.a depicts the share of main consumption segments. Figures 1.4.3.b depicts the share of lubricants used in different types of automobiles. Figure 1.4.3.c depicts the share of industrial lubricants in different types of applications.

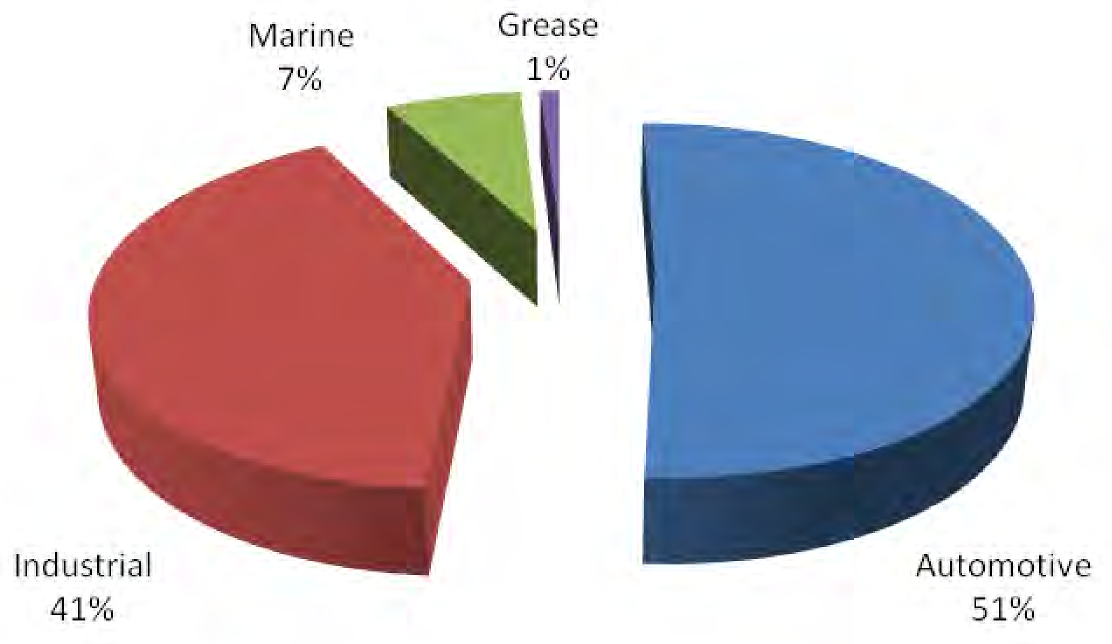

Figure 1.4.3.a: Share of main segments within lubricating oil consumption
Source: U.S. Department of Energy (Office of Oil and Natural Gas, Office of Fossil Energy), July 2006. Used oil re-refining study to address energy policy act of 2005, Section 1838

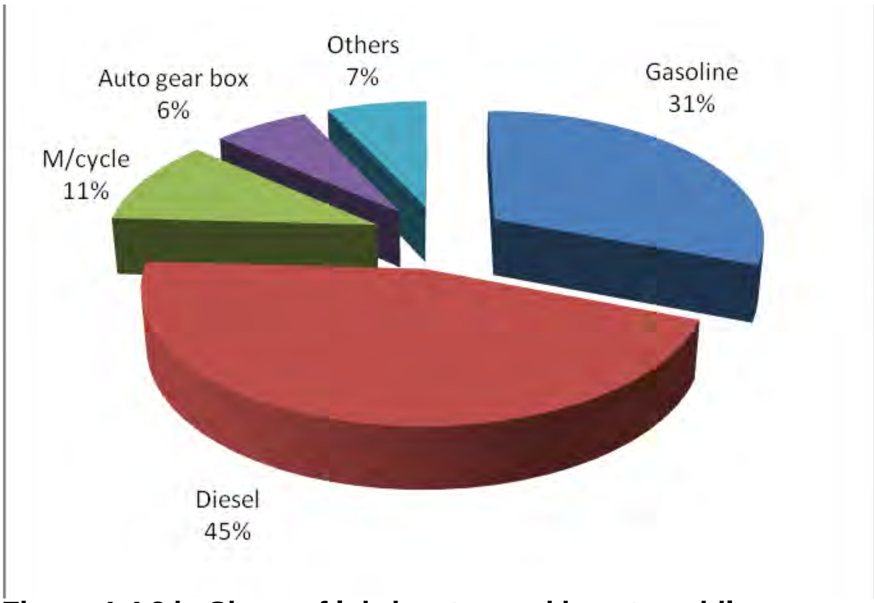

Figure 1.4.3.b: Share of lubricants used in automobiles

Source: U.S. Department of Energy (Office of Oil and Natural Gas, Office of Fossil Energy), July 2006. Used oil re-refining study to address energy policy act of 2005, Section 1838

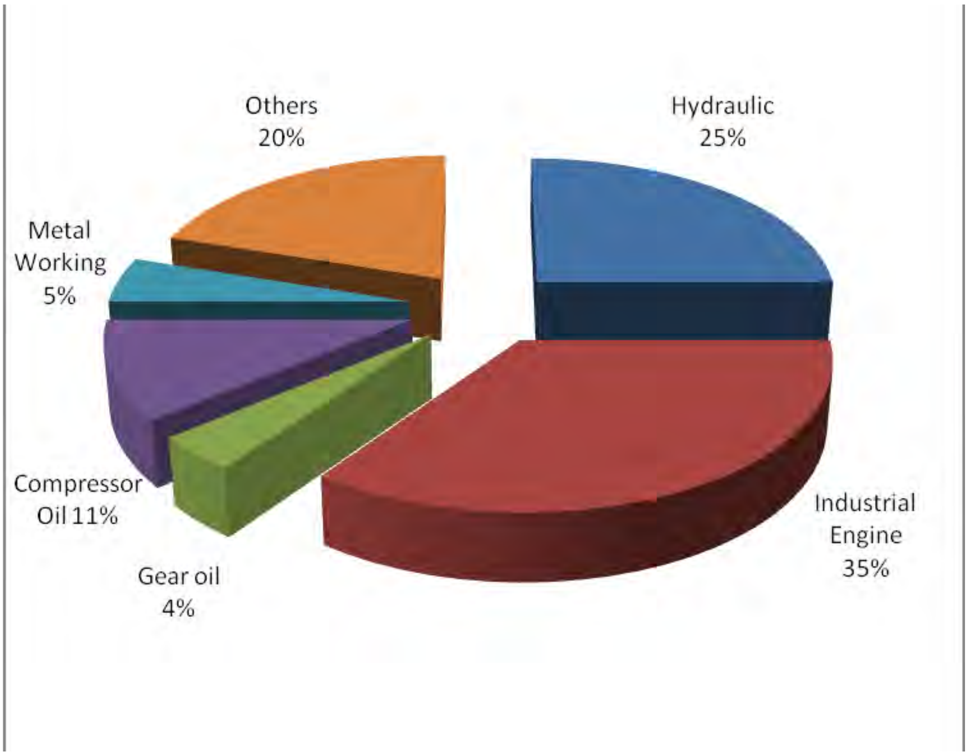

Figure 1.4.3.c: Share of industrial lubricants

Source: U.S. Department of Energy (Office of Oil and Natural Gas, Office of Fossil Energy), July 2006. Used oil re-refining study to address energy policy act of 2005, Section 1838

In the diverse industrial sector, original equipment manufacturers (OEMs) influence initial fills and then subsequent fills are sold on technical performance.

(b) European Union[19]

Figures on waste oils generated in selected European countries (collectable and collected portions of the lubricating oils in the EU) have been reported by the U.S. Department of Energy. According to European Commission resources, about 5 MMT of base oils are consumed in Europe annually, with the automotive and industrial sectors accounting for 65% and 35% respectively. More detailed information on waste oils was reported as follows:

- 50% of consumed oil is lost during use (combustion, evaporation, residue left in containers etc.);
- 50% is collectable waste oil;
- Engine oil represents more than 70% of collectable waste oil (1.75 MMT);
- Industrial oils comprise the balance of 30%;
- The average waste oil collection rate reached 70 to 75% in the EU in 2000 (1.25 MMT);
- The remaining 25 to 30% is assumed to be illegally burnt or dumped in the environment;
- These phenomena widely vary from country to country;
- The efficiency of collection systems is often high for engine oils (>80%) and low for black industrial oils (<10%);
- In 1999, an average of 25% of collectable waste oil (i.e. 33% of collected waste oil) entered regeneration plants, while about 50% of waste oils was used energetically in the EU in 1999;
- Rotary kilns in cement plants play an important role in the energetic use of waste oils.

Figure 1.4.3.d depicts the scenario of collectable and actually collected waste oils for recycling in the EU.[18] It may be seen that while about 46% of waste oil has been estimated as collectable, only about 37% was actually collected for recycling, meaning that about 30% of the collectable amount was not collected. The collectable amount of waste oils is lower than 50% in most of the above cases (and needs to be improved to at least 50%).

[19] U.S. Department of Energy, Used oil re-refining study to address energy policy act of 2005, Section 1838. Office of Oil and Natural Gas, Office of Fossil Energy, July 2006

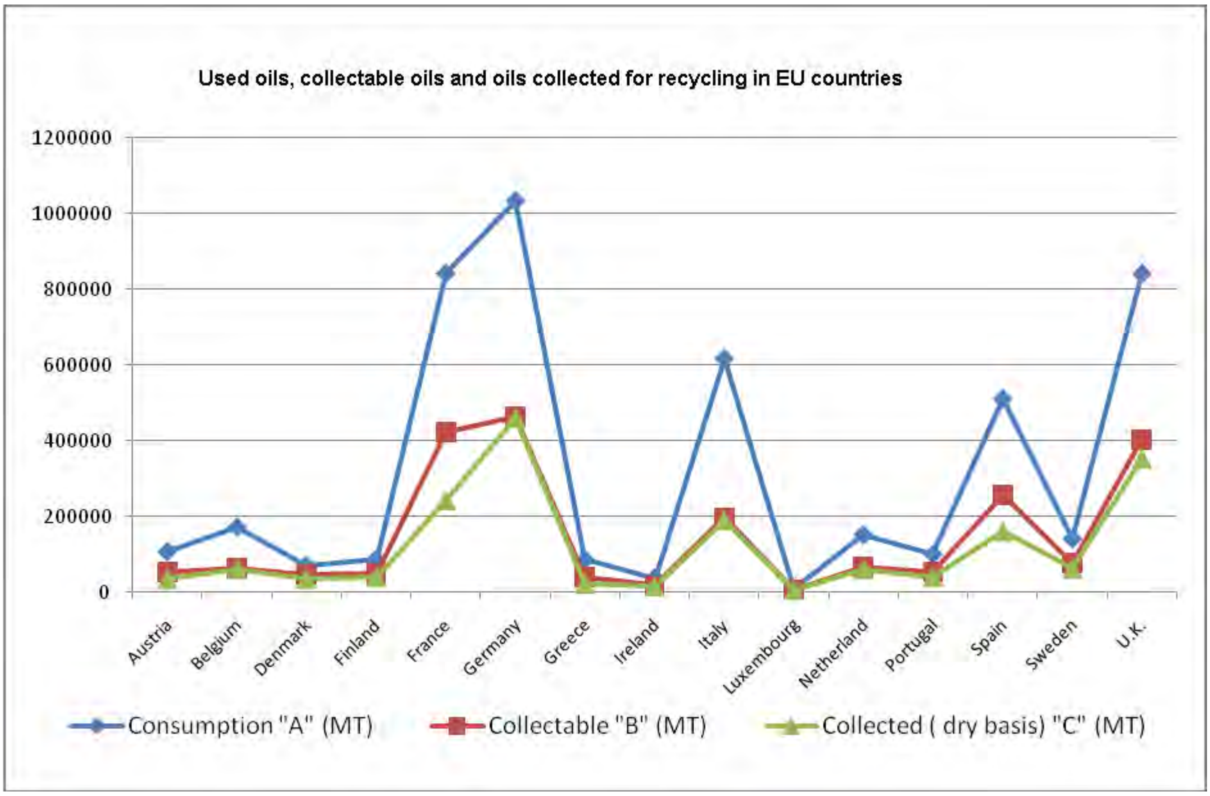

Figure 1.4.3.d: Used oils, collectable oils and oils collected for recycling in EU countries

Source: U.S. Department of Energy, Used oil re-refining study, n.d.

(c) Asia [20]

The Asian region is the world's largest lubricating oil market, accounting for 30% of global demand; automotive grades comprise the largest segment. The EPA reports that used motor oil alone accounts for 0.67 MMT of waste oil per year and notes that less energy is required to produce a gallon of re-refined base stock than a base stock from crude oil.[21]

The lubricating oil growth potential for 2005 through 2010 was projected to range from 0.5% to 4.8% per annum for various Asian countries, with Japan at the lowest level at 0.5% and China the highest at 4.8%, followed by India at 4.6%. Also, with regard to Group II base oils, Asia is transitioning to Group II/II+. Asia's strong lubricating oil demand growth is driven primarily by China. Strong growth rates were reflected in projections for 2010, where lube demand in China was estimated to reach 5.5 MMT, an amount approaching 40% of the Asian lube market.

Economic growth has led to grassroots refining investments in Asia. Many blenders in China used Group II/III base oils initially because of better regional availability. Higher quality requirements for automotive lubricants in these markets are driven by original equipment manufacturers for Japanese/US and European automotive brands. India is also a large

[20] Bulow, H. et al.: Lube base stocks - A perspective for Asia, Tri-Zen International, 9th ICIS-LOR world base oils conference, London, 17-18 February 2005

[21] US EPA, n.d., http://www.epa.gov/waste/conserve/materials/usedoil/oil.htm

market for base oils, albeit with characteristics slightly different from those of the Chinese market. Nearly a third of Indian base oil demand is found in specialty oils, such as white oils, transformer oils and petroleum jelly. This makes India a big market for Group II/III oils, particularly of South Korean origin.

China remains the engine of growth in the Asian base oil market. Burgeoning Chinese car sales, which are now overtaking sales in the U.S., has boosted Chinese base oil demand for automotive lubricants, which are estimated to account for over 50% of base oil consumption. Additionally, China's strong recovery in industrial production in 2009 has accounted for ongoing robust growth in industrial lubes. Automotive and marine applications in India are lesser than in China. However, regional sales of automotive lubes in total base oil demand are estimated at 40%. This means that there is ample scope for waste oils recycling facilities in Asia.

(d) Latin America[22]

Brazil consumed more than 1.122 MMT of base oils in 2008. Brazil's largest re-refiner of used lubricating oils collects more than 50% of the waste lubricants collected under current environmental standards in the country. Using 15 collection centers located across Brazil and a fleet of more than 200 trucks, collection has reached 0.106 MMT/year of used lubricants from service stations, oil change centers, car repair shops and industries.

Mexico produced about 0.247 MMT of base oils in 2008, supplying about 40% of Mexican demand. The remainder was imported, at a total of approximately 0.605 MMT per annum. Assuming that only 50% of virgin lube oils are collectible as used oils, out of which only around 70% is actually collected, the amount of collected used oil in Mexico can be estimated at 0.210 MMT per annum.

Argentina's lube market is 0.350 MMT per year. Venezuela also consumes about 0.350 MMT per year of base oils. For these two countries, the amount of collected used oil can be estimated by the same process used for Mexico above, giving an estimate of approx. 0.122 MMT per annum for each.

(e) Australia[23]

Around 0.45 MMT of lubricating oil is sold in Australia each year. While some engines, such as two-stroke lawn mower engines, burn oil completely, others like motor vehicle engines and machinery produce large volumes of waste oil that can be reclaimed and reused. Industry and the community generate at least 0.225 MMT of waste oils in Australia each year. Supported by the Australian Government's Product Stewardship for Oil Program, Australia recycled approximately 0.194 MMT of waste oil in 2004–2005. Even though this

[22] Jagger, A. ICB, ICIS, 16.02.2010 (Adopted from www.icis.com/Articles/2010/02/22/9334893/base-oils-2010-after-a-sharp-slump-in-2009-latin-americas-base-oils-markets-are.html)

[23] Department of Sustainability, Environment, Water, Population and Communities, Government of Australia, Used oil recycling http://www.environment.gov.au/settlements/waste/oilrecycling/index.html, 20.08.2011

rate is high, 0.05 to 0.09 MMT of waste oils remain unaccounted for. During 2008-2009 about 0.27 MMT of waste oil was generated by industry and the community and was available for recycling, but only about 0.24 MMT of waste oil was collected and recycled.

(f) New Zealand [24]

Used oil is the single largest non-watery liquid waste stream in New Zealand. An estimated 26,000 MT (0.026 MMT) of such waste is generated each year. (Approximately 53,000 MT [0.053 MMT] of lubricating oils are sold each year. About 50% is leaked, burned or otherwise lost during use.)

Used oil recovery programmes have been in place for some years. The major oil companies operate nationwide collection networks and supply waste oil to Milburn, New Zealand's Westport cement kiln, where it is burned at high temperatures. The burning of waste oil in high temperature kilns is a good practice environmentally because it deals effectively with contaminants. In some areas, local operators collect oil for low temperature burners (which often do not require resource consent) or for burning in asphalt plants or for use in road oiling. An unknown but possibly small quantity of waste oil is land filled or dumped in the environment.

(g) South Africa [25]

An estimated 0.106 MMT of waste oils are generated in South Africa annually. In 2008, successful recovery of over 70% of waste oils was reported.

(h) Turkey [26]

Turkey generates around 0.32 MMT of waste oils per year. Highest generators are trucks and buses due to their high share of transportation and high engine oil requirement. Currently, most waste lubricating oils are recycled for use as heating fuels rather than being converted back into base oil that can be sold back into the lubricants industry.

As recovery to base oil is energy intensive, it is not necessarily the best option. However, concerns over depleting oil reserves, ever-increasing carbon emissions and climate change are now driving a re-assessment of best practices in the waste oil industry.

(i) Nigeria [27]

Nigeria imported a total of 0.332 MMT per annum of base oils in 2004. Assuming that at least 80% of these base oils are blended into different grades of virgin oils, the virgin oil market is estimated at about 0.260 MMT per annum. Assuming an estimate of used oil

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[24] Ministry for the Environment, Government of New Zealand. http://www.mfe.govt.nz/issues/waste/special/oil/index.html, 22/08/2011
[25] WSP Environment & Energy, South Africa http://www.wspenvironmental.com/expertise/waste-oil-management-for-the-rose-foundation--south-africa, 20.08.2011
[26] Yilmaz, O. and U. Tetis, Waste Oil Generation from Road Vehicles in Turkey, Conference Proceedings, http://www.srcosmos.gr/srcosmos/showpub.aspx?aa=13028, 20.08.2011
[27] Bamiro, O.A. and O. Osibanjo, Pilot study (sponsored by the Secretariat of the Basel Convention) of used oils in Nigeria, Latin America, 2004.

generation at roughly 50% of virgin oil while the figure for collectible used oil could be as low as 30%, the volume of used oils in Nigeria is estimated at about 0.130 MMT. Thus, collected oil could be is as low as 0.078 MMT for re-processing or re-refining.

1.5 Constituents of Waste Oils

1.5.1 Constituents of Waste Oils

The main constituents of waste oils are base oils, degraded additives, metallic debris, oxidation products and carbon soot. A large number of additives are used to impart performance characteristics to the lubricants. The main families of additives are antioxidants, detergents, anti-wear elements, metal deactivators, corrosion inhibitors, rust inhibitors, friction modifiers, extreme pressure withstanding elements, anti-foaming agents, viscosity index improvers, demulsifying/emulsifying agents, complexing agents (in the case of greases) and stickiness improvers.[28]

During their use, these additives lose their characteristics, making the lube oil non-usable for lubricating purposes, thereby rendering it into waste oil. In addition, during their use, the lubricating oils and the metal processing oils pick up fractions of various metals as a result of components wearing out. These include carbon residue, chlorine, sulfur, zinc, calcium, barium, phosphorus, lead, aluminum, iron, chromium, molybdenum, nickel, arsenic etc. The intensity of these elements depends purely on the application to which the particular oil is put.

Contaminants in Waste/Used Oils

Some contaminants, such as chlorinated solvents, are picked up by waste oil during use or during storage while waiting for collection. However, not all chlorine found in waste oil is necessarily the result of contamination; small amounts (up to hundreds of ppm) may have come from additives in the original product. Other contaminants enter waste oils as a result of operational conditions. They include:

Water

Burning fuel produces CO_2 and H_2O. When an engine is cold, the water generated can pass through to the lube oil.

Fuel

Unburnt petrol/diesel passes through to the lube oil during engine start-ups.

Carbon

Carbon forms as a result of incomplete combustion when an engine is warming up and passes through to the lube oil.

Dust

[28] Southern Oil Refineries, Australia, 24.08.2011 (Reference taken from www.sor.com.au/products/re-refining/rrp01.ppt)

Small particles pass into the engine through the air breather.

Metals

Metals contaminate waste oils due to normal wear and tear of components.

Oxidation products

Additive chemicals at elevated temperatures in the presence of oxygen can oxidise, forming corrosive acids.

Characteristics of Waste Oils

A typical sample of chemical analyses[29] performed on waste oils, primarily for inorganic constituents, is summarised in Table 1.5.1.

Table 1.5.1: Typical properties of waste oils vs. virgin oils

Property or test	Motor oils	Industrial oils	Virgin motor oil (Average)
Viscosity, at 40°C, SUS	87 – 837 (15-180 cSt)	143 – 330	Up to 210 cSt
API gravity, at 15.6°C	19.1 – 31.3	25.7 – 26.2	25 on average
Specific gravity at 15.6°C	0.9396 – 0.8692	0.9002 to 0.8972	0.85 to 0.92 on average
Water, vol %	0.2 – 33.8	0.1–95	Traces
Bottom sediment and water, vol %	0.1 – 42	NA	Nil
Benzene insoluble, wt %	0.56 – 3.33	NA	Nil
Gasoline dilution, vol %	2.0 – 9.7	NA	Nil
Flash point, °C	79 – 220	157 – 179	>200
Heating value, kcals/kg	7,500 – 10,000	9580 – 9,500	NA
Ash, Sulfated, wt %	0.03 – 6.43	3.2 – 5.9	0.78 to 1.0 typical
Carbon soot, wt %	1.82 – 4.43	NA	Nil
Fatty oil, wt %	0 – 60	NA	Nil
Chlorine, wt %	0.17 – 0.47	<0.1 – 0.83	Nil
Sulfur, wt %	0.17 – 1.09	0.54 – 1.03	Group I oils >0.03
Zinc, ppm	260 – 1787	NA	Nil
Calcium, ppm	211 – 2291	NA	Nil
Barium, ppm	9 – 3906	NA	Nil
Phosphorus, ppm	319 – 1550	NA	Nil
Lead, ppm	85 – 21,676	NA	Nil
Aluminium, ppm	<0.5 – 758	NA	Nil
Iron, ppm	97 – 2401	NA	Nil

Source: Partly adopted from D.W. Brinkman and B.J. Parry, Energy Policy and Conservation

[29] Brinkman, D.W. and B. J. Parry, Energy Policy and Conservation Act, Public Law 94-163, U.S. Congress, Washington, D.C., Dec. 22, 1975.

NA: not available

1.5.2 Range of Hazardous Elements in Various Types of Waste Oils

In typical waste oils, the ranges of various components are as shown in the Table 1.5.3.

Table 1.5.2: Range of various hazardous components[27] in different types of waste oils

Property or test, ppm	HF	MWF	E/O
Arsenic	Up to 3.26	2.0 – 21.5	<1
Barium	1.4 – 460	0.3 – 8.1	<1
Cadmium	1.4 – 10.1	1.3 – 4.8	<0.25
Chromium	1.0 – 1.6	1.0 – 5.4	<1
Lead	1.0 – 7.0	1.0 – 6033	1.0
Benzene	ND	<5	<5
Trichloroethylene	ND	<5	<5
Perchloroethylene	ND	<5	<5
Trichloroethane	ND	<5	<5
Tetrachloroethane	ND	<5	<5
Benzo[b]fluoranthene	<5	6	<5
Benzo[k]fluoranthene	<5	<5	<6
Benzo[a]pyrene	<5	<5	<5
PCBs	ND	ND	ND

Source: Brinkman, D.W. and B.J. Parry, Energy Policy and Conservation, 1975

ND: Not detected
HF: Hydraulic fluids, MWF: Metalworking fluids, E/O: Engine oils)

1.6 Legislation, Regulations and Statutes

1.6.1 Need for Regulations and Legislation

Legislation and regulations constitute an important part of the management of waste oils. Individual countries may design their own statutes in accordance with local needs, not withstanding the fact that the environmental impact of waste oils is a global and trans-boundary issue.

In designing appropriate regulations, it may be advisable to refer to some regulations and guidelines designed by various state and country agencies such as “A Guidebook for Implementing Curbside and Drop-off Used Motor Oil Collection Programs,” written by the Washington Citizens for Recycling Foundation, February 1992,[30] “A manual for community

[30] Environmental Improvement and Energy Resources Authority. Published by the MU Extension Household Hazardous Waste Project in cooperation with EIERA. WM6010, October 1994

used oil recycling programs of the Pennsylvania (USA) Energy Office,[31] or in the case of Australia, guidelines used by Transpacific,[32] one of the largest waste oil collectors, which reprocesses waste oil collected from thousands of clients. They operate under an externally certified Integrated Management System meeting the requirements of key Australian standards for quality, environment and occupational health and safety.

In Europe, ATIEL is a body whose membership consists of various world-renowned lubricant manufacturers, namely BPCastrol, CEPSA lubricantes, Chevron, Eni, ExxonMobil, Fuchs, GALP, Kuwait Petroleum, Lotos Oil, LUKOIL, Neste Oil, ORLEN OIL, PETRONAS, REPSOL, Shell, SK Lubricants, Statoil Lubricants, Total, UEIL (Union Indépendante de l'Industrie Européenne des Lubrifiants) and Valvoline.

Legislation relating to lubricating oils has been reviewed at the European level and also within individual member states. This section examines existing legislation and the background to current developments, drawing heavily on the findings compiled in a 2009 report by the ATIEL Used Oil Technical Committee.[33]

Used oil is a field where management systems and legislation continue to evolve but also where it is possible for lubricant marketers in one member state to learn from those in another in terms of best practice. ATIEL members should remain aware of developments in legislation regarding used oil and comply with legislation.[34]

1.6.2 European Used Oil Policy and Legislation

A review of European legislation relating to used oils is available on the website of the European Commission. Specifically, it states:

> Waste oils are governed by Waste Framework Directive 2008/98/EC, especially by Article 21, which stipulates that Member States shall take necessary measures to ensure that
>
> (a) Waste oils are collected separately, where this is technically feasible;
>
> (b) Waste oils are treated in accordance with Articles 4 (waste hierarchy) and 13 (protection of the environment and human health);
>
> (c) Where this is technically feasible and economically viable, waste oils of different characteristics are not mixed and waste oils are not mixed with other kinds of waste or substances, if such mixing impedes their treatment.
>
> Thus, it is crucial to collect as much as possible this very valuable resource, in order to avoid the contamination of the environment and to be able to profit from the very high recovery potential of this waste stream. Industries, consumers, garages and do-it-yourselfers have to participate, by not dumping these precious liquids but by handing them to authorised collectors that will ensure their adequate recovery.[35]

[31] The Pennsylvania Energy Office, www.portal.state.pa.us

[32] http://www.transpacific.com.au/content/waste-oil-collection.aspx

[33] Report of the ATIEL Used Oil Technical Committee, 16 March 2009

[34] Section 8 of the report contains a statement of the ATIEL position.

[35] http://ec.europa.eu/environment/waste/oil_index.htm

The main EU documents addressing used oil issues are the Waste Framework Directive (WFD), which was preceded by the Waste Oil Directive (WOD), the Waste Incineration Directive (WID) and the European Waste Catalogue (EWC).

The 2009 report of the ATIEL Used Oil Technical Committee referenced above overviewed several EU directives, stating as follows in sections 1.6.3 through 1.6.6:

1.6.3 Waste Oil Directive (WOD) 75/439/EEC[36]

The Directive requires member states ensure the safe collection and disposal of used oil. It gives priority to disposal by regeneration where technical, economic and organisational constraints allow and contains clauses relating to permitting, record keeping and mixing with PCBs and other toxic substances. WOD pre-dates the Waste Framework Directive.

1.6.4 Waste Incineration Directive[37]

This directive came into force 28 December 2005 and poses limits on atmospheric emissions from burning of waste. It applies to co-incineration plants such as cement kilns as well as dedicated incinerators.
To help in the development of policy concerning used oil the European Commission commissioned a review of existing environmental impact studies which was published in 2001. The Commission produced a strategy document, the "Thematic Strategy on Prevention and Recycling of Waste" in 2005 aimed at reducing waste and seeking to improve the use of waste materials. This report applied life cycle thinking to used oil disposal and concluded that "priority to regeneration of waste oils over use as fuel is not justified by any clear advantage." A further conclusion was that collection rates are too low.

1.6.5 Hazardous Waste Directive 91/689/EEC

This Directive places requirements on the management of used oils ensuring controlled consignments of hazardous wastes.

1.6.6 European Waste Catalogue (EWC 2002)

The European Commission has developed a classification system for waste which is based on the EWC, issued in annex to Commission Decision 2000/532/EC as amended by 2001/119/EEC. The EWC consists of 20 chapters, each dealing with a different industry sector. Materials which are hazardous wastes are defined within the EWC. Used oils are listed in section 13 of the catalogue.

[36] Waste Oil Directive (WOD) 75/439/EEC amended by 87/101/EEC

[37] Waste Incineration Directive (WID) 2000/76/EC

1.6.7 Used Oil Disposal in Europe

Management systems for used oil collection and disposal vary from one country to another. This variation is illustrated by some examples as follows.

1.6.8 A Selection of Individual European Member Country Provisions

1.6.8.1 Italy

The 2009 ATIEL Used Oil Technical Committee report overviewed the Italian system as follows:

> The Italian system is of particular interest as much quantitative data are available and a high degree of material recycling to base oil is promoted. There are five active lubricant re-refining plants in Italy, with a combined nameplate capacity of about 260 ktpa.
> The Waste Oil Directive is adopted in Italian law as DPR 691/82, under which a non-profit Consortium (COOU: Il Consorzio Obbligatorio degli Oli Usati) was established. The Consortium is responsible for the collection, selection, quality control and appropriate disposal of used oils – by re-refining, combustion or incineration. A further role is in providing information on appropriate used oil disposal.
>
> An incentive for recycling comes in the form of reduced excise duty. In Italy, re-refined product pays 50% of the excise duty applied to virgin lubricant. This tax advantage is granted only if the used oils for re-refining are collected in Italy. The European Commission believes that this discriminates against re-refined base oil manufactured from used oils collected in other EU countries and thus infringes Article 90 of the EC Treaty. The Commission has requested Italy to cease application of the ruling concerning used oil from outside of Italy.

1.6.8.2 Portugal

The report then discusses Portugal, saying:

> The lubricants market in Portugal is 100 ktpa. Portuguese law 153/2003 established a new company 'Sogilub' to manage used oil collection and disposal. A new system was introduced from 01.11.05 in which lubricant manufacturers and importers pay a levy of €63/m^3, based on the volume of lubricant sales, to fund the used oil management system. A target was established to collect 30 ktpa in 2003.

1.6.8.3 France

ATIEL assesses the French system as follows:

> A summary of the French system was published by ADEME (Agence de l'Environnement et de la Maîtrise de l'Energie [Agency for Environment and Energy Management])[38] in 2004. France a tax is levied on sale of finished lubricants, except those which generate no recoverable waste (e.g. two stroke oils, white oils, soluble metalworking fluids, mould release oils and base oils).

ADEME is a public industrial and commercial organisation under the joint supervision of the Ministries for Ecology, Sustainable Development, Transportation and Housing, of Higher Education and Research and the Economy, Finance and Industry. Under its mission objective, ADEME works toward the implementation of public policies in the areas of environment, energy and sustainable development. To enable progress in undertaking environmental approaches, the Agency provides its expertise and advice to both private and public sector entities as well as to the general public.

The ATIEL report continues by stating:

> Subsidies to collectors are managed by the French Environment Agency ADEME, with a committee responsible for setting the level of subsidy. The subsidy to collectors [depends] on the price paid to collectors by their customers.
>
> Disposal is through use as fuel in approved installations such as cement kilns.
>
> In 2006 the French government reviewed its policy with regards to use of oil and was keen to further promote material recycling of used oil into materials which can only be manufactured from hydrocarbons. This seems likely to include further re-refining and increased emphasis on use as feedstock for conventional refineries, producing either fuel or lubricant base oil.

1.6.8.4 Spain

ATIEL continues, stating:

> Royal Decree 679/2006 came into force in Spain in June 2006, requiring lubricant manufacturers to establish a non-profit organisation (Sistema integrado de gestión de aceites usados [SIGAUS]) to handle used oil collection and disposal. Each marketer is required to pay SIGAUS to collect used oil in proportion to the amount of lubricant sold.

Spanish oil and gas company Repsol states on its website:

> As is permitted by law, the disposal of the waste oil is carried out by SIGAUS, which has been in operation since January 2007. Since its creation, SIGAUS has been responsible for the collection and subsequent treatment of used oil in the whole of Spain, resulting from industrial use as well as vehicles.

[38] http://www2.ademe.fr/servlet/KBaseShow?sort=-1&cid=96&m=3&catid=13089

SIGAUS is financed through fees paid by participating manufacturers in respect of the oil that they place on the national market: €0.06 per kilogram of marketed oil, which the manufacturer passes on to the consumer.

SIGAUS also has a commitment to finance the economic deficits declared by companies undertaking the collection and recovery of used oil and which have reached respective agreements with SIGAUS.[39]

The ATIEL report continues its overview of the Spanish system, and then of the overall situation in the EU, by stating:

The legislation sets recycling milestones:

Re-refining yields must exceed 50% and must be greater than 55% by 1 January 2008.

95% of used oil must be collected by 1 January 2006 and value must be recovered from all of the oil collected.

The quantity of used oil employed as feedstock for re-refining is required to increase from 55% in 2007 to 65% in 2008.

The non-profit organisation is also charged with conducting campaigns of public awareness and education with regard to used oil handling and disposal.

The differences between the systems adopted by each country demonstrate opportunity to develop different approaches within the framework established by Brussels.

The issues of the application of the waste hierarchy to used oil and the priority to regeneration have been discussed by the ATIEL Used Oil Technical Committee. Some members note the priority of regeneration in the WOD and cite certain life cycle assessment studies describing environmental benefits for re-refining compared with use as fuel (IFEU study). Other members cite other life cycle assessment studies (e.g. Sofres) which do not reach such a clear conclusion and argue that environmental benefits accrue from increased collection rates offered when disposal routes are less constrained. They cite the technical, economic and organisational constraints referred to by the WOD, the conclusions of the EC Thematic Strategy report and a CO_2 balance favouring use as fuel over other disposal routes (Europia report).

Legislation will emphasise the separate collection of used oils and Member States will have an option to create barriers to cross-frontier shipment of used oil destined for use as fuel to help protect established re-refining industries….

Hence, the direction of future European legislation continues to be uncertain but will turn on revision of the waste framework directive in

39 http://www.repsol.com/es_en/productos_y_servicios/productos/lubricantes/documentacion_y_publicaciones/gestion_del_aceite_usado/default.aspx

> Brussels, outcomes of end to waste debate focussed in the UK as well as further initiatives above the requirements of Brussels in individual Member States.
>
> Apart from ATIEL, organisations which have a voice in the used oil debate are Europia (crude oil refiners), GEIR (used oil re-refiners), organisations which collect used oil, those which manufacture fuels from used oil and also the trade bodies representing industries which have historically employed the material as fuel.

MobilOil has joined hands with earth911.com to facilitate a used oil collection programme. The site www.earth911.com contains a comprehensive list of used oil recyclers and collection centers across the USA and Canada.

1.6.8.5 The United Kingdom

Pollution Prevention Guidelines[40]

A publication compiled by the Environmental Alliance of the Environment Agency for England and Wales, the Scottish Environmental Protection Agency, and Environment and Heritage Service (predecessor to the Northern Ireland Environment Agency) in February 2004 overviewed pollution prevention guidelines focusing on the safe storage and disposal of used oils as follows:

> These guidelines are intended to help everyone that handles used oils – from people carrying out a single engine oil change to large industrial users. They are jointly produced by the Environment Agency for England and Wales, the Scottish Environment Protection Agency and the Environment and Heritage Service in Northern Ireland. Compliance with these guidelines will help to reduce the risk of oil pollution of surface waters, groundwater, sewers and drains.
>
> Many sites where waste oil is stored are regulated under the Pollution Prevention and Control Regulations, collectively described in this guidance as the PPC Regulations, and the Waste Management Licensing Regulations. These Regulations cover the storage of waste mineral oils and are intended to protect the whole environment.
>
> In England, the storage of waste oils (except waste mineral-based oils) is covered by the Control of Pollution (Oil Storage) (England) Regulations 2001. These regulations are made under the Water Resources Act 1991 and are intended to protect the water environment.

Engine Oil

The publication continues, stating:

> Used oils such as engine and gear box oil from vehicle or machine maintenance [must be taken] to an oil bank for recycling. Oil banks can be found at most civic amenity sites[41].

[40] Environment Agency, Scottish Environment Protection Agency and the Environment and Heritage Service (2004) PPG08: Safe Storage and Disposal of Used Oils, http://publications.environment-agency.gov.uk/pdf/PMHO0304BHXB-e-e.pdf

[41] www.oilbankline.org.uk

The Special Waste Regulations are due to be replaced to fully implement the Hazardous Waste Directive (91/689/EEC) in the UK. This, amongst other things, extends the range of wastes defined as hazardous.

The NetRegs website[42] provides such information.

The following sections on disposing of domestic used oils and commercial and industrial used oil are also taken from the publication, which states:

Disposing of Domestic Used Oil

a. Engine Oil

[People should] take these oils to an oil bank for recycling. Oil banks[43] can be found at most civic amenity sites. For the location of one's nearest oil bank, the public can contact the Oil Bank Helpline on free phone. Alternatively, [they can] contact their local authority recycling officer. [They should] not mix used oil with other substances such as white spirit, paint or solvents, as this makes recycling extremely difficult.

Disposing of Commercial and Industrial Used Oil

Used mineral oil from commercial and industrial sources [are] classified as hazardous waste and may also be special waste under the Special Waste Regulations, [44] which impose additional specific legal requirements for its movement, recovery and disposal. Further guidance is given in "A guide to the Special Waste Regulations" 1996. [45] […]

The new definition of hazardous waste already applies to certain legislation including the Duty of Care, [46] the Landfill Regulations[47] and the PPC Regulations. For the Duty of Care, any waste must additionally be described in a transfer note by reference to the appropriate code or category in the European Waste Catalogue.

[The generators can] seek advice on the management of oil waste and wastes containing oils from specialist contractors or from [the] local Agency office.[48]

a. Industrial Oil

Larger quantities of used oil such as hydraulic fluid or lubricants from lorries, buses or mechanical plant should be stored securely to await collection by a registered waste carrier. There are specialist companies that will collect used cutting oils, and then treat and recover the oil.

b. Garages and Workshops

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[42] www.netregs.co.uk
[43] www.oilbankline.org.uk
[44] Waste Management Licensing Regulations 1994 (applies to England, Wales and Scotland)
[45] Waste Management Licensing Regulations (Northern Ireland) 2003
[46] Waste Management, the Duty of Care, a code of practice (revised 1996). ISBN 0-11-753210X
[47] www.defra.gov.uk/environment/waste/management/doc/)
[48] www.netregs.co.uk

This oil can be collected by a registered waste carrier or, as an alternative in England and Wales, it may be feasible to use it as a fuel for space heating. This will require adequate storage to balance the supply with seasonal demands and will require an appropriate burner. Such installations require authorisation from the local authority. Further information on handling wastes from garages is given in PPG19.[49]

c. Transformers

Electrical transformers may use specialist oil [and] used transformer oil is a hazardous waste… likely to contain PCBs. This is likely to be classified as special waste and will require a consignment note for its movement.

Waste Oil Storage and Pipelines

In all cases, care must be taken to avoid spillage when transferring waste oil to storage facilities. Any spills should be dealt with using absorbent materials. The Agencies recommend that waste oil tanks and pipework are installed above ground whenever possible. This enables regular maintenance checks to be carried out more easily and leaks to be identified earlier.

Detailed specifications have been developed for the following fours types of facilities.

a. Above-ground storage
b. Removal of bund waste
c. Underground tanks and pipes
d. Oily water waste

Details for the same can be referred from PPG2[50] PPG26[51] and information in England and Wales.[52]

1.6.9 Australia

The Department of Sustainability, Environment, Water, Population and Communities overviews its waste oil-related initiatives as follows.[53]

The Product Stewardship for Oil Program (PSO) was introduced by the Australian Government in 2001 to provide incentives to increase used oil recycling. The Program, administered by the Department of the Environment, Water, Heritage and the Arts, aims to encourage the environmentally sustainable management and re-refining of used oil and its re-use.

The Product Stewardship (Oil) Act 2000 establishes the general framework and benefit entitlements of the PSO arrangements. The arrangements comprise a levy-benefit system, where a 5.449 cent per litre

[49] Special Waste Regulations 1996 (as amended) (applies to England, Wales and Scotland)
[50] Special Waste Regulations (Northern Ireland) 1998
[51] Special Waste Regulations (Northern Ireland) 1998
[52] A guide to the Special Waste Regulations 1996
[53] http://www.environment.gov.au/settlements/waste/oilrecycling/index.html

levy on new oil, helps fund benefit payments to used oil recyclers. These arrangements provide incentives to increase used oil recycling in the Australian community.

There are 3 parts to the arrangements:

Product Stewardship levy

Product Stewardship benefits

Transitional Assistance funding

1.6.10 Japan

Although primarily applied to waste cooking oils, the system adopted in certain locations in Japan could be modified to a suitable and appropriate system for the collection of waste oils in general. The bus services provided by the organized sector can be used for collection of the waste petroleum-based oils.

Local governments can cooperate with local residents' associations, gas stations, community councils, and companies to involve citizens. The system can work in such a way that citizens or small generators of waste oil collect the oil in a standardized or typically-found bottle or container (supplied by the authorities) to be handed over to a bus driver when boarding the bus. In return they may receive an "eco-friendly" voucher which can be used as a fare ticket, with a value in proportion to the quantity of waste oil they deliver.

In September 2009, the city of Higashiomi launched a used cooking oil collection service for residents using its municipal "Chokotto" transit buses (*chokotto* bus means "quick bus ride" in Japanese). To carry out the project, the city began cooperating with the local residents' association, gas stations, community councils and companies. So far, it has collected 32,000 liters of used cooking oil, which represents 32 percent of all household-derived waste cooking oil in the city.

To recover used oil most efficiently, the focus of the bus-collection service is to promote citizen involvement. For residents, the system works like this: first, they peel off the labels from an empty clear plastic cooking oil bottle and rinse it; next, they fill it with their used cooking oil. Finally, they pass the full bottle to the bus driver when they get on the bus, and in return they receive a Chokotto Bus "Eco-Tomo" (which means "eco-friendly") voucher to use as a fare ticket worth 100 yen (about U.S.$1.10) on their next bus trip.

Excerpted from the article, "NPO Has Integrated Approach to Create Sustainable Community in Higashiomi"

1.6.11 Singapore

In its information paper entitled, "Management of Toxic Industrial Wastes in Singapore," the National Environment Agency of Singapore lays out the following with regard to its management of toxic industrial wastes.[54]

The key elements in Singapore's strategy to control toxic industrial wastes and ensure their safe treatment and disposal are as follows:

(i) Avoid generation of intractable wastes;

(ii) Encourage waste minimisation;

(iii) Encourage waste reuse, recovery and recycling;

(iv) Regulate collection, treatment and disposal;

(v) Monitor and audit collection, treatment and disposal; and

(vi) Promote and support educational and training programmes.

[54] National Environent Agency of Singapore, n.d. Management of Toxic Industrial Wastes in Singapore. app2.nea.gov.sg/data/cmsresource/20090316748986342293.pdf

All new industrial developments are screened by the Pollution Control Department (PCD) at the planning stage. One of the key areas checked in this screening process is the generation and disposal of wastes from proposed industrial developments. PCD approves the proposed industrial development only if the wastes generated could be safely disposed of in Singapore. This avoids the generation of intractable wastes that cannot be safely disposed of in Singapore.

In addition, PCD requires industries to use processes that minimise waste generation or facilitates the reuse, recovery and recycling of the wastes. Industries also need to incorporate measures into the design of their facilities to ensure wastes generated can be properly handled and managed.

The collection, recycling, treatment and disposal of toxic industrial wastes are controlled under the Environmental Public Health Act (EPHA) and the Environmental Public Health (Toxic Industrial Waste) Regulations (TIWR). In order to facilitate controls and proper management, the functions and responsibilities of key persons involved in handling of the toxic industrial wastes are clearly delineated in the TIWR. The key persons include the following:

(a) Generator of wastes
(b) Collector
(c) Carrier or transporter
(d) Driver

The responsibilities of the following key persons in the transportation are clearly defined in the TIWR:

(a) Consignor: the person who presents a consignment of controlled wastes for transport. The consignor can be either the generator or the licensed collector. Transport approval shall be obtained from PCD to transport the wastes.
(b) Carrier: the person who undertakes the transport of the controlled wastes. He can either be the generator, the licensed collector or the transport company engaged by either one of them.
(c) Consignee: the person who receives the controlled wastes. He is usually the licensed collector.
(d) Driver: the driver of the vehicle transporting the toxic industrial wastes.

To prevent illegal dumping and disposal of toxic industrial wastes, the movement of every consignment of wastes from a generator through a carrier to a collector is tracked by means of an Internet-based electronic submission of consignment note system (known as the e-Tracking System).

Monthly checks are conducted on premises of toxic industrial waste collectors and the records are audited to ensure requirements on collection, storage, treatment and disposal of toxic wastes are complied with.

Conclusion

While individual member countries and states may design their own legislative frameworks and regulations regarding the handling of waste oils, it is of the utmost importance that local legislations and regulations do not interfere with the neighbouring countries' environment or ecology. Polluted water does not know any geopolitical boundaries. A sense of mutuality of purpose needs to be considered as the foundation on which the edifice of waste oil issues stands.

1.7 Waste Oil Management Practices

1.7.1 Waste Oil Management Programs

Various countries have designed their own systems for management of waste oils. The salient features and action points of such efforts in selected countries are depicted in Table 1.7.1.[55]

Table 1.7.1: Features of waste oil management programs in various countries

Country	Features of the waste oil management program
France	78% collection of used oils; government-funded programs and fees are imposed on virgin lubes producers; 42% of used oil is re-refined by government directed re-refining associations.
Germany	94% recovered; high level of consumer interest in recycling, all used oils treated as hazardous waste; all oil marketers must provide collection facility near the retail establishment; retailers pay for used oil pick up; 41% of used motor oils are re-refined, 35% burned in cement kilns, and 24% processed and burned in other applications; recovering 48% of total lube oils sold.
Japan	No national level recycling program; no subsidies/funding; essentially no DIY market in Japan; high percentage of used motor oil is recovered, treated, and burned for heating value; re-refining is very limited.
Italy	Mandated use of re-refined oils in motor oils; six operating re-refining plants; funded by lube oil sales taxes; collectors and re-refiners both subsidised; only 10% of used oil can be directed to cement kilns. The collection efficiency of used oil has increased from 42.6% in 2008 to 48.7% in 2009.[56] An incentive for recycling comes in the form of reduced excise duty. In Italy, re-refined product pays 50% of the excise duty applied to virgin lubricant. This tax advantage is granted only if the used oils for re-refining are collected in Italy. The EC has requested Italy to cease application of the ruling concerning used oil from outside of Italy.[57] Also, it was estimated that the quantity of used oil collected by the COOU consortium is steadily over 95% of the collectible oil.
Australia	High subsidies for re-refining, low subsidies for low grade burning oils; none for reclaimed industrial oils; collecting 81% of available oil; $10M Australian funded by government to subsidise recycling; revising re-refining incentive downward; collecting 38% of total lube sold.

[55] U.S. Department of Energy, Used oil re-refining study to address energy policy act of 2005 (Office of Oil and Natural Gas, Office of Fossil Energy, July 2006

[56] Giovanna, F.D.: Lubricants Recycling – A Case Study: How Italy Managed to Become an Excellence and an Example for the Other EU's Member States: B. Bilitewski et al. (eds.), Global Risk-Based Management of Chemical Additives I: Production, Usage and Environmental Occurrence, Hdb Env Chem, DOI 10.1007/698_2011_100, # Springer-Verlag Berlin Heidelberg, 2011

[57] Report of the ATIEL Used Oil Technical Committee, 16 March 2009

Canada (Alberta)	Focus on increasing collections; little emphasis on avoiding contamination; little emphasis on re-refining; funded by sales tax; recovering 51% of total lube oil sold.
United States	The United States has implemented a broad range of recycling programs; some states impose sales taxes to subsidise collections; some states classify used oil as hazardous waste to discourage illegal dumping; some local municipalities fund collection activities; signs of quick lube facilities growth which has produced positive results by reducing oil improperly disposed of by DIY oil changers; small re-refining industry; disposition of used oil as a fuel encouraged. The United States has no central coordinating body that focuses on used oil management similar to Europe, therefore industry statistics are not readily available. The U.S. does have a mandatory federal policy requiring the preferential purchase of re-refined oil and does promote the source reduction and recycling of materials over their treatment (including burning as a fuel) and disposal under the Resource Conservation and Recovery Act and the Pollution Prevention Act.
India	The Ministry of Environment and Forests (MoEF), GOI has licensed about 170 small to medium recyclers (352 MT per annum to 26,460 MT per annum) with a total licensed capacity of about 0.69 MMT of used and waste oil recycling capacity.

Source: Based primarily on Used oil re-refining study (U.S. Department of Energy, July 2006)

Observations on Worldwide Waste Oil Programs

Used oil management programs have evolved in various forms in different countries and no standard or best practices exist. Overall, it appears that burning waste oil is the most prevalent practice, although the re-refining of waste oils is slowly increasing.

1.7.2 Recent Trends and Developments

In the overview of its 2007 industry study forecasting up to 2015, the Freedonia Group stated:

> The prevailing global trend is toward reducing the amount of lubricant consumption, both for environmental reasons as well as cost-effectiveness purposes. Thus, in developed regions such as North America and Western Europe, increasing standards for lubricants will result in significantly improved quality, decreasing the volume of lubricant needed for a particular application. Lubricant quality will also improve in developing regions, as outdated motor vehicles and machinery are replaced with products that require smaller amounts of better-performing lubricants.[58]

Meanwhile, bio-based lubricants and re-refined base-stocks are likely to experience greater demand because of environmental factors.

Also, in the automobile sector, the transmission fluid changing frequency ranges between 20,000 km to 45,000 km depending on the individual designs, makes and models. With engine design ever changing, efficiencies are on the increase. With the development of the use of higher grade of lube oils, the consumption frequency also is decreasing. These figures can be anywhere between 100,000 to 160,000 km, depending upon the make of the

[58] Freedonia Group, April 2007. World Lubricants: Industry Study with Forecasts for 2010 and 2015. www.freedoniagroup.com/brochure/21xx/2182smwe.pdf

vehicles. Unlike engine oil, transmission oil doesn't burn up. So if the oil levels fall, it is only because of leaks, which cannot be easily collected.[59]

The other side of the picture is that during the year 2009, the total worldwide production of cars stood at 47,772,598, which then grew by about 22.4% in 2010 to reach a production level of 58,478,810.[60] In light of this trend, despite the advancements referred above, the additional expected demand for automotive lubricating oils may well increase in the future, resulting in the increased generation of waste oils.

1.8 Collection and Storage of Waste Oils

Collection and storage of waste oils and treatment of hazardous waste from the process residues are important issues for environmentally sound management.

As has already been mentioned earlier in the compendium, the estimated global collection of waste oils is only on the order of about 33% (about 15 MMT) of the total estimated production of virgin lubricants (about 45 MMT).

It can be seen that not all generated waste oil is put to recycling. This also means that a major portion of such oil is disposed of in environmentally unsound ways.

Collection of waste oils can be a daunting task as generation points are often widely distributed and there may not be an expressed economic viability. Moreover, the necessary infrastructure may not exist and there may not be a ready market for waste oil.

1.8.1 Major Entities Involved

In its online used oil management resource for small businesses, the US EPA overviews the areas laid out in sections 1.8.1.1 through 1.8.1.6 below.[61]

1.8.1.1 Generators of Used Oils

These are entities which generate waste oils through commercial or industrial operations or from the manufacturing or maintenance of vehicles and equipment. These generators range from large-scale institutional level to tiny repair shops. The main categories of waste oil generators are described below. Examples of common generators are car repair shops, service stations, quick lube shops, motor pools, department stores, metal working industries, boat marinas etc.

1.8.1.2 Collection Centers and Aggregation Points

This category is representative of agencies that collect used oil from smaller generators and store it and transport it to a recycling/disposal facility. Collection centers typically accept used oil from multiple sources that include both businesses and individuals. Aggregation points collect oil only from places run by the same owner or operator and from individuals.

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[59] Cars.com, Transmission Fluid, http://cars.cartalk.com/content/advice/transmissionfluid.html, 18.07.2011

[60] OICA, OICA correspondents survey, World Motor Vehicle Production By Country And Type, http://www.oica.net/category/production-statistics for the years 2009 and 2010, accessed 18.07.2011

[61] Based on US EPA, n.d. Managing Used Oil: Advice for Small Businesses. www.epa.gov/osw/conserve/materials/usedoil/usedoil.htm

1.8.1.3 Transporters

This category includes companies that pick up used oil from all sources and transport it to re-refiners, processors, or burners. These also include intermediate transfer facilities, like loading docks and parking areas.

1.8.1.4 Re-refiners and Processors

This category consists of facilities that blend or remove impurities from used oil so that it can be burned for energy recovery or reused. It includes re-refiners who process used oil so that it can be reused in a new product such as a lubricant and recycled again and again.

1.8.1.5 Burners (Those who use waste oils as fuel)

The burners cover all those businesses who burn used oil for energy recovery in boilers, industrial furnaces, or in hazardous waste incinerators.

1.8.1.6 Marketers (Those who trade in waste oils)

They are handlers who either directly ship used oil to be burned as fuel in regulated devices or sometimes even in unregulated devices. They also sometimes help move shipments of used oil to burners.

1.8.2 Challenges and Ways to Collect Used Oils

Considering the very thinly distributed and scattered way in which used oils are generated globally, an effective supply chain system needs to be put in place.
The generation points of waste oils can be broadly categorised in two ways.

1.8.2.1 Bulk Generators

These are points where large quantities of waste oils are generated. The entities that fall under this category may be identified as the centralised and company operated or authorised service stations, defense establishment entities (garrison workshops), state owned transport corporations, electricity utilities (especially the power distribution companies), sea and airports, railways maintenance workshops etc. Insofar as most of the periodic maintenance of the vehicles and equipment is carried out at a central location, a large portion of vehicles and equipment comes to such central places, enabling the accumulation of waste oils at these points. At such points it is much easier to collect and segregate at source various types of waste oils.

1.8.2.2 Small Generators

These are points where smaller quantities of waste oils are generated on a daily basis. The generated oils at such points are generally mixed up, forming multi-grade waste oils. The generated quantities are small and may not offer any explicit economic advantage or incentive for collection or safe handling. It is this sector that needs the utmost care and concerted state supported efforts to collect and consolidate waste oil in a central place. Well-designed incentive schemes must be put in place to ensure that such oils find their rightful place in recycling businesses.

One way could be to adopt a multi-layered collection system in which micro level generators are incentivised to store their waste oils in proper storage containers, with these then collected periodically by vendors of the recyclers. Depending upon the geographical distribution, such oils can be transferred to a central processing facility in two to five stages.

The following figures depict such a system conceptually.

Figure 1.8.2.2.a depicts the cycle of generation and collection.

Figure 1.8.2.2.b depicts the stage by stage collection layers to transfer the waste oil to the central collection system.

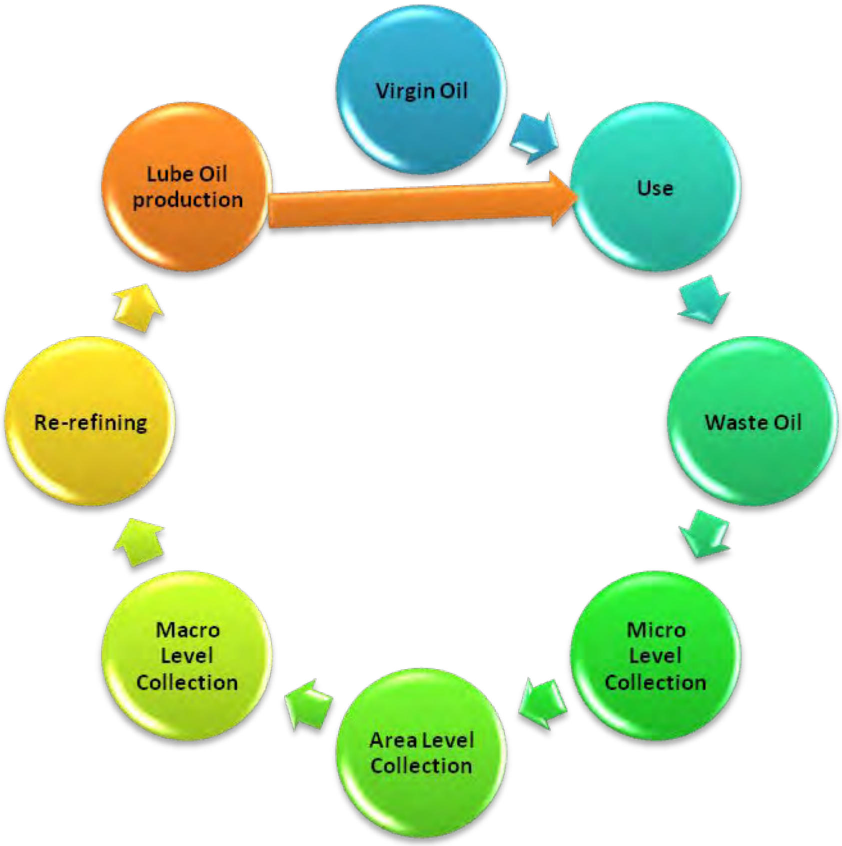


Figure 1.8.2.2.a: Waste oil generation, collection and re-refining cycle

Figure 1.8.2.2.b: Multi-layered collection system for waste oils

Sections 1.8.2.3 through 1.8.2.4.1 overview more of the online advice given to small businesses by the US EPA.[62]

1.8.2.3 Record Keeping

As these oils are classified as hazardous materials, they need to be handled under controlled conditions. Such conditions are essential to ensure human safety and avoid environmental mishaps. A system similar to that of the EPA may be adopted with appropriate modifications to suit local geopolitical conditions. The EPA has developed 12-digit identification (ID) numbers to track used oil. Transporters hauling used oil must have a valid license and ID number, and generators, collection centers, and aggregation points must use only such transporters for shipping used oil off site. Individual countries may develop their own norms for qualifying entities to be covered under such regulations. For example, the EPA has specified that generators, collection centers, aggregation points, and any handler that transports used oil in shipments of less than about 200 liters (55 US gallons) do not need an ID number, but may need a state or local permit.
Used oil transporters, processors, burners, and marketers also must record each acceptance and delivery of used oil shipments. Records can take the form of a log, invoice, or other shipping document and must be maintained for a specified amount of time (the EPA standards adopt a three years period for such records).

[62] Based on US EPA, n.d. Managing Used Oil: Advice for Small Businesses. www.epa.gov/osw/conserve/materials/usedoil/usedoil.htm

1.8.2.4 Safety Precautions for Waste Oil Storage Facilities

Re-refiners, processors, transfer facilities, and burners must have secondary containment systems (e.g. oil-impervious dike, berm, or retaining wall and a floor) so that oil cannot reach the environment in the event of a leak or spill. The EPA also encourages generators to use a secondary containment system to prevent used oil from contaminating the environment. The handlers of used oils must be aware of the local regulations governing the management of used oil, which might at times be even stricter than those specified by the national regulations. They must abide by the local regulations and thus determine the best and most suitable course of action.

1.8.2.4.1 Mixing Used Oil and Hazardous Waste

In addition to such used oil management standards, the oil handlers (both the generators and users) may be required to comply with federal and state hazardous waste regulations if the used oil, which may be recyclable, becomes contaminated from mixing it with hazardous waste. The only way to be sure the used oil does not get contaminated with hazardous waste is to store it separately from all solvents and chemicals and not to mix it with anything.

1.8.2.4.2 Containment Devices for Catching Drips and Leaks Effectively

The process of waste oil collection will necessarily require equipment, such as collection and containment vessels, that enable effective spill control response while also catching leaks. Such equipment includes:

- Mobile drum containers
- Portable tanks for waste oil collection
- Containment tanks for oil spills
- Waste oil collection pans

Entities responsible for collection must be knowledgeable about local regulations governing waste oil collection, transportation and disposal.

1.8.3 Recommended Procedures for Collection Centres

Collection centres may keep log books as one aspect of their tracking mechanism. The centres may require waste oil generators to record not only the amount of oil deposited but also identifying information (e.g. name, address) and a signature.

While visual inspection and scanning for the quality of used oil can be done, the use of a halogen detector to scan incoming oil is suggested in order to help minimise the potential for contamination of the collection tank. Halogen detectors are hand-held equipment that use fumes to detect pesticides, solvents and other hazardous substances containing halogens. Staff at these centres should be provided nitrile gloves, chemical splash goggles and other such protective clothing to prevent contact with the skin and the eyes.

When accepting incoming waste oil, the centres use a wire mesh to strain out foreign particles as the oil is being drained into the collection tank. The storage tanks may be targeted for dumping and should therefore be kept locked and secured when not being supervised. The collection/storage tanks must be periodically checked and inspected.

Should there be minor spills, non-biodegradable absorbents must be used. The need for a non-biodegradable absorbent is emphasised as any biodegradable absorbent will be dissolved in nature leaving the hazardous absorbed contents to leach and pollute the environment. The non-biodegradable absorbent will ensure that the absorbed ingredients remain contained in it, which will facilitate safer handling and further treatment in a semi-solid form.

The collecting entity may be liable in the event that any collected used oil is disposed of improperly. The collection agency must therefore ensure that the oil is removed by an authorised agency or licensed transporter and taken for disposal to a reputable recycler or other such disposal facility. The collecting entity should confirm that the selected used oil transporter:

- Has valid licenses and operates in a safe and environmentally sound fashion;
- Maintains regular records of the quantities of used oil that are collected, delivered and handled;
- Delivers used oil to reputable management facilities.
- Guarantees coverage of any accidents that may occur in transportation; and
- Signs a contract with the collection agency that describes how the transporter will meet the above terms.[63]

The individual countries must have a system and details of such authorised/licensed transporters to haul used oil and also a list of approved facilities that re-process, re-refine or burn used oil for energy recovery. The state/country may also have a system in place to check a company's compliance history.

1.9 Generation Factors for Different Types of Waste Oils

A diverse multitude of facilities generates a variety of waste oils. Although in principle it may be possible to collect the total amount of waste oils generated, as a point of fact not all generated waste oils are collected effectively. The collection efficiency of waste oils depends on many factors, namely the organisational culture, the control systems and procedures, accountability within the system and most important of all, the realisation that waste oils are in fact a source of revenue and collecting and recycling them has an environmental impact. As has been already said earlier in the compendium, only about one-third of total waste oil is collected for recycling.

Despite a thorough search of the literature, no ready references were found and no literature was available concerning the generation factors for waste oils. In this chapter, an attempt has been made to assess the waste oil generation factors in different sectors. The assessment has been made on the basis of personal discussions with a selected number of agencies like company authorised service stations, roadside garages, utility managers of institutions and power distribution company workshops. The figures also have been corroborated with experienced industry professionals and managers.

In general, low volume waste oils, e.g. gear oils, brake oils etc. are found to be mixed with the larger components of waste oils, such as engine oils and hydraulic fluids.

[63] University of Missouri Extension (October 1994), Setting Up a Used Oil Collection Site, http://extension.missouri.edu/publications/DisplayPrinterFriendlyPub.aspx?P=WM6010

The handling and treatment of waste transformer oils have been found to be much better organised than those for lubricating oils.
In the automotive sector, the manufacturers of automobiles are, by and large, more organised and the systems for accounting for and handling waste oils are streamlined. This approach is extended to company-managed or -certified workshops as well. However, the systems are not so well organised when it comes to unorganised workshops and garages, particularly the smaller ones dealing with smaller numbers of vehicles.

As far as the type of industry or facility is concerned, every industry, irrespective of the nature of its work or products, uses similar kinds of equipment like metal cutting machines, DG sets, compressors, transformers, gear boxes, pumps etc. To that extent, the generation of waste oils from such facilities follows much the same patterns as in the generation of waste oils.

To estimate the generation of waste oils within an entity, it is felt necessary to evolve some 'rule of thumb' norms to assist the entity in estimating the generation of such oils in its domain. It is recommended to evolve such standards for individual industries or entities. However, if, due to certain reasons, this is not feasible, the factors as given in Table 4 may be used. Column 3 in the table provides the percentage of expected generation of waste oils for the source shown in column 1 and for the type of oil given in column 2. Column 4 indicates the collection efficiencies of such oils. It has been observed that generally the generators of waste oils have realised the value of the product and there is an increasing tendency to streamline the collection and recycling of such waste oils. In the future, the collection efficiencies can thus be expected to be much higher, with a figure in excess of 80% a reasonable possibility.

Table 1.9: Generation factors and collection efficiencies of waste oils

Sources of waste oil generation	**Type of waste oil**	**Estimated waste oil generation factor and collection efficiency**		**Remarks**
Type of source (1)	(2)	Waste oil generation factor as a % of use (3)	Collection efficiency in % (4)	(5)
1. Automotive				
a. Manufacturing	a. Engine oils	5.0	90.0	In the automotive manufacturing sector, the generation factor would be very low due to high levels of automation and managerial controls on the shop floor. The collection efficiency would also be very high for the same reasons.
	b. Transmission fluids	5.0	90.0	
	c. Gear box fluids	2.0	90.0	
	d. Brake fluids	20.0	80.0	
	e. Hydraulic fluids	2.0	70.0	
b. Garages/repair shops	a. Engine oils	85.0	60.0	Except for the auto manufacturing company owned or certified garages (which are much fewer in number than unorganised garages and repair shops), the generation factor is higher and the collection efficiency is lower.
	b. Transmission fluids	50.0	50.0	
	c. Gear box fluids	30.0	50.0	
	d. Brake fluids	20.0	15.0	
	e. Hydraulic fluids	80.0	50.0	
2. Industries				
a. Engineering industries	a. Hydraulic oils	20.0	80.0	
	b. Cooling oils	10.0	90.0	

	c. Compressor oils	30.0	90.0	
	d. Gear oils	20.0	15.0	
	e. Bearing and circulating oils	80.0	15.0	
	f. Thermic/heat transfer fluids	90.0	80.0	
	g. Turbine oils	80.0	70.0	
b. Petroleum industries	a. Hydraulic oils	80.0	60.0	
	b. Cooling oils	50.0	30.0	
	c. Compressor oils	30.0	50.0	
	d. Gear oils	20.0	15.0	
	e. Bearing and circulating oils	80.0	15.0	
	f. Thermic/heat transfer fluids	10.0	80.0	
	g. Turbine oils	80.0	70.0	
c. Refrigeration industry	a. Refrigerator compressor oils	20.0	70.0	
d. Other industry	a. Hydraulic oils	10.0	60.0	
	b. Cooling oils	50.0	30.0	
	c. Compressor oils	30.0	50.0	
	d. Gear oils	20.0	15.0	
	e. Bearing and circulating oils	80.0	15.0	
	f. Thermic/heat transfer fluids	10.0	80.0	
	g. Turbine oils	80.0	70.0	
3. Process plants	All of these segments are equivalent with any other industry and use essentially similar equipment, e.g. motors, DG sets, compressors, conveyors, heat exchangers, pumps, metal cutting machines, thermic fluid heating equipment etc. Hence, the waste oil generation factor and the efficiency of collection can be treated as the same as those of other industries.			
a.Cement				
b.Paper				
c.Sugar				
d.Mining				
e.Fertiliser				
Others				
4. Power plants				
5. Marine industry	The nature of the industry or the sector is such that lubricants find a much lower priority in controls. Being an ocean-going operation, it is possible to dispose of the waste oils on the high seas. Hence, while the generation may be normally higher than the average industry, the collection efficiencies would be much lower, most of the waste oil being treated as unaccounted for.			
6. Aviation industry	The safety and maintenance standards of equipment being of a very high order, there is a very low chance that the equipment has any leakages or losses. Being a more organised sector, the collection efficiencies would also normally be much higher than those of others industries. The generation factor may be considered to be greater than that of other industries, as the change frequencies would normally be higher. Over all, the generation factor may be considered to be about 50% and the collection efficiency 90%.			
7. Others	The generation factors need to be judiciously selected, depending upon the specific nature of the organisation and operations.			

1.10 Suggested Methodology for Estimating Waste Oil Generation

1.10.1 Introduction to the Methodology

From the previous discussions it is obvious that the first step in dealing with waste oils in a given area is to develop a complete inventory of waste oil generation, including the sources of generation, quantities of different types of waste oils and their present reuse/disposal methods. If possible, one should also develop projections of waste oil generation into the future, say, over the next 10 to 20 years, so that the measures taken have long-term applicability.

This section outlines a step-by-step methodology of developing data inventory (baseline data). It may be noted that this is only a suggested methodology and is not a prescribed one. It may be used as a general guideline and can be adapted and modified to better suit local circumstances.

1.10.2 Step-by-step Methodology

Step 1: Inventory of Sources

After fixing the boundaries of the selected area (e.g. either at a national level, state level, district level, geographical boundary of a city or an industrial area etc.), the first step is to determine the sources of waste oil generation. Sufficient care must be taken to include all possible sources. Waste oils may be generated from a wide variety of sources such as manufacturing industries (industrial oils), motor garages and repair shops (crankcase oils), repair/installation of transformers (transformer oils), capacitor banks (used for power factor improvement) etc. The size range of different sources and their number should also be determined. Table 1.10.1 could be used as a format for developing such an inventory.

Step 2: Determination of Waste Oil Generation

The next step is to assess the generation of waste oil from the above sources. Inclusion of all possible sources must be ensured. Different types of waste oils are generated from different sources; therefore, it is desirable to prepare an inventory for each type of waste oil. This will facilitate determination of a future course of action, namely, if that type could be recycled or burned as fuel under controlled conditions, or if it has to be disposed of in an environmentally sound manner. In performing this quantification, the best and most reliable methodology would be to carry out actual measurements in a statistically representative population of each category or source and then extrapolate the results to cover the entire population. Such a method presupposes a certain level of uniformity among individual entities in the source-category—an assumption which may not be entirely valid. Other constraints include not only the time and cost, but the availability and deployment of appropriately skilled human resources for carrying out such measurements. An alternative way could be to determine specific waste oil generation factors (WOGF) or waste oil indices (WOI) for different sources. It is suggested that such WOGF or WOI be generated by carrying out actual measurements on a locally applicable and statistically representative basis so as to reflect the local culture, situation and working conditions. In case it is not possible to do so, then, as a last resort, one could use the WOGF or WOI as described in section 1.9, table 1.9. However, when using the default WOGF or WOI, one should keep in mind that these are highly generalised and hence the emanating figures of waste oil generation could, at best, be taken only as indicative figures, and should be further verified before using them for designing relevant facilities and creating the infrastructure.

Table 1.10.2 could be used as a format for quantifying waste oil generation.

Step 3: Assimilation of Data on Waste Oils of Different Types from Different Sources

As different types of waste oils are generated from different sources, it is desirable to prepare an inventory for each type of waste oil. For developing an effective waste oil management system, it is necessary to assess the actual generation of each type of waste oil. This information will be used later to facilitate determining ways to handle them, i.e. whether it could be recycled or burned as fuel under controlled conditions or has to be disposed of in an environmentally sound manner. For example, lubricating oils, whether generated from industrial or automotive sources, can generally be reprocessed and refined to be converted back into lubricating oils, whereas transformer oils will have to be handled differently, as they contain PCBs. Care should be taken to include all sources and all types of oils regarding the information collected above. Table 1.10.3 could be used to record information under this step. A sample of calculations for estimating the generation of automotive waste oils is provided in Box 2.

Box 2: Sample calculations for estimating the generation of crankcase/engine oils in the automotive sector in India

This format could be used as a guideline by individual entities.

Waste oil generation in India

Number of registered motor vehicles in India, estimated (as of 2008)	~ 100,000,000
A. Total number of cars (14%)	14,000,000
Estimated oil change per car (in litres/annum)	10
Estimated used oil generated by cars (in litres)	140,000,000
B. Total number of buses (1%)	1,000,000
Estimated oil change per bus (in litres/annum)	50
Estimated used oil generated by buses (in litres)	50,000,000
C. Total number of goods vehicles (5%)	5,000,000
Estimated oil change per goods-vehicle (in litres/annum)	50
Estimated used oil generated by goods vehicles (in litres)	250,000,000
D. Total number of other vehicles (3%)	3,000,000
Estimated oil change per other vehicle (in litres/annum)	24
Estimated used oil generated by other vehicles (in litres)	72,000,000
Total estimated used oils from all motor vehicles, sum of A-D (in litres)	512,000,000
Ratio of used industrial oils to crankcase oils	1:2
Estimated used oils from industry (in litres)	256,000,000
Estimated used oils from motor + industry (in litres/annum)	768,000,000
Estimated used oils from motor + industry (in barrels/annum)	4,830,000
Estimated used oils from motor + industry (in barrels/day)	13,234
Estimated used oils from motor + industry (in million tonnes/annum) *(20,000 barrels per day corresponds to 1 million metric tonnes/annum)*	0.6617
Estimated used oils from motor + industry (in tonnes/annum)	**~ 666,000**

Step 4: Assessment of Actually Collectable Waste Oils

As discussed earlier, the quantity of waste oils that can actually be brought to recycling/disposal may be much less than the amount generated. While collection efficiency will be different for different sources, it is important to know the potential amount of waste oil that can actually be collected. Determining standards for collection efficiency of different sources is indeed a difficult task. It will differ from place to place and situation to situation. Stringent regulations will help in improving the collection of waste oils. The ideal way would be to carry out actual measurements and data gathering from primary sources. In some cases, such as company-certified garages and service stations, it may be possible to determine such data from log sheets/books as centres maintain records in one format or other (mandated in most countries under Hazardous Waste Management Laws). Such records would indicate whether the waste oil generated was sold, recycled or dumped. If none of this is felt possible, then one could use the default factor, bearing in mind that these factors are at best indicative. Table 1.10.4 could be used to facilitate the generation of this information.

Step 5: Consolidation of Information

In the final stage, each entity may estimate the overall waste oil generation under its domain in a consolidated form to enable its use in policy formulation. Table 1.10.5 could be used for such consolidation. Each of the entities could use or adapt this sample format and develop its own version as may be required.

Table 1.10.1: Sources of waste oil generation in Area ABC

Type of source		Number of such sources	Size range*	Type of waste oil**	Applicability	
1. Automotive					Yes	No
a. Manufacturing	Passenger car mfg.		/year	a. engine oils b. transmission fluids c. gear box fluids d. brake fluids e. hydraulic fluids f. compressor oils g. others		
	Truck/bus chassis mfg.		/year			
	Two wheeler mfg.		/year			
	Three wheeler mfg.		/year			
	Farm equipment mfg.		/year			
b. Garages/repair shops			/year			
c. Public Transport	Road transport		/year			
	Public vehicles		/year			
	Goods transport		/year			
2. Industries						
a. Engineering industries			/year			
b. Petroleum refineries			/year			
3. Process plants						
Cement			/year			
Paper			/year			
Sugar			/year			
Mining			/year			
Fertiliser			/year			
Others			/year			
4. Power plants			/year			
5. Marine industry			/year			
6. Aviation industry			/year			
7. Others			/year	…		

Note: Further classification of type of industry under each category may be incorporated as per the particular local circumstances, e.g. under 'marine industry,' we may have (i) shipbuilding, (ii) dock yards, (iii) fishing trawlers/boats, (iv) personal boats/yachts etc. Similarly, under the 'mining' category, we may have (i) quarries, (ii) open cast and underground mines, (iii) iron ore, (ii) copper ore etc.

*Size range: The appropriate volumes of the occurrence need to be used, e.g. number of vehicles per year for automobiles, million tonnes per year for cement, million tonnes per year for fertilisers, million cubic meters for liquid products, etc.
**Types of waste oils: A listing may be used that is applicable within individual entities. A representative list is provided for reference.

Table 1.10.2: Quantification of waste oil generation in Area ABC, according to source

Source	Number of such sources	Size range*	Type of waste oil**	Waste oil generation factor (default)	Quantity of waste oil generated per year
1. Automotive					
a. Manufacturing		…/year	a. engine oils b. transmission fluids c. gear box fluids d. brake fluids e. hydraulic fluids		
b. Garages/repair shops		…/year			
2. Industries					
a. Engineering industries					
b. Petroleum industries					
c. Refrigeration industry					
d. Other industry					
3. Process plants					
a.Cement					
b.Paper					
c.Sugar					
d.Mining					
e.Fertiliser					
f.Others					
4. Power plants					
5. Marine industry					
6. Aviation industry					
7. Others					

Note: Further classification of type of industry under each category may be incorporated in keeping with the particular local circumstances, e.g. under 'marine industry,' there may be (i) shipbuilding, (ii) dock yards, (iii) fishing trawlers/boats, (iv) personal boats/yachtsetc. Similarly, under the 'mining' category, there may be (i) quarries, (ii) open cast and underground mines, (iii) iron ore, (ii) copper ore etc.

*Size range: The appropriate volumes of the occurrence need to be used.

**Types of waste oils: A listing may be used that is applicable within individual entities. A representative list is provided for reference

Table 1.10.3: Quantification of waste oil generation in Area ABC, according to type

Type of waste oil	Source*	Number of such sources	Quantity of waste oil generated per year **
a. Engine oils	a. Garages/repair shops b. Public transport company c. Industry		
b. Transmission fluids			
c. Gear box fluids			
d. Brake fluids			
e. Hydraulic fluids			
f. Hydraulic oils	a. Engineering industries		
g. Cooling oils			
h. Compressor oils			
i. Thermic/heat transfer fluids			
j. Gear oils			
k. Bearing and circulating oils			
l. Turbine oils			
m. Refrigerator compressor oils	Refrigeration industry		
n. Oils from DG sets	Power plants		
o. Others			

*All possible sources in the given area should be included.

**Metric tonnes

Table 1.10.4: Quantification of collectable waste oil generated in Area ABC

Type of waste oil	Source	Number of such sources	Quantity of waste oil generated, in tonnes/year	Collection efficiency, in %			Actual quantity collectable, in tonnes/year
				Value	Obtained from	Default value	
a. Engine oils	a. Garages/ repair shops b. c.			50	Default	50	
b. Transmission fluids	a.			70	Practical measurement		
c. Gear box fluids						50	
d. Brake fluids							
e. Hydraulic fluids							
f. Hydraulic oils	a. Engineering industries						
g. Cooling oils							
h. Compressor oils							
i. Thermic/heat transfer fluids							
j. Gear oils							
k. Bearing and circulating oils							
l. Turbine oils							
m. Refrigerator compressor oils	Refrigeration industry						
n. Oils from DG sets	Power plants						
o. Others							

Table 1.10.5: Consolidation of information in Area ABC

Sources of waste oils generation				**Quantification of waste oil generation**		**Quantification of waste oil generation, according to type**	**Quantification of collectable waste oil generated**				
Type of source	Number of such sources	Size range/ year	Type of waste oil	Waste Oil Generation Factor as % of use (default)	Quantity of waste oil generated per year	Quantity of waste oil generated per year	Quantity of waste oil generated, in tonnes/year	Collection efficiency as a %			Actual collectable oil in tonnes/year
1. Automotive								Value	Obtained from	Default value	
a. Manufacturing			a. Engine oils	5.0				90.0	Default		
			b. Transmission fluids	5.0				90.0			
			c. Gear box fluids	2.0				90.0			
			d. Brake fluids	20.0				80.0	Practical measurement		
			e. Hydraulic fluids	2.0				70.0			
b. Garages/repair shops			a. Engine oils	85.0				60.0			
			b. Transmission fluids	50.0				50.0			
			c. Gear box fluids	30.0				50.0			
			d. Brake fluids	20.0				15.0			
			e. Hydraulic fluids	80.0				50.0			
2. Industries											
a. Engineering industries			a. Hydraulic oils	20.0				80.0			
			b. Cooling oils	10.0				90.0			
			c. Compressor oils	30.0				90.0			
			d. Gear oils	20.0				15.0			
			e. Bearing and circulating oils	80.0				15.0			
			f. Thermic/heat transfer fluids	90.0				80.0			
			g. Turbine oils	80.0				70.0			

b. Petroleum industries			a. Hydraulic oils	80.0				60.0			
			b. Cooling oils	50.0				30.0			
			c. Compressor oils	30.0				50.0			
			d. Gear oils	20.0				15.0			
			e. Bearing and circulating oils	80.0				15.0			
			f. Thermic/heat transfer fluids	10.0				80.0			
			g. Turbine oils	80.0				70.0			
c. Refrigeration industry			a. Refrigerator compressor oils	20.0				70.0			
d. Other industry			a. Hydraulic oils	10.0				60.0			
			b. Cooling oils	50.0				30.0			
			c. Compressor oils	30.0				50.0			
			d. Gear oils	20.0				15.0			
			e. Bearing and circulating oils	80.0				15.0			
			f. Thermic/heat transfer fluids	10.0				80.0			
			g. Turbine oils	80.0				70.0			
3. Process plants											
f.Cement											
g.Paper											
h.Sugar											
i.Mining											
j.Fertiliser											
Others											
4. Power plants*											
5. Marine industry*											
6. Aviation industry*											
7. Others*											

*For other sectors, a similar classification of oils would need to be developed and used.

CHAPTER 2: RECYCLING AND DESTRUCTION TECHNOLOGIES FOR WASTE OILS

An Overview of Destruction Technology

The inappropriate destruction and disposition of waste oils on land and in water has emerged as a major cause of environmental damage in many industrialised countries. It is therefore essential to have environmentally sound waste oil destruction technologies in place to stop any further environment damage.

Destruction (or treatment for safe and environmentally sound disposal) of waste is near the bottom of the waste management hierarchy. Preventive approaches, namely preventing waste generation, minimising or reducing the waste at source and reusing/recycling waste are definitely the preferred approaches. It is only when such preferred approaches have been used to the maximum possible extent and there is still some residual waste requiring disposal do destruction technologies for treatment and safe disposal of such waste begin to be considered.

Waste oils are particularly suited for the adoption of preventive approaches. As discussed earlier, most of these oils are discarded because of contamination/degradation. As the basic properties of lube oils remain by and large intact in most cases, the discarded waste oils can be properly collected and treated.

Basically there are two alternatives for the destruction/disposition of waste oils:

- Re-refining to produce lubricating base oils
- Burning as fuel

Many problems are likely in both options because of the presence of high amounts of metals and organometallic compounds in waste oils, originating from lube oil additives.

Recycling technologies, as the name implies, enable the recycle/reuse of waste oils, thus conserving precious resources that are mostly non-renewable. When waste oils are burned, a high ash content (up to 1.5% wt.) results, which in turn leads to inorganic ash fouling the furnace, thereby increasing furnace operating costs while reducing tubes and refractory life. The air pollution that may result from such burning is both socially unacceptable and hazardous to human health, with the respiration of submicron-size lead particles being of particular concern. For these reasons, legislation in many countries now prohibits the combustion of waste oils in power plants.

This section, therefore, first deals with recycling technologies. Subsequently, destruction technologies for waste oils are also discussed.

2.1 Waste Oil Recycling

Inspiring Statements

- "One gallon of used motor oil (waste oil) provides the same 2.5 quarts of lubricating oil as 42 gallons of crude oil." (The conversion ratio can be taken as 1 US gallon = 4 quarts, or we may say every litre of waste oil gives 0.63 litre of lubricating oil)
- The used oil from one oil change can contaminate 1 million gallons of fresh water—a years' supply for 50 people.
- Oils and fats are an essential part of every day for many people. It is an unfortunate fact that many people simply discard waste oil such as that used in cars, reports the US EPA. Waste oils come from more than petroleum sources; they also come from animals and plants. Recycling waste oils reduces society's impact on the environment and helps the economy.
- Re-refining used oil takes only about one-third the energy of refining crude oil to lubricant quality.
- One litre of waste oil processed for fuel contains about 9,300 Kcals of heat energy, and most important of all, assists in conserving crude reserves, while minimising unemployment through the building/construction of used lubricating oil recycling plants and eliminating used lubricants as a factor contributing to environmental pollution.
- Thus management of waste oils/re-refining has an economic advantage apart from being a solution for disposal with little or no effect on human health or the environment.

Sources: US EPA, Used Oil Management Program, http://www.epa.gov/waste/conserve/materials/usedoil/index.htm; Udonne, J.D., A comparative study of recycling of used lubrication oils using distillation, acid and activated charcoal with clay methods, www.academicjournals.org/jpge/PDF/Pdf2011/February/Udonne.pdf; Huebsch, R. "Types of Waste Oil," http://www.ehow.com/about_5552616_types-waste-oil.html

2.1.1 An Overview

With increasing prices of the base raw material, i.e. crude oil, recycling of waste oil has become an economically attractive proposition, in as much as it is a way of minimising environmental hazards while also helping conserve a scarce non-renewable resource.

The recycling of used lubricants has been practiced to various degrees since the 1930s[64] and particularly during the Second World War, when the scarcity of adequate supplies of crude oil encouraged the reuse of all types of materials, including lubricants. In the earlier part of the 20th century, lubricating oils contained few or no additives at all. Recycling these oils usually involved some basic and simple processes which were a combination of heating to remove volatile components; settling to separate water, dirt, and sludge; and centrifuging or filtering to remove most of the remaining insoluble contaminants. While this limited processing could not bring recycled oils to match the original oil quality, technological improvements now enable recycled oils to be at par with virgin oils in quality.

In recent years environmental considerations regarding the conservation of resources have further boosted interest in recycling. Recent developments, in particular the emphasis on waste recovery, have led to further renewed interest in recycling used oils. In some developed countries up to 50% of the countries' need for lubricating oil is met through recycled oils. There are different methods used by different countries for recycling used oils. It has been established that almost 85 to 90% of dehydrated waste oils can be converted into useful products, including base oils for

[64] Udonne, J.D., A comparative study of recycling of used lubrication oils using distillation, acid and activated charcoal with clay methods, Journal of Petroleum and Gas Engineering Vol. 2, February 2011, www.academicjournals.org/jpge/PDF/Pdf2011/February/Udonne.pdf

further processing into lubricating oils or fuel. The examples in Table 2.1.a and Table 2.1.b show two cases of product yield, one in a developed and one in a developing country.

Table 2.1.1.a: Typical product output from a waste oil recycling facility in a developed country (Southern Oil Refineries, Australia)

Batch size: 65,000 litres/day		
Output constituents	% yield (approximate)	Output in litres/day
Water	10	6,500
Light fuel oil	5	3,000
Gas oil	10	6,500
Light lube distillate	37	24,000
Heavy lube distillate	16	10,500
Heavy fuel oil	2	1,500
Residue	20	13,000

Table 2.1.1.b: Typical product output from a waste oil recycling facility in a developing country (Konark Petrochemicals, India) [65]

Batch size: 1,000 litres/day of waste oil (Batch processing)		
Output constituents	% yield (approximate)	Output in litres/day
Moisture condensate	4.5 to 5.0	45 to 50
Light oils	5.0 to 6.0	50 to 60
Light oils at second stage	0.5	5
Carbon and heavy oils in the residue cake	2.0	20
Net product** (The split of this component into base oil and heavy fuel oil is shown below)	82.0	820 of useful product
Unaccounted loss in the cake	About 7.0	
**Base oil: 37% of total		
**Heavy fuel oil: 45% of total		

The lighter ends of the processes generate enough fuel to support the process without much external fuel, except for the electricity needed to operate the processing equipment.

Re-refining is complicated due to the fact that the waste oils come from over 500 commercial grades and 1,500 formulations encompassing literally every conceivable application in the automotive, industrial and marine segments. [66] Modern lubricating oils are more sophisticated and functionally diverse, containing complex additives of up to 20% or more by volume. Such oils present greater recycling challenges.

[65] Konark Petrochemicals, 6th road, Auto Nagar – Vijayawada, AP, India, +919248172644, 0866-2543467. Data collected through private communication.
[66] Indian Oil Corporation, R&D center, Faridabad, Haryana, India, extracted from http://www.iocl.com/aboutus/Research_Development.aspx

Consequently, for traders, who deal with large quantities of waste oils, it is not feasible on a practical level to segregate various grades of oils. Invariably, almost all kinds of lubricants are mixed together, with this mixture forming the bulk of waste oils.

2.2 Parameters and Considerations for Successful Recycling Technologies

There are seven principal drivers necessary for a re-refining technology to be successful in meeting market, industry and environmental demands. Failure in any one of these aspects may limit the success of the technology.

2.2.1 Environmentally Sound Technologies[67]

Environmentally Sound Technologies (ESTs) are technologies that have the potential for significantly improved environmental performance relative to other technologies. ESTs protect the environment, are less polluting, use resources in a sustainable manner, recycle more of their wastes and products, and handle all residual wastes in a more environmentally acceptable way than the technologies for which they are substitutes. ESTs are not just individual technologies. They can also be defined as total systems that include know-how, procedures, goods and services, and equipment, as well as organisational and managerial procedures for promoting environmental sustainability.

Defining environmentally sound technologies in an absolute sense is difficult since the environmental performance of a technology depends upon their impacts on specific human populations and ecosystems, the availability of supporting infrastructure and human resources for the management, monitoring and maintenance of the technology, as well as their sustainability. The soundness of environmental technology is also influenced by temporal and geographical factors, to the extent that some technologies may be considered environmentally sound now but may be replaced in the future by even cleaner technologies.

What is environmentally sound in one country or region may not be in another, unless it is redesigned or adapted to make it appropriate for addressing local needs. Thus the term ‘environmentally sound technology’ can be applied to all technologies and their transition to becoming more environmentally sound; this ranges from basic technologies to fully integrated technologies. This definition captures the full life cycle flow of the material, energy and water in the production and consumption system. It also implies the development and application of environmentally sound technologies underpinned by more holistic environmental management strategies based on the characteristics of natural systems, which include species diversity, resilience, adaptiveness, regenerative capacity, interconnectedness, spatial and temporal fluctuation and so on.

A re-refining technology must not be harmful to the environment. It should not be a major source of pollution and it should not produce hazardous waste streams – otherwise it is part

[67] United Nations Environment Programme, Division of Technology, Industry and Economics, http://www.unep.or.jp/ietc/publications/freshwater/fms7/2.asp

of the problem rather than the solution. In most countries around the world there are strict regulations controlling the type and amount of acceptable pollution. It would be highly undesirable and socially unacceptable for the re-refinery itself to be a significant source of pollution.

2.2.2 High Quality Products

For a re-refiner's products to be able to compete with virgin base oils (which are derived from crude oil) and ensure profits for the re-refinery, its products must be of high quality. Products of lower quality will ultimately impact upon the commercial viability of the re-refining, as such products must be sold at a discount and have a limited range of uses. In contrast, high quality products have more salability as they enjoy broader based market acceptance and can be used for more applications.

The shift in the base oil market currently underway towards greater use of Group II and also Group III base oils is expected to continue because of the increasing emphasis on fuel economy, extended drain levels and lower levels of emissions. For a re-refinery to maintain a sufficiently competitive product in future markets, it must adopt a technology system capable of producing API Group II and Group III base oils in an economically viable manner.

2.2.3 Product Quality Consistency

The technology must also ensure a high degree of consistency in product quality. Blenders and compounders purchase base oils and combine them with chemical additives to create finished lubricating oils that are specific to particular applications. The finished lubricating oils undergo a number of quality control tests, with the final blend needing to be reformulated if stringent property standards are not met. As quality issues with the base oils cause blenders and compounders to need to spend more time and money reformulating their blends, a re-refinery that fails to produce base oils that are highly consistent will be paid less for these base oils in order to compensate for this need to reformulate the lubricating oils later.

2.2.4 High Base Oil Yield

The re-refining technology should have a high yield of base oil, which is the re-refining product having the highest value (twice the value of fuel oil, the next highest value product). Insofar as a technology having a high base oil yield is one that is recovering the highest-value waste oil product, base oil yield can be used as a yardstick for measuring the efficiency of the process overall.

2.2.5 Economics

A re-refining project must go beyond environmental and conservation benefits and be economically sound if it is going to attract investment. Aspects affecting commercial viability include capital costs and operating costs in addition to the amount and quality of products to be made.

2.2.6 Capable of Processing a Variety of Waste Oils

As feedstock can vary considerably in quality, the re-refining technology must be one that capably handles such variability. Waste oil types include gasoline and diesel engine oils as well as industrial oils, hydraulic oils, metalworking oils, gear oils and synthetic oils, among others. Although the waste oil generated at any given collection point may experience dramatic changes in its properties, the entirety of a re-refiner's feedstock typically sees less dramatic variation. Nevertheless, such changes can affect both the quality and the consistency of the finished products as well as the yields. Such changes also naturally impact upon operating costs and therefore commercial viability.

2.2.7 Capable of Rendering Contaminants Benign

Contamination of waste oil with hazardous materials including solvents, glycols, PNAs, chemicals, residuals, and so on is typical. The re-refining technology must therefore address the issue of contaminants, eliminating them from the final product and rendering them benign from an environmental/ecological standpoint.

Various recycling technologies, generic as well as specific, have been covered here.
Wherever possible, the locations and references of the working plants on the basis of individual technologies have been referred to in this compendium. However, each of the technology providers has its own individual web site providing details and offering their services on request through those sites.

Barring exceptional and limited cases, most technology providers do not provide much data about their capital requirements or the costs of their plants. These details are only available through specific client requests.
Similarly, from the process flow charts of various technologies, details concerning every piece of equipment, such as the motors, pumps, and gear boxes for drives, conveying systems, and sizes of the main core equipment and so on are not easily available. That said, these details may be disclosed by providers on a case by case basis.

2.2.8 Handling and Treatment of Hazardous Waste Residues

With ever-growing global environmental awareness, even developing and most of the underdeveloped countries have statutory regulations guiding the treatment of hazardous residual wastes generated through waste oil processing.

2.3 Technologies for the Destruction of Waste Oils

Starting in the 1920s, waste oil handling has progressed through various stages of development. With advancements in science and technology, various processes have gradually evolved over a period of time. While many research and development pursuits have died a natural death, many others have emerged as technical solutions applicable to the menace of waste oils and their hazardous constituents. Prior to this era, waste oils were either dumped in low-lying areas or burnt for their fuel value. However, with the advent of environmental consciousness throughout the world, more and more stress has been put on the hazardous nature of this waste, with stringent environmental norms now in place in almost all the countries in the world.

The Government of India set forth the specifications of used oil and waste oil under The Hazardous Wastes (Management, Handling and Transboundary Movement) Rules, 2008 Schedule V [Rule 3(ze) and (zf)], Parts A & B (referred to as 'HW Rules 2008' hereinafter).

In India the composition of waste oil (defined in India as oil which (i) includes spills of crude oil, emulsions, tank-bottom sludge and slop oil generated from petroleum refineries, installations or ships and (ii) can be used as fuel in furnaces for energy recovery, if it meets the specifications laid down in Part B of Schedule 5 of HW Rules 2008 either as such or after reprocessing) and used oil (known as waste oil/used oil in other countries) are the same as, or correlated with, the composition laid out in Part A of HW Rules 2008.

Part A: Specifications of used oil suitable for reprocessing/recycling

S. No.	Parameter	Maximum permissible limit
1.	PCBs	< 2 ppm*
2.	Lead	100 ppm
3.	Arsenic	5 ppm
4.	Cd+Cr+Ni	500 ppm
5.	PAHs	6%

Part B: Specifications of fuel derived from waste oil

S. No.	Parameter	Maximum permissible limit
1.	Sediment	0.25% wt.
2.	Lead	100 ppm
3.	Arsenic	5 ppm
4.	Cd+Cr+Nil	500 ppm
5.	PAHs	6%
6.	Total halogens	4000 ppm
7.	PCBs	<2 ppm*
8.	Sulfur	4.5% wt.
9.	Water content	1%

*The detection limit is 2 ppm by gas liquid chromatography (GLC) using an electron capture detector (ECD).

According to these Rules, any used oil or waste oil not meeting the above-mentioned specifications has to be incinerated either in suitable incinerators or used as fuel in cement kilns.

2.3.1 Overview

The ability to recycle waste oils is very closely linked to the oils' composition, level, type of contamination and of course economic aspects.

There are about 200 oil recyclers in North America alone. Of these, only three are primarily re-refiners, which recover lube oil for reuse. The others recycle waste oil by producing fuel for burning/energy recovery. In Europe, there are about 20 re-refiners.

Worldwide there are about 400 oil re-refining plants using a variety of technologies, with an overall capacity of 1.8 million tonnes/year. [7]

Recycled lubricating oil products are potentially suitable for all uses, including their original use, if given proper segregation, cleanup and additive treatment. Studies across the world have demonstrated that re-refined oils using modern technology produce a safe product, including consideration of carcinogenicity.[68]

In recycling used oils to regain useful products, a number of processing steps are possible, depending on the original source of the waste oil, the level of contamination, the sophistication of the recycling technology and the requirements for the end product.
Figure 3.1 depicts the general schematic of a waste oil recycling process. Through the process, an average of 4 to 5% of the total dehydrated waste oils results in residues identified as hazardous waste. The main constituents of this hazardous waste are heavy metals, PAHs and PCBs and other chemical compounds.

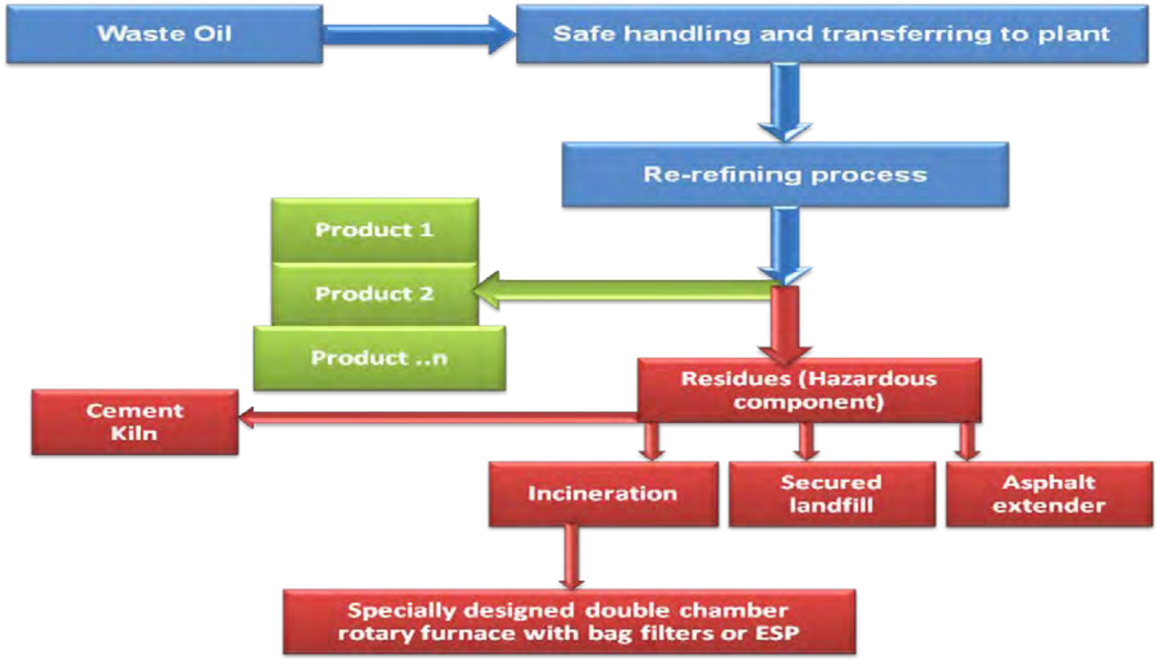


Figure 2.3.1: General schematic of the waste oil recycling process

The principle of recycling waste oils utilises many of the following basic steps:

- Removal of water and solid particles by settling
- Sulphuric acid treatment to remove gums, greases, etc.
- Alkaline treatment to neutralise acid

[68] Brinkman, D.W. et al. (April 2010), *Kirk-Othmer Encyclopedia of Chemical Technology*, John Wiley & Sons, Inc.

- Water washing to remove “soap”
- Stripping to drive off moisture and volatile oils; vacuum distillation and/or solvent extraction
- Clay contacting to bleach the oil and absorb impurities
- Filtering to remove clay and other solids
- Hydrogenation to improve colour
- Blending to specification[69]

The various terms related to the processing and handling of waste oils and hazardous waste oils are clarified under Part 279—Standards for the Management of Used Oil of the Electronic Code of Federal Regulations (USA; current as of April 21, 2011).[70]

2.3.2 Generic Technologies

Over time, the re-refining processes are advancing and thus improving, especially from the aspects of yield and reduced environmental impacts. The most common of the generic systems are:

2.3.2.1 Acid-clay Re-refining

2.3.2.1.1 Process Description

This ancient and once popular process, namely the acid-clay re-refining process, was first employed in the mid-1960s by many companies in United States, wherein large amounts of sulphuric acid and clay were used to treat waste oils. While the technology produced acceptable, although sub-standard, base oil, it also generated acid tar, oil saturated clay, and other hazardous waste by-products. Under increasing environmental pressure this technology has been banned in most countries, including many developing countries. Figure 2.3.2.1.1 depicts the flow process in the acid-clay refining process.

[69] Udonne, J.D., A comparative study of recycling of used lubrication oils using distillation, acid and activated charcoal with clay methods, www.academicjournals.org/jpge/PDF/Pdf2011/February/Udonne.pdf
[70] http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&tpl=/ecfrbrowse/Title40/40cfr279_main_02.tpl

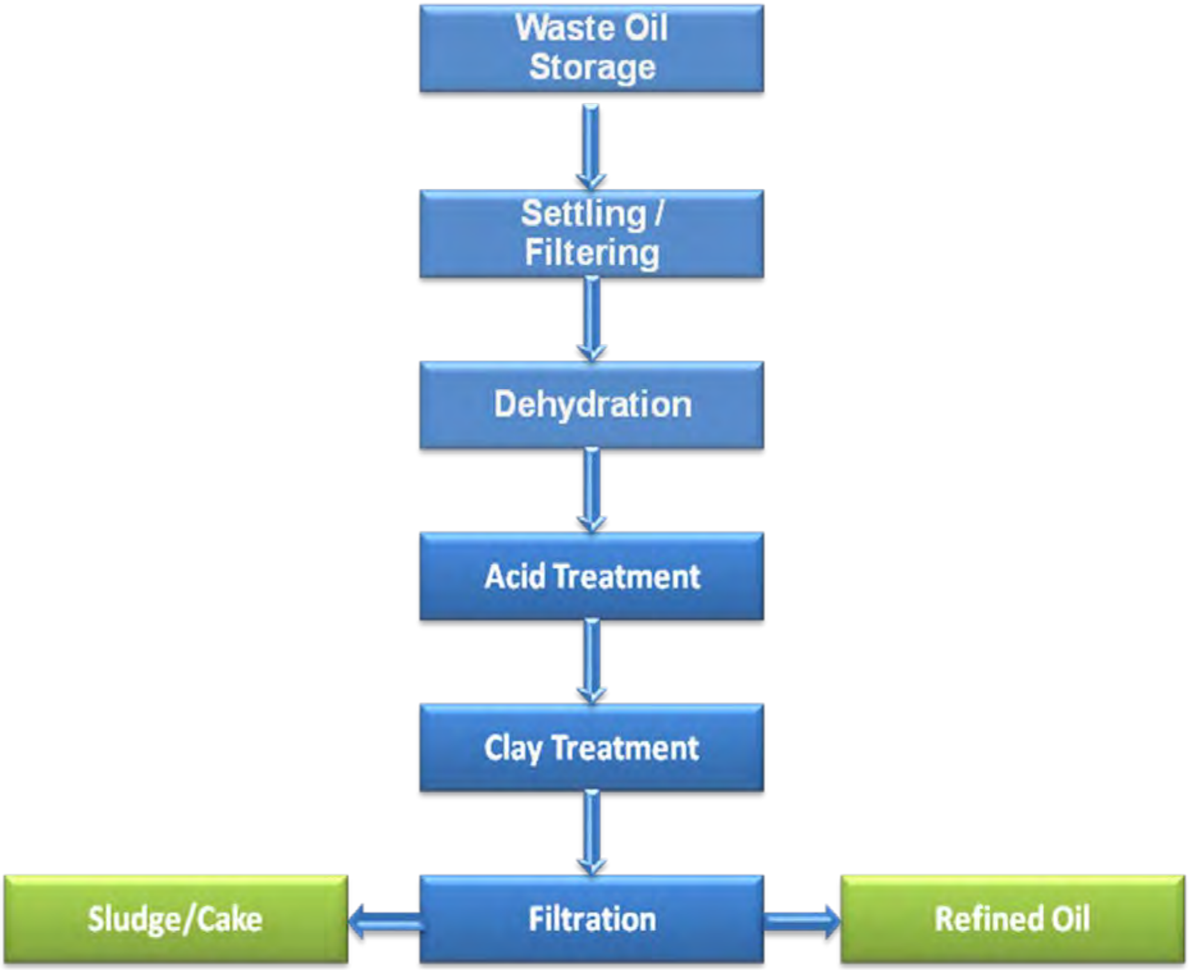


Figure 2.3.2.1.1: Acid-clay treatment process

2.3.2.2 Acid Activated Clay Technology

2.3.2.2.1 Process Description

This is a process in which no acid is used. Other than that, the remaining process is similar to the above-mentioned acid-clay process. Drawbacks to this process include the use of large amounts of clay and its subsequent disposal problems together with low oil yields.

Under increasing environmental pressure, both of the above technologies have lost importance and neither is now in use. In recent decades a number of innovative re-refining technologies have been developed and those can solve the technical, economical and environmental problems associated with waste oil recycling.

The current technologies in re-refining are based on special chemical treatment, vacuum distillation, extraction and hydrogenation.

2.3.2.3 Vacuum Distillation/Evaporation Technology

2.3.2.3.1 Process Description

Waste oils are chemically pre-treated to avoid the precipitation of contaminants which can cause corrosion and fouling of the equipment.

Pre-treated waste oils are distilled to separate off water and light hydrocarbons. The resulting water is treated and sent to a wastewater treating facility, while the light hydrocarbons are used at the plant as fuel or sold as a product.

The water-free oil then undergoes high vacuum distillation using a conventional vacuum column or in a thin film evaporator for separation of diesel fuel. Materials such as residues, metals, additive degradation products etc. are passed on to a heavy asphalt flux stream.

The distillate is hydrotreated at high temperature and pressure in the presence of catalyst to remove nitrogen, sulphur, chlorine and oxygenated organic components. The used catalyst from the hydrotreating process is disposed off-site.

Under high vacuum, the hydrotreated oil is further fractionated into desired cuts which are used as components of motor, industrial and hydraulic oils. Residue from the vacuum distillation is used for producing road and roof bitumen. Figure 3.2.3.1 depicts the general flow process of this technology.

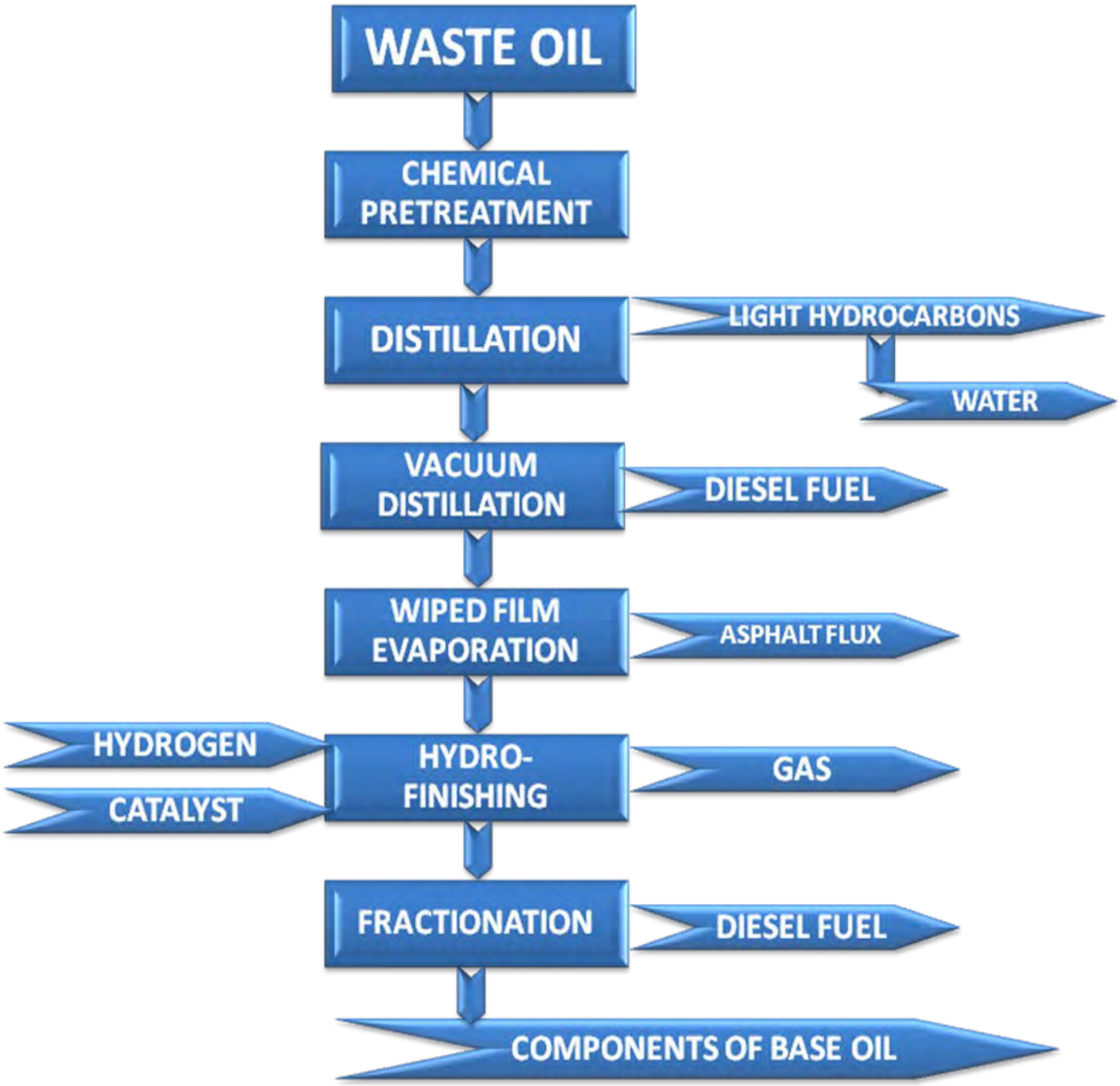


Figure 2.3.2.3.1: Flow diagram of vacuum distillation based process

2.3.2.4 Hydrogenation Based Technologies

2.3.2.4.1 Process Description

A specially designed, pressurised mixing chamber is used to mix hot hydrogen with feedstock that has been filtered to remove solids. The heated mixture is then transferred to a flash separator, with the resulting flash separator bottoms liquid routed to a residue stripper.

The combined flash separator vapour and residue stripper overheads are processed first through a catalytic guard reactor for soluble metals removal and then through a severe hydro finishing reactor where desulfurisation, dechlorination, oxygenate conversion, denitrification, aromatic saturation and mild hydro cracking reactions take place. The resulting catalytically treated hydrocarbons have improved chemical properties, colour, and odour.

Processing conditions such as pressure, space velocity and hydrogen circulation rate vary from unit to unit depending on feedstock quality, with the highest pressure being about 80 bars.

The results of this processing is a hydrocarbon product having a wide boiling range. This is then fractionated into neutral oil products having different viscosities, which are used to blend lubricating oils.

The process can achieve more than 85% lube oil recovery from the lube boiling range hydrocarbon in the feedstock.

A schematic of the process is given in Figure 2.3.2.4.1

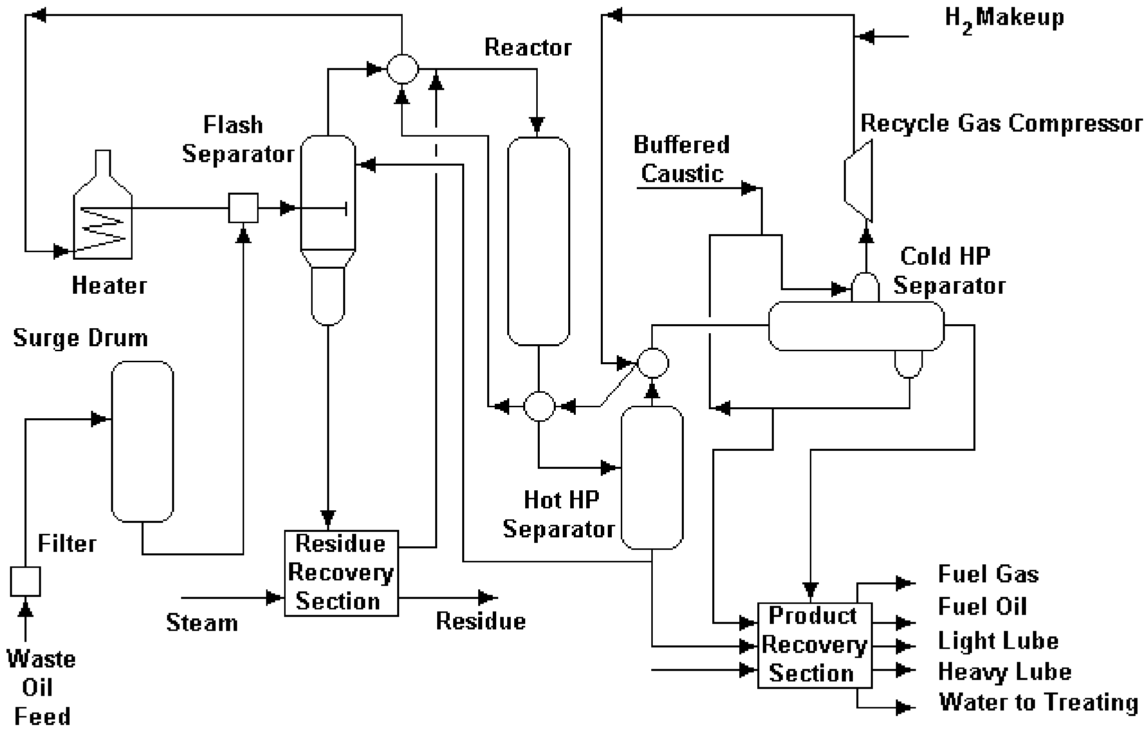


Figure 2.3.2.4.1.a: Schematic of hydrogen based technology

Figure 2.3.2.4.1.b depicts a simpler flow process for the same technology.

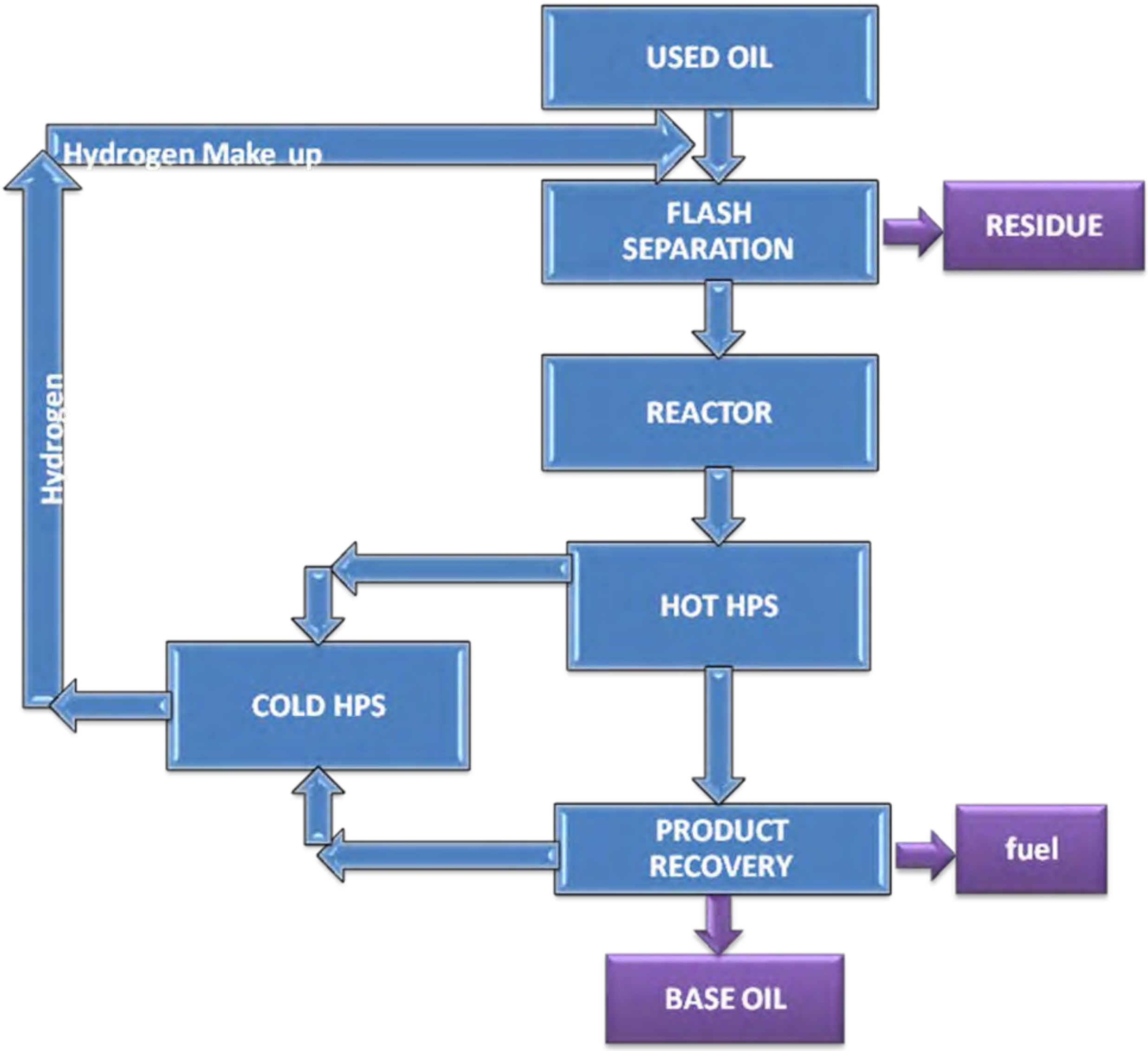


Figure 2.3.2.4.1.b: Hydrogenation based technology

2.3.2.4.2 By-products of the Process

- Fuel gas: non-condensable hydrocarbon compounds dissolved in the feed or produced by conversion, as well as dissolved hydrogen gas from the liquid products.
- Fuel oil: non-lube range liquid hydrocarbon, hydrotreated and stabilised for storage.
- Heavy oil: heavy neutral oil, which represents the remainder of the recovered lube boiling range product, possible to add into heavy fuels.
- Stable heavy residue: non-volatile material present in the feed or produced in the process, acceptable for asphalt blending.
- Dilute aqueous effluent containing the converted sulphur, nitrogen, and chloride in the form of inorganic salts, liquidated in a wastewater treatment plant.

The capital investment and operating costs of the process are quite competitive.

2.3.2.5 Ultra-Filtration Technology

2.3.2.5.1 Process Description

This is a much cleaner and more energy efficient re-refining technology. The process is based on ultra-filtration of waste oils using efficient membrane/barriers with carbon support. The technology includes centrifugation of waste oil at low temperatures to eliminate water and large size deposits and pre-distillation, for removing water and solvents. Pre-treated oil is treated by chemicals for quality improvement and transferred to a fractionating column, where gas oil is separated.

The key stage of the process is ultra filtration at high temperature to separate oils, polymers and fine particles using tubular filters with smaller diameters.

A catalytic hydro treatment is used for improving the colour of the final product. This step produces gaseous fuels.

A final vacuum distillation allows the production of various base oils.

2.3.2.6 Extraction Based Technologies

2.3.2.6.1 Process Description

Extraction based technologies are more recent innovations in vacuum distillation and earth treatment technologies. The chemical treatment is replaced by extraction using propane during the initial stages and conducted at room temperature.
The basic steps of this process are as follows:

1. Extraction using solvents;
2. Separation of the oil;
3. Atmospheric distillation;
4. Vacuum distillation; and
5. Filtering using earth treatment.

Waste oils are pre-treated with a basic solution containing ammonium hydroxide and/or potassium hydroxide to neutralise undesirable compounds. The oil is then mixed with a propane solvent having high selectivity for hydrocarbons which rejects metals and other contaminants. The mixture is then sent to an extraction vessel and subjected to a process where most of the additives, water and solids are separated in asphalt residue and the propane oil mixture is then pumped through a series of heat exchangers for separation of propane in the flash separator. The propane is re-condensed with cooling water and returned to the solvent vessel. The separated oil is then stripped to remove light hydrocarbons and any remaining propane. The oil is further vacuum distilled for fractionation as well as for any finishing aspects such as clay treatment or hydro-finishing.

Initially there was one plant using this technology in Salt Lake City (Utah, USA), with another put into operation in Stoke-on-Trent (England) in 1996. There is another in Sandy (Utah, USA), and one is in the assembly stage in Seoul (Republic of Korea).

Another version of the process is shown in Figure 2.3.2.6.1, in which propane extraction is performed twice.

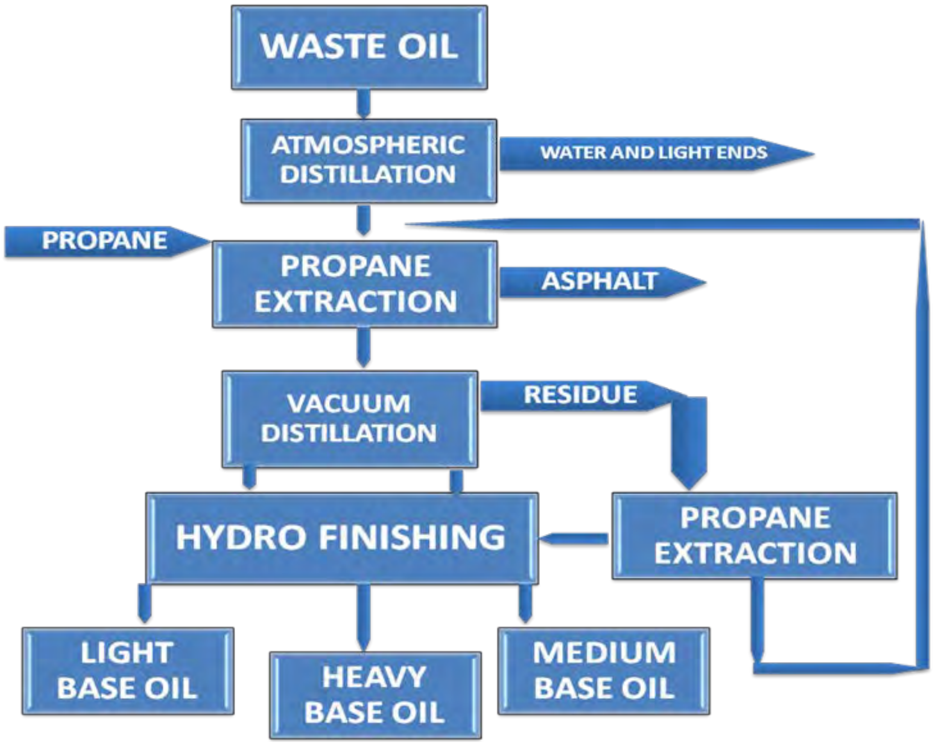


Figure 2.3.2.6.1: Extraction based re-refining technology

Table 2.3.2.6.1 provides a bird's eye view of a comparison between various generic technologies for waste oil recycling and use.

A summary of various factors, namely the process or technology adopted, waste products generated, use of by-products and means and ways of waste disposal is provided in Table 2.3.2.

Table 2.3.2: Residue generation and disposal from various re-refining technologies

Process/ technology	Waste generated	By-products/ utilisation	Waste disposal
Acid-clay re-refining	Residue from settling & course filtration of waste oil, acid sludge and spent clay	Fuel products (utilised within the plant itself as fuel)	Major problem is of acid sludge, which is neutralised with lime before disposal. Spent clay is disposed to brick kilns and cement plants.
Acid activated clay treating process	Residue from settling and course filtration of waste oil, large quantities of spent clay	Fuel products (utilised within the plant itself as fuel)	Spent clay (increased amount) is disposed to brick kilns and cement plants
Vacuum distillation based	Residue from settling & course filtration of waste oil; distillation residues	Fuel products (utilised within the plant itself as fuel)	Distillation residue may be disposed to cement plants or mixed with asphalt for road construction. Spent clay is disposed to brick kilns. Regeneration of clays is also an option and is now underway.
Extraction based	Residue from settling & course filtration of waste oil, extraction residues	Fuel products (utilised within the plant itself as fuel)	Extraction residue to cement plants/mixed with asphalt for road construction. Spent clay is disposed to brick kilns or regeneration.
Membrane based	Residue from centrifugation; concentrate from membranes	Fuel products (utilised within the plant itself as fuel)	Concentrate from the process may be disposed to cement plants.

Note: The initial residue obtained from waste oil settling, filtration and centrifugation in the above processes/technologies is generally disposed to secured landfills. Residues generated from specific technologies also follow the same routes of disposal as hazardous residual wastes.

Table 2.3.2.6.1: A comparative statement of various generic technologies for waste oil recycling

			Features	Drawbacks
1.		Acid-clay Process (Typical consumption: Bentonite 1 to 2%; however, in some cases, up to 5%)	Acid-clay process for used oil recycling/reprocessing has a long history and had been popular.	Causes environmental pollution due to generation of acid sludge and acid gas emission. Disposal of acid sludge is a problem.
			This is a proven technology that has worked for many years worldwide. Can be set up to handle very small capacities.	Causes corrosion of equipment, reducing its life.
			Low capital investment, making it the most cost effective for small- and tiny-scale plants.	Gives lower yield due to loss of oil in sludge as well as clay since a higher dosage of clay is required.
			Non-sophisticated, very simple process. Simple to operate, with no advanced instruments or skilled operators required.	As most governments have adopted stringent pollution control regulations, this process is on its way out.
2.		Acid Activated Clay Process	No acid is required.	Very high clay consumption, low yield, inconsistent quality.
				Disposal of large quantity of spent clay is an environmental problem.
			Simple process. Suitable for small capacity plant.	Suitable only for very small capacity plants.
				Process is dependent on a particular type of clay which may not be available from all sources.
3.	Vacuum Distillation	(a)Thin/Wiped Film Evaporator	Suitable for high capacity plants.	Operates at high temperature & very high vacuum. Requires special/expensive thermic fluids & heating system. High cost of heating fluid and high operational costs.
			Thin film evaporator is capable of operating at high vacuum and is normally used for high value and heat sensitive products.	Requires high capital investment.
			Does not cause pollution.	Plant has to be of a higher capacity to make it economically viable.
			Sophisticated equipment & processing.	Requires highly skilled operational maintenance staff as it uses very sophisticated equipment; has higher fuel costs.

			Produces good quality base oils.	Due to multiple stages of distillation involving heating & cooling.
		(b) Pipe Furnace Vaporiser	Simple pipe furnace, convection heating at low heat flux by re-circulating flue gases.	
			No moving parts on process side.	
			No prior removal of gas oil is required.	
			Simple instrumentation.	
4.		Solvent Extraction Process	Propane is used as a solvent to remove bitumen, additives, metals and tar etc.	Has to operate at higher pressure (10 atm) at ambient temperature (27^{o}C), requiring high pressure sealing systems (making the system expensive and complicated).
			Solvent is recyclable.	Involves operational solvent losses; highly skilled operating and maintenance personnel and system are required.
			Does not cause pollution.	Economical only for high capacity plants.
			Produces good quality base oils.	Propane being very hazardous, fire & explosion hazards are associated with this process.

2.3.3 Specific Technologies for Waste Oil Recycling

Based on the generic technologies referred to in the previous section, many companies have developed specific processes for recycling waste oils. Some of the more prominent and better known among them are detailed below. It may however be noted that the following technologies do not cover all those which have to date been tried and experimented with. Not all have found their way to the commercial markets. Another few have been tried but no plants exist that use these technologies commercially. For ease of understanding, they have been classified as "C" (commercially available), "R&D" (only researched and developed at the laboratory level) and "OD" (outdated and no longer in use).

2.3.3.1 KTI Process ("C")

2.3.3.1.1 Process Description

The KTI (Kinetics Technology International) Process, also known as KTI Relube Technology, combines vacuum distillation and hydrogenation treatment to eliminate most of the polluting substances in used oil.[71]

Basic Steps of the Process

Atmospheric distillation: This involves eliminating water and light hydrocarbons.

Vacuum distillation: The resultant product comes within the range of the lubricating oils. The working temperature should not exceed 250ºC.

Hydrogenation: Oils distilled in the previous stage are subjected to a hydrogenation treatment to eliminate the sulphur, nitrogen and oxygen compounds. This stage is also used to improve the colour and odour of the oil.

Fractionation: the hydrogenated oil is separated into different base oil fractions according to the specifications and necessary equipment of the product.

This technology accepts PCBs and other hazardous materials and gives an efficiency of 82% of high quality base oils. The waste produced in the vacuum distillation stage contains degraded additives, asphalt by-products, oxidised products and other impurities that have economic value. The first re-refinery based on this technology was established in Greece in 1992. At the present time, several plants of this type are in commercial operation, including plants in Tunisia and California.

The technology combines vacuum distillation and hydrofinishing to remove most of the contaminants from the waste oil. The basic stages of this process comprise atmospheric and vacuum distillation, hydrofinishing of the vacuum distillates, and fractionation. In this technology, an atmospheric distillation column removes water and light hydrocarbon

[71] Audibert, F. Waste engine oils: Re-refining and energy recovery, 2006

fractions, while a first vacuum unit generates a product in the lubricating oil range. This process has no pre-treatment step, as it uses a special vacuum distillation that minimises thermal stress by applying temperatures not in excess of 250°C in short bursts.[11] These conditions favour thin-film evaporation. By using a wiped-film evaporator, the facility can take most types of feedstock.

The distilled oil is then mixed with hydrogen, heated and passed through a reactor to remove sulphur, oxygen and nitrogen-containing compounds and improve the colour. The hydrogenated oil is finally stripped with steam or fractionated into different base oil fractions depending upon the product requirements and specifications. This technology accepts PCBs and other hazardous materials and produces high-quality base oils with a yield of about 82%. Polluting by-products are minimised. The vacuum residue generated contains additives, asphaltenes, oxidation/polymerisation products, metal and other impurities. The residue has commercial value. Figure 2.3.3.1 depicts the flow process chart for the KTI Process.

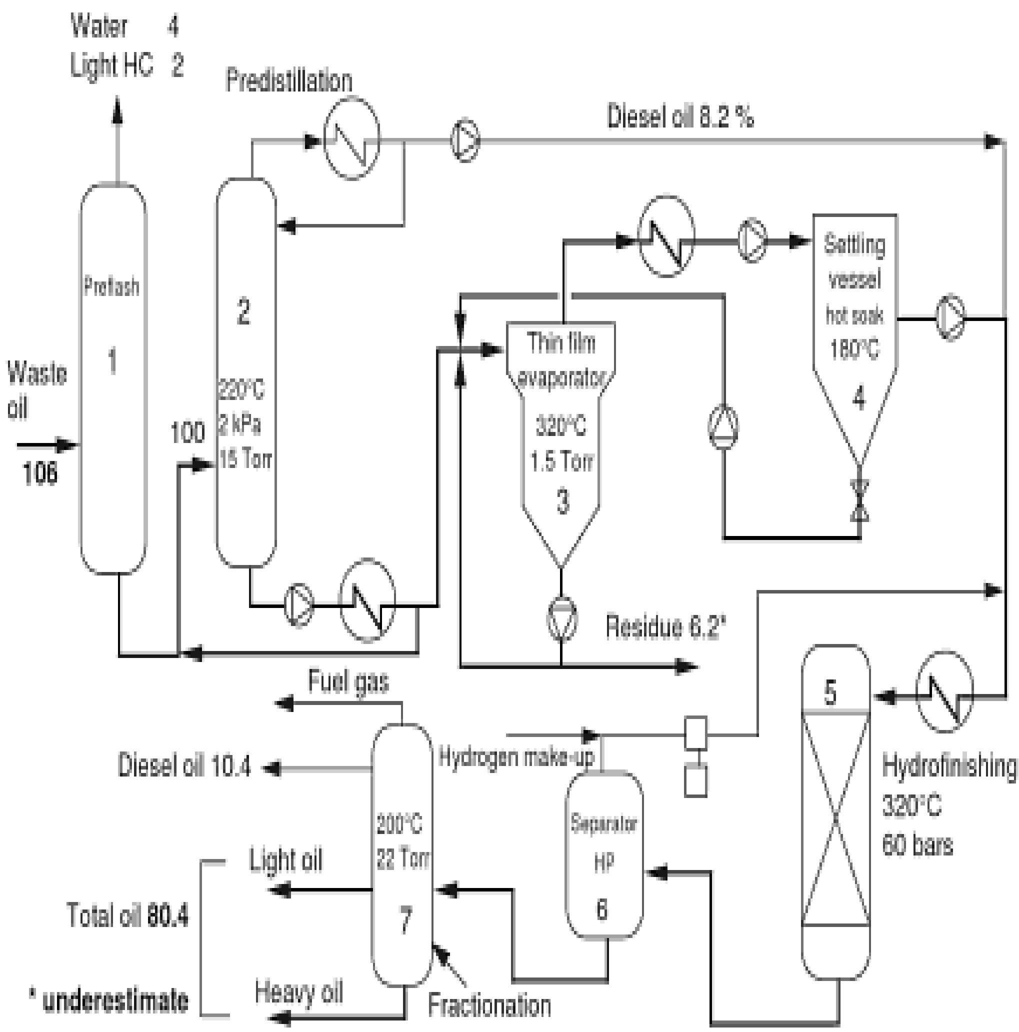


Figure 2.3.3.1: KTI Process flow diagram

2.3.3.2 Safety Kleen Technology ("C")

2.3.3.2.1 Process Description

The Safety Kleen Process combines wiped-film vacuum distillation and fixed-bed catalytic hydrotreatment.[2] Figure 2.3.3.2 depicts the process at the plant at East Chicago, Indiana, USA,[1] which is one of the largest waste oil re-refineries in the world. It has a capacity of about 250,000 MT per year.

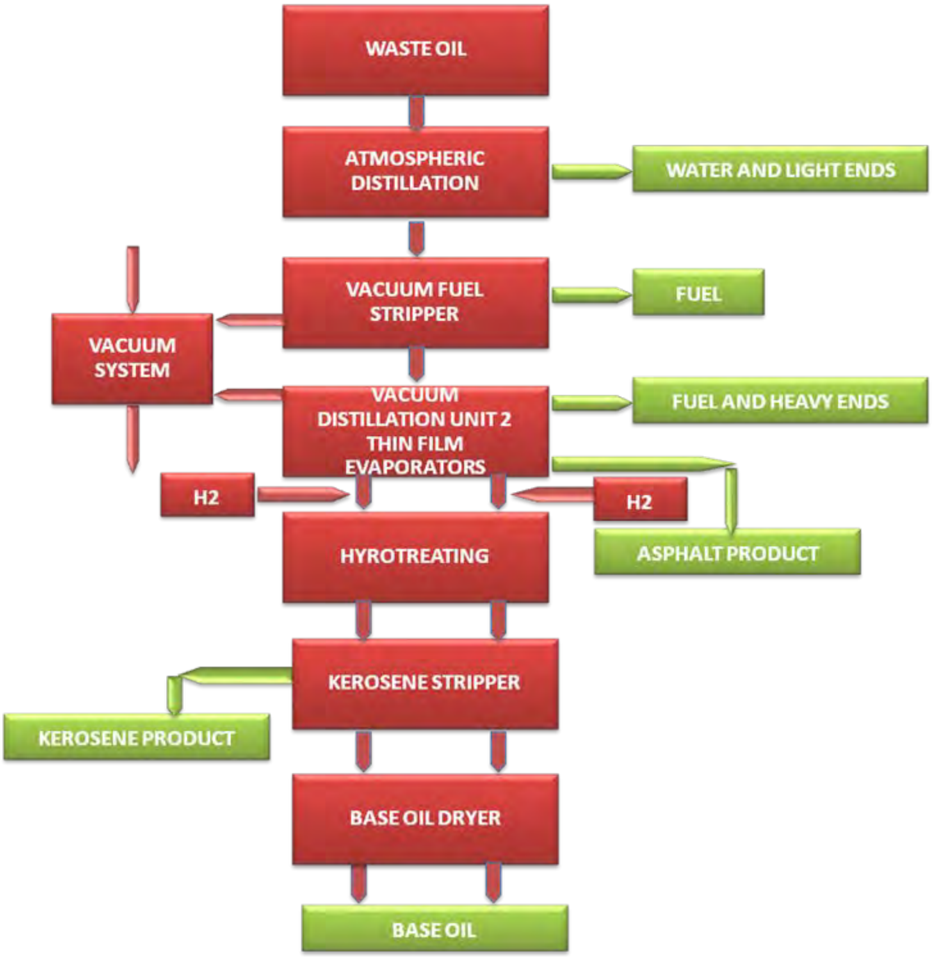


Figure 2.3.3.2: Safety Kleen Process diagram

The steps in the Safety Kleen Re-refining Process are as follows.[72]

2.3.3.2.1.1 Dehydration

Water from waste oil is first removed through evaporation. The water is collected, treated to be chemically and biologically safe and then discharged. Water and light solvents are removed using an atmospheric flash drum.

2.3.3.2.1.2 Light End Recovery

With the water removed, the waste oils go to tall distillation towers where light fuels are separated under atmospheric conditions and collected. The vacuum column/fuel stripper removes most of the fuel and heavier solvents. The vacuum distillation unit performs the combined functions of separating the lubricating oil from the heavy ends and generating multiple product streams. Chemically non-pretreated waste oil tends to foul heated surfaces over time, so thin-film evaporators are used. The lubricating oil fractions (cuts) are then hydrotreated over fixed beds of nickel-molybdenum catalyst. The hydrotreating is performed in stages to reduce catalyst fouling/poisoning and to enhance final product quality. This step improves thermal stability, colour and odour while reducing polynuclear aromatics and removing higher-boiling halogenates and polar compounds.

2.3.3.2.1.3 Fuel Stripping

The waste oils are now subjected to heating and vacuum distillation, thereby removing middle weight oils. By-product fuels can be used for industrial heating. The last steps include a kerosene stripper and base oil dryer. The aqueous by-product from the atmospheric distillation unit is sent for water treatment, while low-boiling hydrocarbon contaminants (light ends) recovered from all steps are combined for use as a fuel within the re-refinery. The boiler system had to be adequately designed due to the fuel having a relatively high chlorine content.

2.3.3.2.1.4 Vacuum Distillation

The waste oils are further distilled under higher vacuum and lube oil base stock/fractions are collected. By-products of the process are the residues, which can be used for industrial applications such as asphalt extenders. The by-product vacuum distillation residue is used as an asphalt extender or as fuel for industrial furnaces fitted with emission controls. The spent catalyst from the hydro treating step can be regenerated.

[72] Safety Kleen Re-Refining Process. Adopted from http://www.safety-kleen.com/services/OilSolutions/Pages/Re-RefiningProcess.aspx, 07.09.2011

2.3.3.2.1.5 Hydrotreating for Removal of Final Impurities

The remaining oils are treated with hydrogen to remove sulphur, nitrogen, chlorine, heavy metals and other impurities. This step also corrects any issues with odour, colour and corrosion performance.

The base oils recovered by the Safety Kleen re-refining process meet API standards for base oils. Lubricants made from Safety Kleen base stock include engine oils, gear lubricants, power transmission fluids, hydraulic oils, and industrial oils, all of which meet industry standards and specifications and therefore do not jeopardise warranties or the performance of equipment. Safety Kleen and its licensees have, worldwide, 262 branches, 13 solvent recycling centers, three fuel blending facilities, and two waste oil re-refining plants.

In general, the technology does not generate unusable by-products. Safety Kleen operates more than ten plants re-refining more than 200 million gallons of used oil in the U.S. alone.

2.3.3.3 Axens/Viscolube (REVIVOIL) Technology [73] ("C")

2.3.3.3.1 Process Description

Viscolube's re-refined lubricating bases, obtained through high pressure catalytic hydrogenation, have excellent chemical-physical and composition features for use in a variety of lubrication applications, in both the automotive and the industrial sector.
The very low sulphur and aromatics content and the high viscosity index favour the choice of formulation solutions within a wide viscosity interval, which are able to meet the most challenging performance demands and the environmental requirements demanded of modern lubricants, thus saving additives in the formulations.
The technological properties of Viscolube's re-refined base oils are also suitable for other industrial applications like rubber processing and as efficient process oils in general.

Viscolube's production plant is essentially made up of three sections.

2.3.3.3.1.1 Preflash

The waste oils are heated up to 140°C and then distilled in a vacuum column where the water and light hydrocarbons are separated.

2.3.3.3.1.2 Thermal De-asphalting (TDA)

The dehydrated oil is distilled at 360°C in a vacuum de-asphalting column (TDA). The asphaltic and bituminous products remain at the bottom and three side cuts of different

[73] http://www.viscolube.it/tool/home.php?s=0,2,23

viscosity are obtained at the same time. An intermediate gas oil is collected from the top of the column. The three side fractions and the gas oil are sent to storage to be subsequently hydro-finished in batches in a high pressure (100 bar) catalytic plant.

2.3.3.1.3 Hydro-finishing

The hydro-finishing process starts in a fired heater where the oil and hydrogen are heated up to 300°C. They are then sent to a reactor containing a catalyst favouring hydrogen reaction with the unsaturated compounds, sulphur and nitrogen.

The reactor effluent is then separated into two phases, the vapour phase and the liquid phase; the first one is washed with water to remove the chlorine and sulphur compounds, while the second is stripped with steam to eliminate the most volatile compounds and restore the flash point. The water contained in the oil after stripping is then removed in a vacuum dryer.

The streams containing sulphur are sent to an amine plant where the hydrogen sulphide is separated from the other compounds. They then go to a Claus plant where H_2S is transformed into pure liquid sulphur.

The final result is a clear oil with very low sulphur and polynuclear aromatics (PNAs) content. This lubricating base oil has many advantages it is beneficial to health and the environment as well as demonstrating excellent performance on the lubrication circuits where it is used.[74] Figure 2.3.3.3 depicts the flow process of the Viscolube process.

[74] Kajdas, C. Major Pathw ays for Used Oil Disposal and Recycling. Part 2, Warsaw University of Technology, Institute of Chemistry in Plock and Central Petroleum Laboratory in Warsaw, Poland, Polish Tribology Society (PTS), Wiley, published online 9 March 2006. Extracted from http://www.tribologia.eu/ptt/kaj/kaj1101.gif

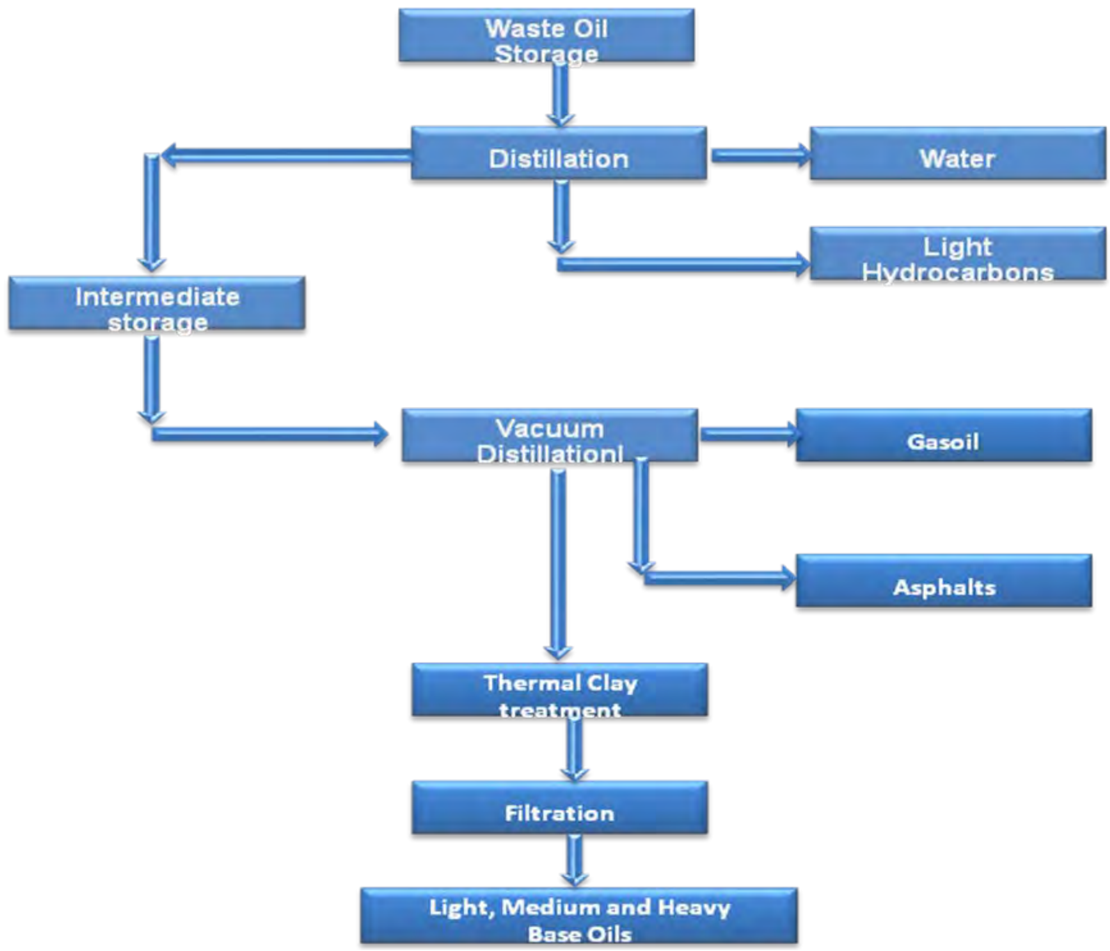


Figure 2.3.3.3: Viscolube Process flow diagram

2.3.3.4 IFP Technology/Snamprogetti Technology ("C")

2.3.3.4.1 Process Description

IFP technology was developed by the "Institut Français du Petrole" and is also known as the Selecto Propane Process. This process combines vacuum distillation and hydrogenation but in this case extraction is carried out using liquid propane. This form of extraction is similar to the kind carried out in crude oil refineries to separate out asphaltenes.
The basic steps of this process are as follows:

2.3.3.4.1.1 Atmospheric distillation

Water and light hydrocarbons are eliminated.

2.3.3.4.1.2 Vacuum distillation and extraction of the oil-containing part using propane

Oil from atmospheric distillation is subjected to extraction with liquid propane at a temperature of between 75 and 95ºC. Light and medium base oils are recovered in this phase.

2.3.3.4.1.3 Hydrogenation

This is the stage where the propane is separated from the propane-oil mixture. Asphaltic compounds, oxidised hydrocarbons and solids in suspension are also separated in this stage. The bright stock fraction is recovered from the waste from vacuum distillation.

The final stage is the hydrogenation of the bright stock fraction.

There is a difference between the IFP and Snamprogetti processes concerning the recovery of the bright stock. In the IFP process, the waste is extracted with the propane remaining from vacuum distillation. The fraction that is obtained is demetalised and hydrogenated through two catalyst beds to obtain the bright stock. In the Snamprogetti process, the vacuum distillation waste is sent through a second extraction, using propane, which is combined together with the vacuum distillate in a hydrogenation process at the end.

Figure 2.3.3.4.1.a depicts the IFP process and Figure 2.3.3.4.1.b depicts the Snamprogetti process.

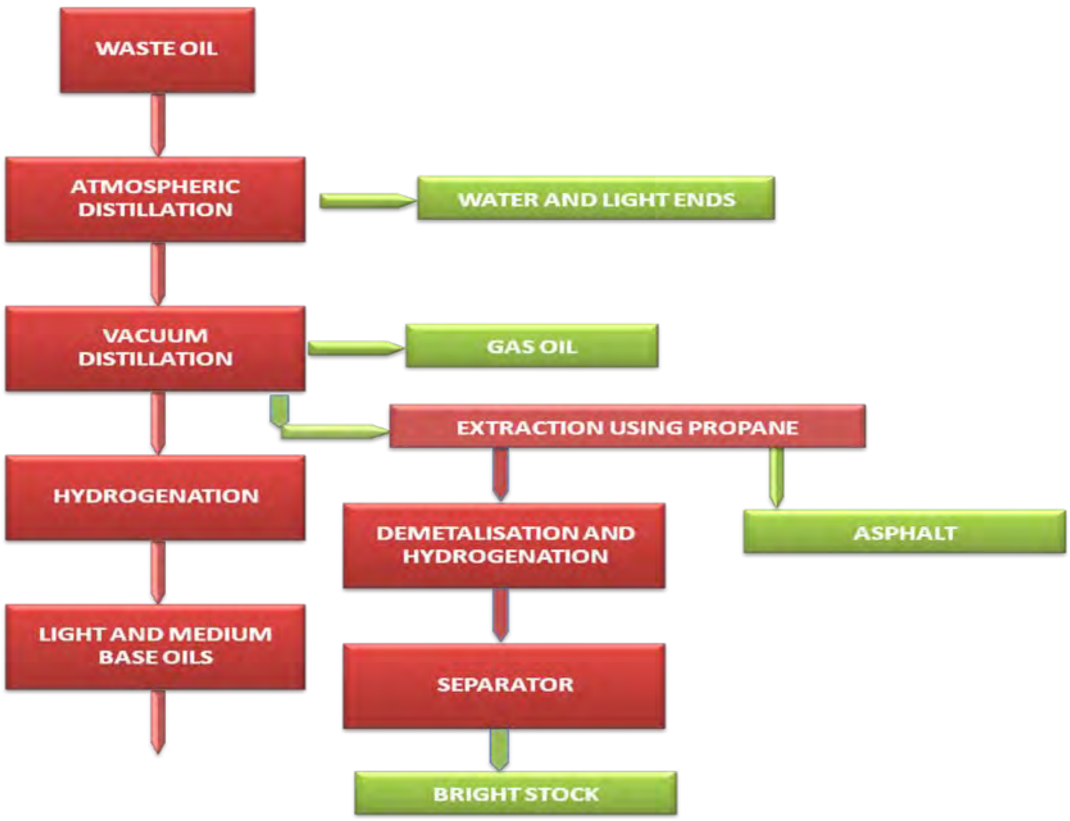


Figure 2.3.3.4.1.a: IFP Process flow diagram

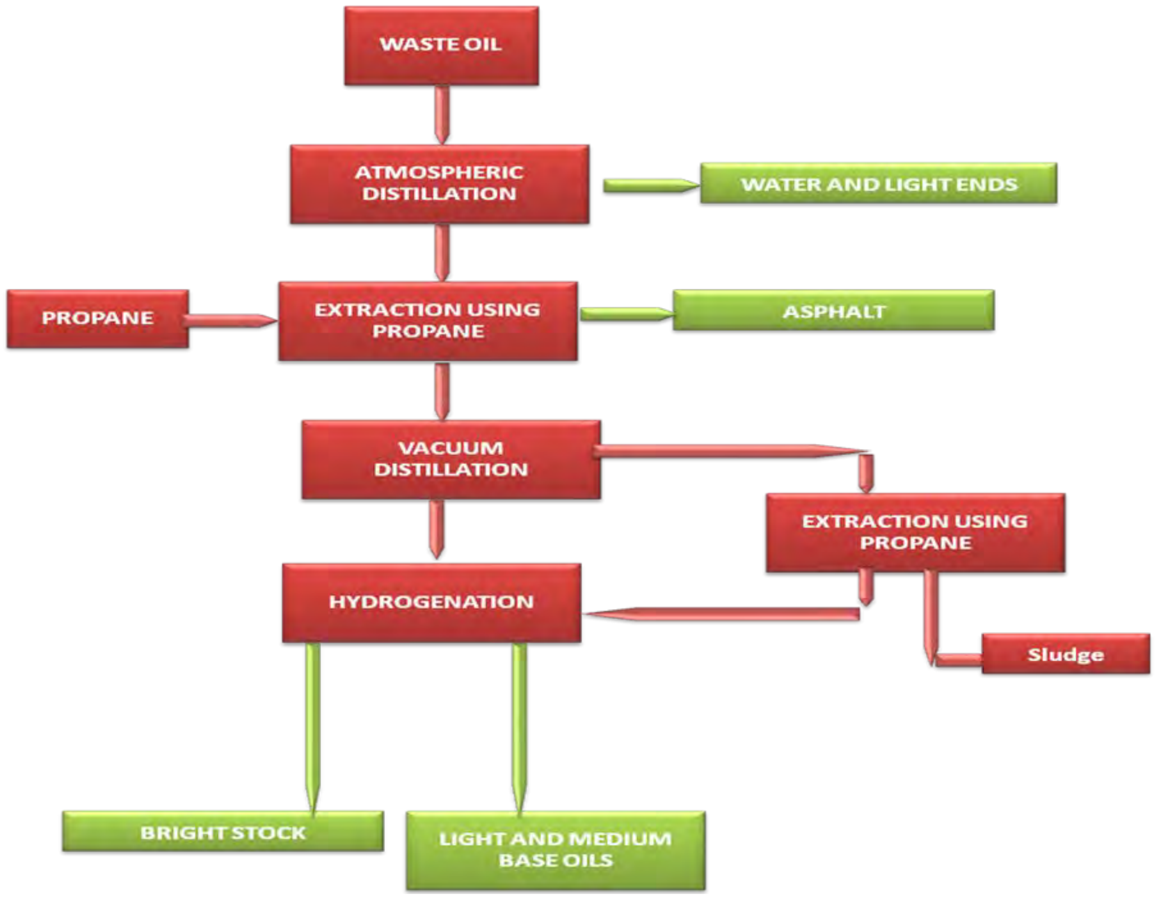


Figure 2.3.3.4.1.b: Snamprogetti Process flow diagram

2.3.3.5 HyLube Process[75] ("C")

2.3.3.5.1 Process Description

The HyLube Process is a proprietary process developed by the world-famous company UOP for the catalytic processing of used lubricating oils into re-refined lube base-stocks for re-blending into saleable lube oils.

A typical HyLube Process feedstock consists of a blend of used lube oils containing high concentrations of particulate matter such as iron and spent additive contaminants such as zinc, phosphorous and calcium.

Figure 2.3.3.5.1 depicts the flow process of the HyLube Process.

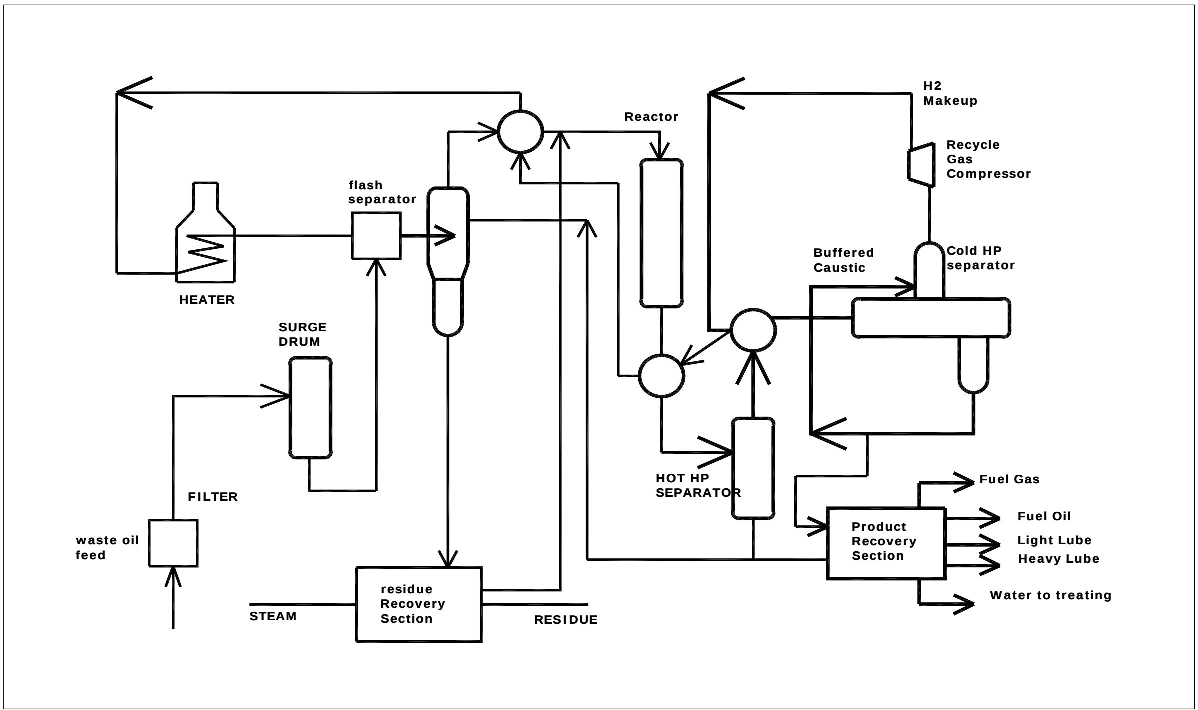


Figure 2.3.3.5.1: HyLube Process flow diagram

2.3.3.5.1.1 The feedstock is first filtered to remove solids and then mixed with hot hydrogen in a specially designed, pressurised mixing chamber.

2.3.3.5.1.2 The heated mixture is sent to a flash separator and the flash separator bottoms liquid is routed to a residue stripper.

2.3.3.5.1.3 The combined flash separator vapour and residue stripper overheads are processed first through a catalytic guard reactor for soluble metals removal and then through

[75] http://www.prokop-engineering.cz/hylubeEN.htm

a severe hydrofinishing reactor where desulfurisation, dechlorination, oxygenate conversion, denitrification, aromatic saturation and mild hydrocracking reactions take place. Relative to the feed, the catalytically treated hydrocarbons have improved chemical properties, colour, and odour.

Processing conditions such as pressure, space velocity, and hydrogen circulation rate are diverse from unit to unit depending on feedstock quality, with the highest pressure at about 80 bars.

2.3.3.5.1.4 The processed feedstock is converted into a wide boiling range hydrocarbon product, which is subsequently fractionated into neutral oil products of different viscosity to be used for lube oil blending.

The HyLube Process achieves more than 85% lube oil recovery from the lube boiling range hydrocarbon in the feedstock. Table 2.3.3.5 provides the details of utilities and chemicals required for a 25,000 MT per year capacity plant working on this technology.

Table 2.3.3.5: Details of utilities and chemicals required for the HyLube Process

A 25,000 t/year capacity plant requires the following utilities and chemicals.		
Hydrogen	2.10^6 Nm^3/year	99.5% purity
Nitrogen	1.10^6 Nm^3/year	
Steam	14.10^3 t/year	
Cooling water	16.10^6 m^3/year	
Caustic soda	4.10^3 t/year	5.0% solution
Sodium carbonate	13.10^3 t/year	2.5% solution
Ammonia	60 litres/year	
Flushing oil	650 barrels for start-up and each shut-down	
Dimethyl disulfide	2000 kg for catalyst sulphurisation	
Fuel gas	3.10^3 t/year	

The Hylube Process is a proprietary feed treatment system which rejects the non-distillable portions of the waste oils. The remaining oil, typically 90-95% of the original feed, is directly processed over a proprietary UOP catalyst. The attractive features of the process are:

- Lube base stocks quality is equal to virgin base oils
- Low sulphur (< 0.03% wt.) fuels
- Aqueous effluent with low chemical oxygen demand and no organochlorines
- Stable heavy residue suitable/acceptable for asphalt blending

This process eliminates numerous pretreatment steps normally associated with waste oils re-refining and does not generate any hazardous by-products.

By-products of the process include:

- Fuel gas: non-condensable hydrocarbon compounds either dissolved in the feed or produced by conversion, as well as dissolved hydrogen gas from the liquid products.

- Fuel oil: non-lube range liquid hydrocarbon, hydrotreated and stabilised for storage.
- Heavy oil: heavy neutral oil, which represents the remainder of the recovered lube boiling range product, possible to add into heavy fuels.
- Stable heavy residue: non-volatile material present in the feed or produced in the process, acceptable for asphalt blending.
- Dilute aqueous effluent containing the converted sulphur, nitrogen, and chloride in the form of inorganic salts, liquidated in Waste Water Treatment Plant.

2.3.3.6 UOP DCH Process[76] ("C")

2.3.3.6.1 Process Description

Honeywell UOP developed the Direct Contact Hydrogenation (DCH) technology in 1989. The main part of this process is the hydrogenation reactor. The feed is mixed with hydrogen in the first separation stage, where metals and other contaminants are removed. After this step the feed is flowed to the fixed bed hydrogenation reactor, which is followed by cooling and the second separation step. The hydrogen flow from the separation step contains light hydrocarbons, H_2S, ammonia and steam, which have to be separated before recycling.

The hydrogenated oil is fractionated to gasoline, gas oil and base oil fractions. The yield of base oil is higher than 90%. Figure 2.3.3.6.1 depicts the flow chart of the process.

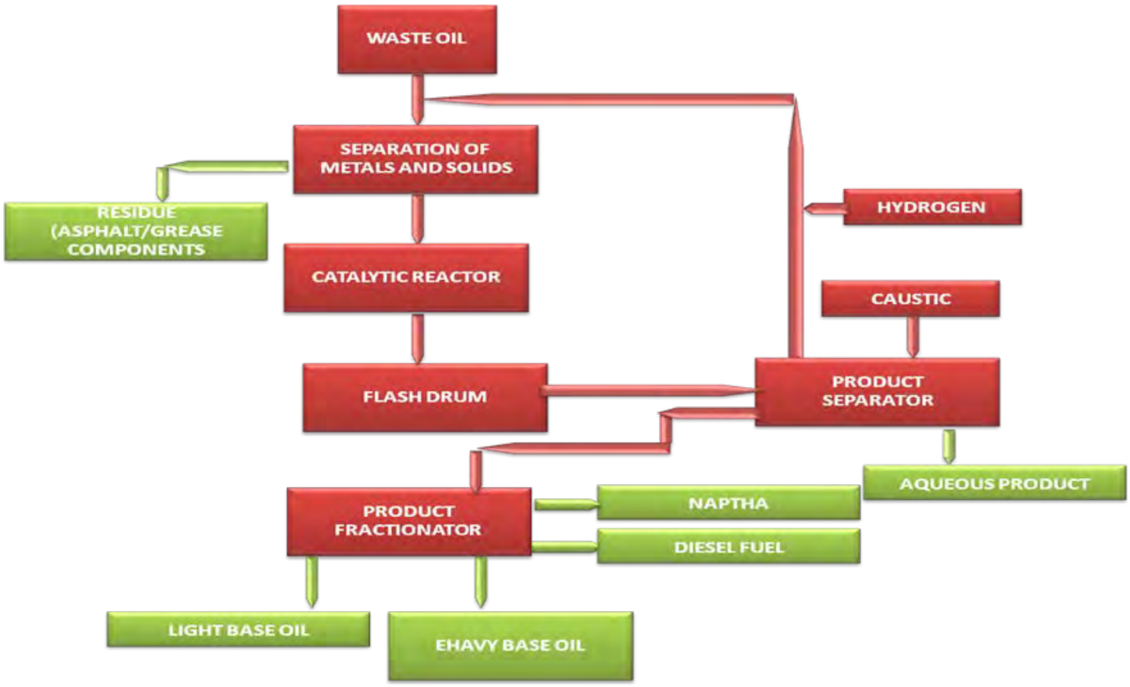


Figure 2.3.3.6.1: UOP DCH Process

[76] Bryant, C. Resource Recycling, Slick new oil re-refining process, November 1989

2.3.3.7 Probex Process ("C")

2.3.3.7.1 Process Description

The Probex waste oil re-refining technology was patented in 1997 by Probex Co.

In the first step the waste oils are treated and light hydrocarbons are separated in flash drum. The residue waste oils are distillated in a vacuum tower.

In this step asphalthenes and other impurities are separated from the oil and different viscosity grade oils can be produced. The treated base oil fraction is extracted with n-methyl-2-pyrrolidone, where unsaturated, aromatic and heteroatom-containing molecules are eliminated. Unsaturated, aromatic and heteroatom containing compounds are in extract phase; the base oil forms the raffinate phase. Solvent is reprocessed from both of the above-mentioned products with stripping. The extract phase contains up to 10% base oil fraction as a function of process parameters. Figure 2.3.3.7.1 depicts the flow chart of the process.

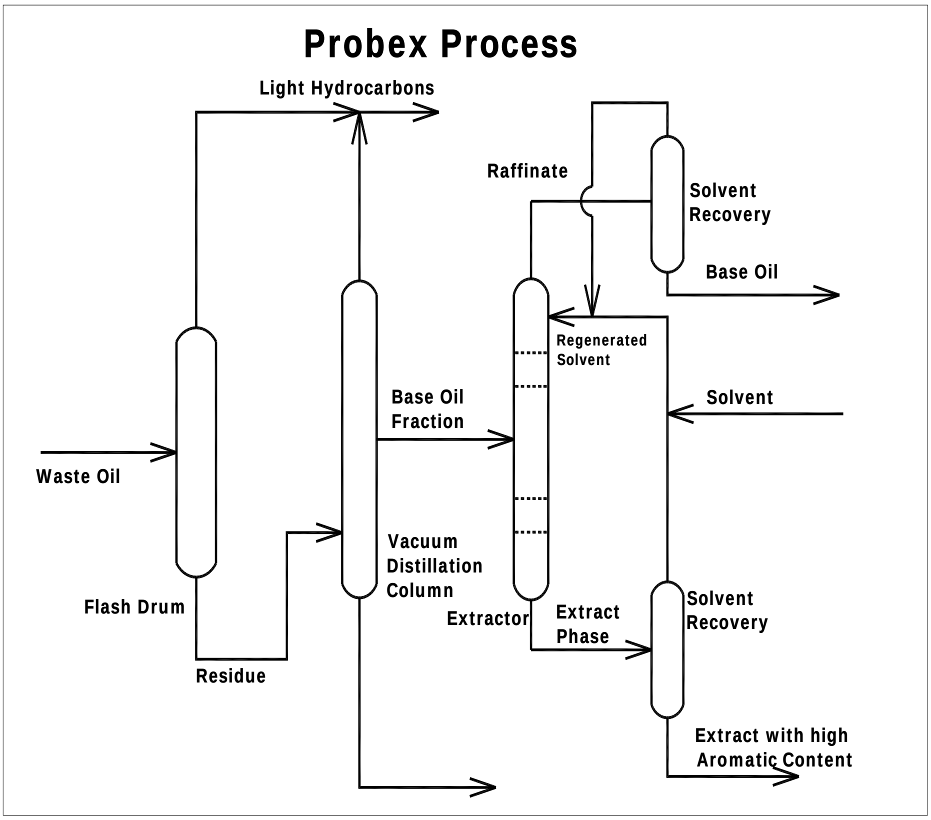


Figure 2.3.3.7.1: Probex Process

2.3.3.8 STP Process[77] ("C")

2.3.3.8.1 Process Description

STP is one of the major suppliers of waste oil re-refining process technology around the world. The STP re-refining process removes all the contaminants from the used lube oil and recovers a base oil product as VGO or high quality lubricant which is in either API Group I by chemical finishing or API Group II by hydro finishing.

The STP re-refining process does not release harmful or pollutant wastes to be disposed of and is therefore environment friendly.
Effluents are oily drains/low BOD/COD oily process water sent to treatment before disposal and process off gas sent to a thermaloxidiser for combustion and destruction, in keeping with environmental laws and regulations. Figure 2.3.3.8.1 shows a process flow diagram of API Group I/VGO production process. Thirteen such plants are in operation worldwide.

The basic steps of the STP Process are as follows.

2.3.3.8.1.1 Dehydration and Lights Removal

The stocked used oil is pumped through a filter and preheated through heat exchangers which help in recovering heat from finished products. It is then treated with chemical additives. The treated oil is flashed in the flash drum to remove water and light hydrocarbons. Gases are burnt in a thermal oil furnace. Water and hydrocarbons are condensed and separated in a settler.

2.3.3.8.1.2 Gas Oil Stripping

The dehydrated oil is sent to the gas oil stripping column working under vacuum. Gas oil from the column overhead is condensed and sent to storage. Incondensable gases from the vacuum system are sent to a thermal oil furnace.

2.3.3.8.1.3 Vacuum Distillation

The oil coming from the gas oil stripping column is introduced into a high vacuum distillation column with thin film evaporator, where the separation of the lubricating fraction and the residue takes place. The lubricating cut is then condensed and sent to finishing while the asphaltic residue is sent to storage.

2.3.3.8.1.4 Finishing

Finishing is done through chemical treatment for API Group I products or through hydro finishing in the case of API Group II lubricants production.

[77] Studi Tecnologie Progetti S.r.l. Extracted from www.stpitaly.eu/bus_lubricants.shtml

Finished oil is then sent towards the fractioning column and separated into two regenerated basic oils cuts (150 SN and 500 SN) that have the same specifications as their corresponding new base oils. The column bottom is recycled towards the vacuum distillation column.

The vacuum in the three different columns is maintained by means of vacuum systems composed of ejectors and tubular condensers. The heat demand of the plant is met through a thermal oil furnace.

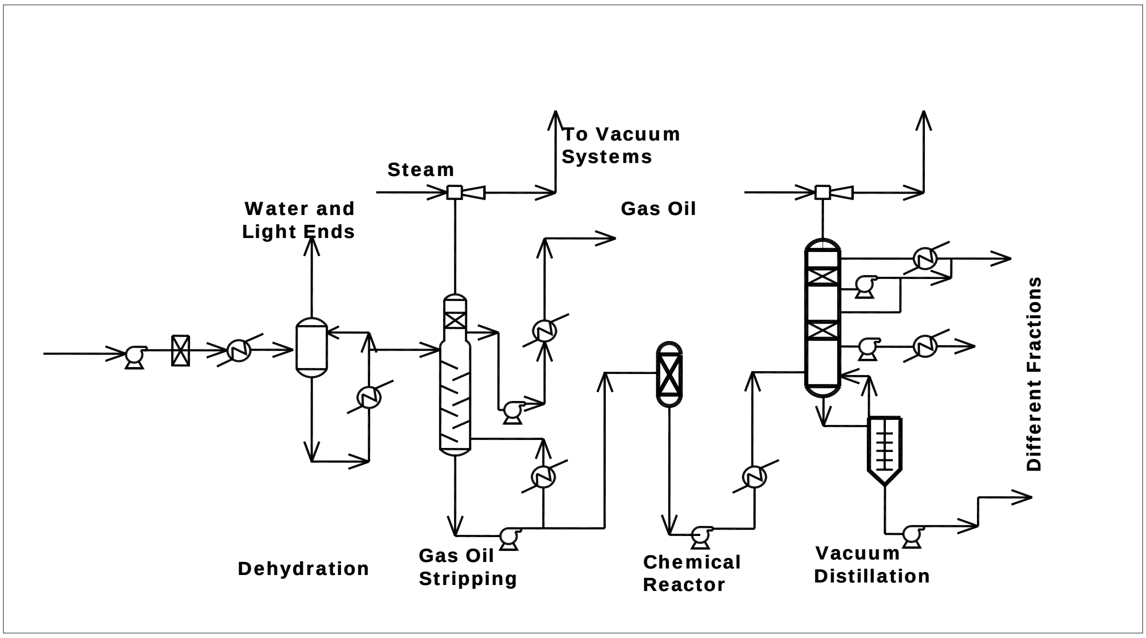


Figure 2.3.3.8.1: Process flow diagram of API Group I base oil

2.3.3.9 Degussa Process (Transformer Oil Recycling) ("C")

2.3.3.9.1 Process Description

The Degussa Company has used a sodium process for used oil re-refining together with other companies, the aim being to perfect sodium treatment for regeneration of electrical insulating oils contaminated with PCBs. An example is the Enervac PCB Decontamination Unit in Canada. The process is patented in both Canada and the United States and has approval of both Environment Canada and the EPA.

The regenerated insulating oil has excellent electrical properties, comparable to those of new insulating oil and meeting the ASTM specification. The process does not produce any emissions, and is cost efficient and cheaper than other disposal means. It makes use of mobile on-site units.

Dispersed sodium used in the treatment is prepared according to the Degussa licensed process. According to Enervac, Canada, a small amount of molten metallic sodium dispersion is added to dehydrated and degasified insulating oil in a mixing tank. A reaction takes place that converts the PCBs into harmless compounds, common salt, and a few hydrocarbon residues. These are removed from the oil as sludge by centrifuge. The sludge is non-PCB-containing and can be disposed of as industrial waste.

2.3.3.9.2 Types of Waste Treated

Using this process, waste oil with up to 7,000 ppm of PCBs can be processed, to reduce the PCB level to below detectable levels (2 ppm).
Another example of this process is found in France, at Daffos et Baudasse, Cie., Villeurbanne, with a proprietary process that regenerates waste oils containing up to 10,000 ppm PCBs at 1,000 litres per hour.

2.3.3.10 Buss Luwa Vacuum Distillation/Clay Filtration Process ("C")

2.3.3.10.1 Process Description

This is another vacuum distillation/clay treatment process using a thin film evaporator which provides relatively trouble-free operation. The high-temperature vacuum distillation step is normally plagued by problems of fouling through coking and carry-over of resinous materials. Continual fouling of the distillation column causes substantial downtime and costly cleanups. Thin-film/wiped-film evaporators have helped to reduce these problems, and the Luwa thin-film evaporator minimises those problems commonly associated with high-temperature vacuum distillation. The time in the Luwa evaporator limits the amount of time the oil is subjected to high temperatures, while the agitation imparted by the rotor reduces hotspots that could allow degradation and coking. Another widely used technique is the Pfaudler wiped-film evaporator.

The Luwa thin-film evaporator is used in fully-automated, continuous mode by Booth Oil Company, Inc., Buffalo, NY, USA. It has also been installed in the biggest European re-refinery, in Dollbergen, Germany. The Pfaudler evaporator is used in the waste oil re-refining plants of Independent Oil Refineries, Australia, and Dominion Oil Refining Co., Ltd., New Zealand. The latter is an example of a successful re-refinery that markets a full range of gasoline and diesel oils as well as specialty and hydraulic oils derived from re-refined base oil. For the past two decades, these oils have been used in the bus fleet of the Auckland Regional Council with Daimler-Benz's endorsement.

No major environmental problems are expected with distillation/clay treatment technology. Odour and wastewater problems are not believed to be any more serious in this process than in typical acid-clay technology. It uses a barometric condenser, as the vacuum column can produce a large quantity of contaminated wastewater. Water- or air-cooled surface condensers are preferable to barometric condensers, but are more expensive, and their extra cost is generally balanced against the decreased cost of wastewater treatment.[41]

2.3.3.11 BERC/NIPER Hydrogenation ("R&D"/"OD")

2.3.3.11.1 Process Description

Bartlesville Energy Research Center (BERC), now called the National Institute of Petroleum and Energy Research (NIPER), technology was developed by US Department of Energy scientists. The technology is similar to the KTI Process, with the addition of a solvent treatment. Its essential steps include (i) atmospheric distillation, (ii) vacuum distillation, (iii) solvent pretreatment, (iv) solvent recovery, and (v) fractional distillation followed by (vi) either hydrofinishing or clay treatment.

The incoming feed is first dehydrated at atmospheric pressure and stripped of light hydrocarbons in the vacuum column. After distillation, the product is then extracted with a 3:1 mixed solvent, composed of butyl alcohol, isopropyl alcohol, and methyl ethyl ketone (1:2:1). The solvent extraction removes coking and fouling precursors.

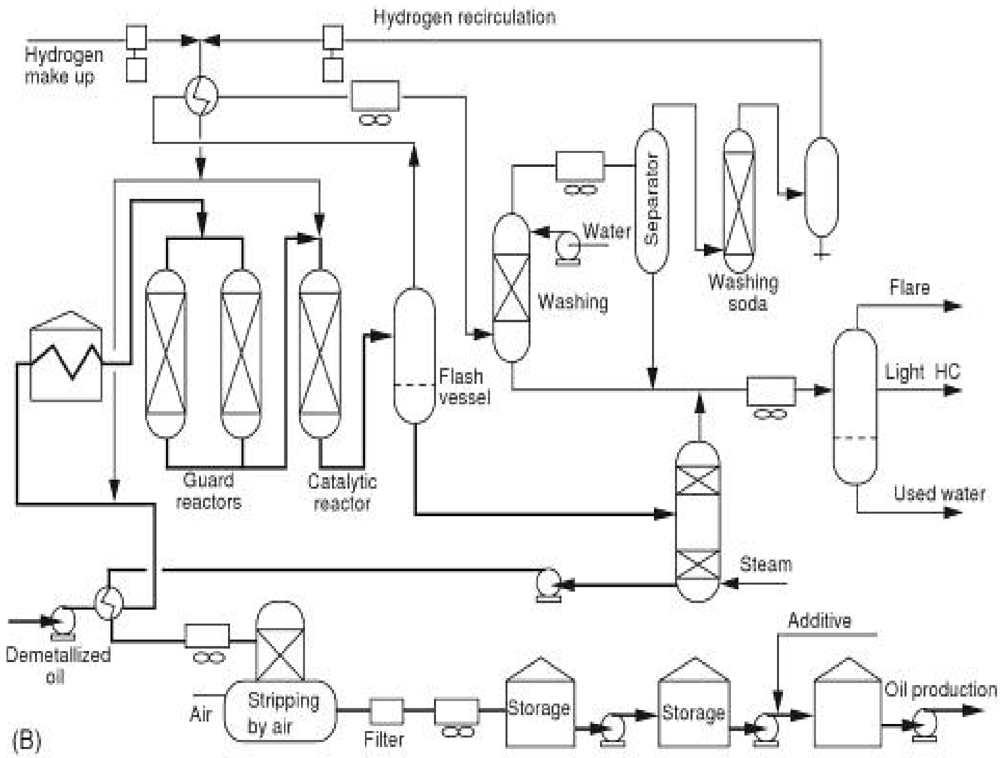
The solvent waste oil mixture is allowed to settle, and sludge, including additives, heavy metals, and other dirt, is drawn off the bottom of the settling tanks or centrifuged to recover the oil and solvent. The solvent is recovered for reuse. The extracted oil is fractionated in a vacuum distillation column, followed by hydrogenation or clay treatment of base oil fractions to improve odour and to remove colour.

2.3.3.12 Phillips Petroleum Company PROP[78] Hydrogenation Technology ("C")

2.3.3.12.1 Process Description

PROP technology, developed by the Phillips Petroleum Company, combines chemical demetallisation and hydrogenation to remove contaminants from the waste oil. The process begins by mixing an aqueous solution of diammonium phosphate with heated waste oil to reduce the metal content of the oil. Chemical reactions lead to formation of metallic phosphates, which are subsequently removed by filtration. The remaining oil is then flashed to remove light hydrocarbons, gasoline, and water. Next, the oil is mixed with hydrogen and percolated through a bed of clay, and passed over a Ni/Mo catalyst in the hydrogenation reactor. The adsorption step removes the remaining traces of compounds which might poison the catalyst. During the hydrogenation process, sulphur-, oxygen-, chlorine-, and nitrogen-containing compounds are removed and the oil's colour is thereby improved.

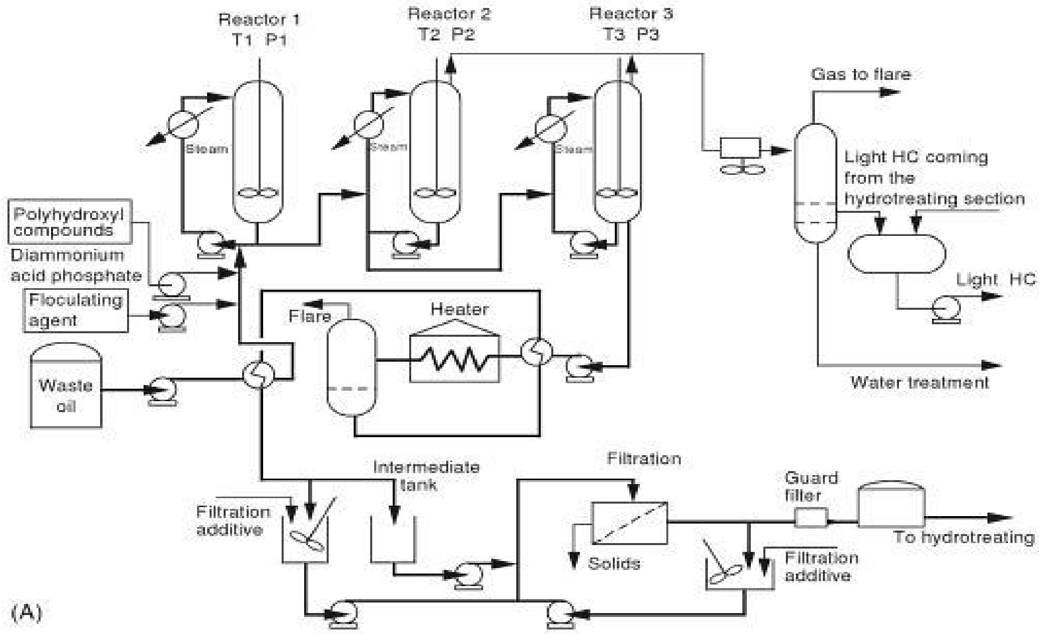
The major solid by-product is described as neutral phosphate material with no potential disposal problem. For example, this by-product can be safely disposed of in a landfill. Liquid stream byproducts relate to light ends and heavy gasoline which can be used as fuel. However, the used catalyst is typically treated as hazardous waste. Figure 2.3.3.12.1.a depicts the demetallisation process flow and Figure 2.3.3.12.1.b depicts the hydrotreatment process flow within PROP technology.



PROP Process (Phillips Petroleum) Hydrotreatment

Figure 2.3.3.12.1.a: PROP Process (Hydrotreatment)

[78] Audibert, F. Phillips Petroleum Company PROP Technology, Elsevier publication, 2006



PROP Process (Phillips Petroleum) Demetallisation

Figure 2.3.3.12.1.b: PROP Process (Demetallisation)

2.3.3.13 Entra Process ("C")

2.3.3.13.1 Process Description

The Entra Company has developed a new proprietary waste oil re-refining process that is, to some extent, similar to the above distillation/clay treatment approach, being also based on distillation and clay polishing. However, the key difference is that distillation is carried out in a special linear tubular vacuum reactor,[11] which consists of a single tube in which the waste oil stream in continuously converted into vapour by rapidly increasing temperature, followed by fractional condensation. The evaporation process, together with chemical reactions, related to cracking heteroatom-containing molecules, proceeds in a controlled How through precise zones of the tubular reactor, at relatively high velocities, with retention times of milliseconds, and maintaining the temperature within 0.2°C of the desired level.

Almost all impurities remain in the residue, which can be generated as granulate, containing all the solid waste oil impurities, soot, and metals. Sulphur and chlorine are converted into salts. Complete dechlorination of the used oil, including the removal of all PCBs, can be achieved by treatment with metallic sodium (usually 0.4% sodium) during which all the chlorine is converted into sodium chloride. To improve the colour of the regenerated oil, 1-3% Fuller's earth is applied.

A pilot plant based on this process has operated since September 1988, with a throughput of 400 kg/h. For dewatered waste oils, the yield of re-refined base stock is over 90%, depending on the contamination content. Another plant of 30,000 tonnes per year has been completed in Germany, for both production and research.

2.3.3.14 ORYX Process[79]: Vacuum Distillation ("R&D"/"C")

2.3.3.14.1 Process Description

The ORYX Process is basically a vacuum distillation process, employed for the purpose of treating used oils or waste oils. It recovers different grades of valuable products and segregates the residual part without addition of any chemical, coagulant or acid to the raw material. This means the quantity of waste generated will be minimised while the quality is of acceptable level so that the same can be safely disposed as a by-product without harming the environment.

From the storage tanks the oil is pumped into the process unit. The process plant consists of four distillation columns, of which the first three operate in series. Each distillation column, consisting of reboilers/heaters, coolers and condensers in addition to the vacuum system, circulating pumps etc., is called a module. The total system is enclosed and no gas is allowed to leak as these columns are operating under vacuum. The unit is capable of re-refining waste oils. The process conditions are adjusted depending on the type of waste oil.
For used oil re-refining using vacuum distillation with a clay treatment process, the parameters found suitable are as follows, together with a description of the process itself.

1st Module
The 1st module operates under 600 mm Hg vacuum and a bottom temperature of about 180°C and top temperature of 40°C. The products removed from this column are a mixture of water and diesel.

2nd Module
The function of the 2nd module is to remove fractions of base oils from the feed. This is accomplished by operating the 2nd module under a vacuum of more than 700 mm Hg and a bottom temperature of about 280°C.

3rd Module
The function of this module is to remove the last trace of base oil from used oil and the bottoms will be a mixture of bright-stock, carbon and other heavier ingredients present in the used oil. This column is operated at maximum vacuum (up to 757 mm Hg) created by a system consisting of vacuum boosters and pumps. The vapour - a mixture of air and a negligible quantity of hydrocarbon - is routed through a condenser to the heater/burner for incineration.

[79] Vacuum Distillation Process Description, http://oryxconsultancy.com/processdetails.html

The products drawn from this column are base oils and the residue can be disposed of as asphalt extender. The raw base oils from the 2nd and 3rd modules are sent to separate tanks. These raw products are recalled to the plant for further treatment with activated clay in the 4th module.

4th Module
The raw base oils produced in the 2nd and 3rd modules are intermediate products, which need further treatment with activated alumina clay. The purpose of the clay treatment is to improve the colour of the base oil, to give it a golden finish. The oil is mixed with clay in an agitator. The quantity of clay used varies from 2 to 5%, depending on the quality of the raw base oil and the clay. This mixture is subjected to heating under vacuum. The oil-clay mixture thereafter is cooled and sent for filtration. This clay is stored in a concrete pit. The oil filtered out at the filter press is a high-value product called lube base-stock. This base-stock of various viscosities is blended with lubricant additives for converting it into different grades of lubricating oils, which are then packed in steel drums and other small packs and sold as lubricants.

2.3.3.14.2 Effluents

The effluents from this plant are effluent water, gases and spent clay. The spent clay coming out from the filter press is stored in a concrete pit. The spent clay will contain about 40% oil content that can be burned in the boiler. It can as well be used for cathodic protection in oil and gas projects either in liquid form and/or carpet form, which is another source of commerce.

2.3.3.14.3 Advantages of the Technology

- High yield of products
- Conforms to environment standards

2.3.3.15 CEP Process[80] ("C")

2.3.3.15.1 Process Description

The first step in the Chemical Engineering Partners (CEP) Process is feedstock analysis and selection. Process considerations require evaluation of feedstock to ensure that it is suitable for re-refining.

The second step of the process is chemical treatment to reduce fouling in the process equipment. Used oil is difficult to process. Since the presence of additives and contaminants makes it very difficult to employ conventional petroleum processing techniques without accelerated fouling and coking in process vessels and heat exchangers. Hence wiped film evaporators are used.

[80] http://www.ceptechnology.com/technology.php?page=43

The third step in the process is to remove water and light hydrocarbons such as fuel. In some cases it is possible to use the light hydrocarbon by-products as plant fuel.

The fourth step of the process is removal of catalyst poisons before the hydrotreating step. Proprietary technology is used to remove the catalyst poisons to extend catalyst life.

The fifth step of the process is to separate the base oil from the additives and high boiling hydrocarbons. A wiped film evaporator operating under vacuum is used to achieve this separation. The vacuum allows separation at temperatures below oil cracking temperatures. The lower temperatures and short residence time in the wiped film evaporator minimise coking that occurs in other types of distillation equipment.

The sixth step is hydrotreating. Three hydrotreating reactors are used in series to reduce sulphur and increase saturates to produce base oils meeting specifications for API Group II base oil. Figure 2.3.3.15.1 depicts the process flow diagram.

The final step is vacuum distillation to separate the hydrotreated base oil into multiple viscosity cuts in the fractionator.

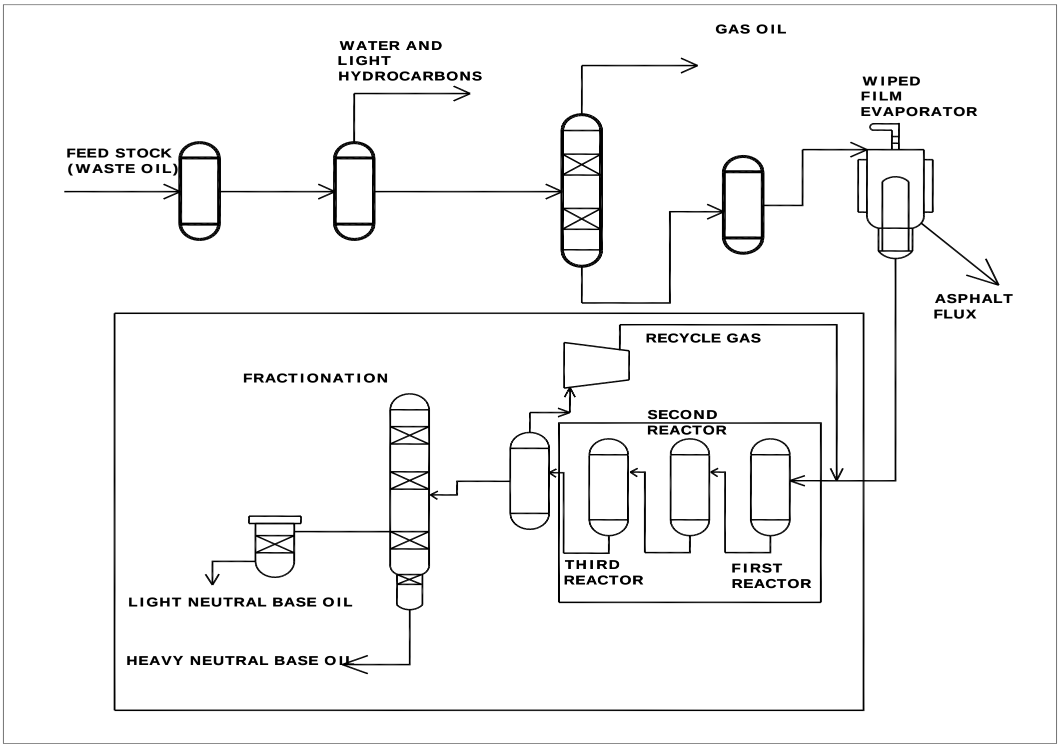


Figure 2.3.3.15.1: CEP Process flow diagram[81]

The vacuum distillation process in use for some recycling/re-refining technologies is based on conventional vacuum distillation (plate/packed) followed by clay treatment and filtration. The wastes generated in this variant are the same, i.e. distillation residue and spent clay, which need proper disposal.

[81] http://www.ceptechnology.com/processtechnology/the-cep-process.aspx

Some of the other re-refining technologies operating in the world on vacuum distillation approach are the Revac process, STP-Sotulub, Probex, and Tiqson, with capacities ranging from 16,000 to over 120,000 tonnes per year.

2.3.3.16 Vaxon Process[82] ("C")

2.3.3.16.1 Process Description

The Vaxon process is used in Germany, Denmark, Spain and Saudi Arabia for recovery of base oils from used lubricating oils. This process involves chemical treatment, vacuum distillation and solvent refining units. The advantage of this process is the special vacuum distillation unit (Vacuum Cyclon Flash Evaporator), in which the cracking of oil is highly decreased.

In the first section of this process the chemical treatment is carried out with alkali-hydroxides (sodium- and potassium-hydroxide) for removal of chlorides, metals, additives and acidic compounds. Alkoxides are formed on the catalyst surface from the insoluble alkali-hydroxides, which are soluble in oil. The impurities can be bonded with asphalthene molecules by these reactants, therefore these impurities can be easily separated from the oil. Figure 2.3.3.16.1 depicts the Vaxon Process (CATOR process) Flow Diagram.

After the chemical treatment, the feed is separated into light products, catalysts, base oils and residue. The feed is distillated to two parts by a cyclonic column. Because of the formation of tangentially flowed thin film, the light hydrocarbons are easily and quickly distillated. The polycyclic aromatic hydrocarbons are separated by solvent refining with polar solvents (dimethyl-formamide, n-methyl-2-pyrrolidone, etc.). This is carried out in a multi-stage extractor, which is followed by solvent recovery from both phases. The raffinate contains wide boiling range base oil, which can be separated by vacuum distillation to different viscosity grade base oils. The polycyclic aromatic hydrocarbons, which concentrated in the extract, are used for heat energy production or as a bitumen blending component.

There is one known plant using this technology at the present time, run by CATOR (Catalana de Tractament d'Olis Residuals, S.A.) in Catalonia (Spain).

[82] Gorman, W.A.: "Recovering base oils from lubricants", Petroleum Technology Quarterly, 2005, (4), 85-88. (Cross reference of Possibilities for processing of used lubricating oils – part 2. MOL group)

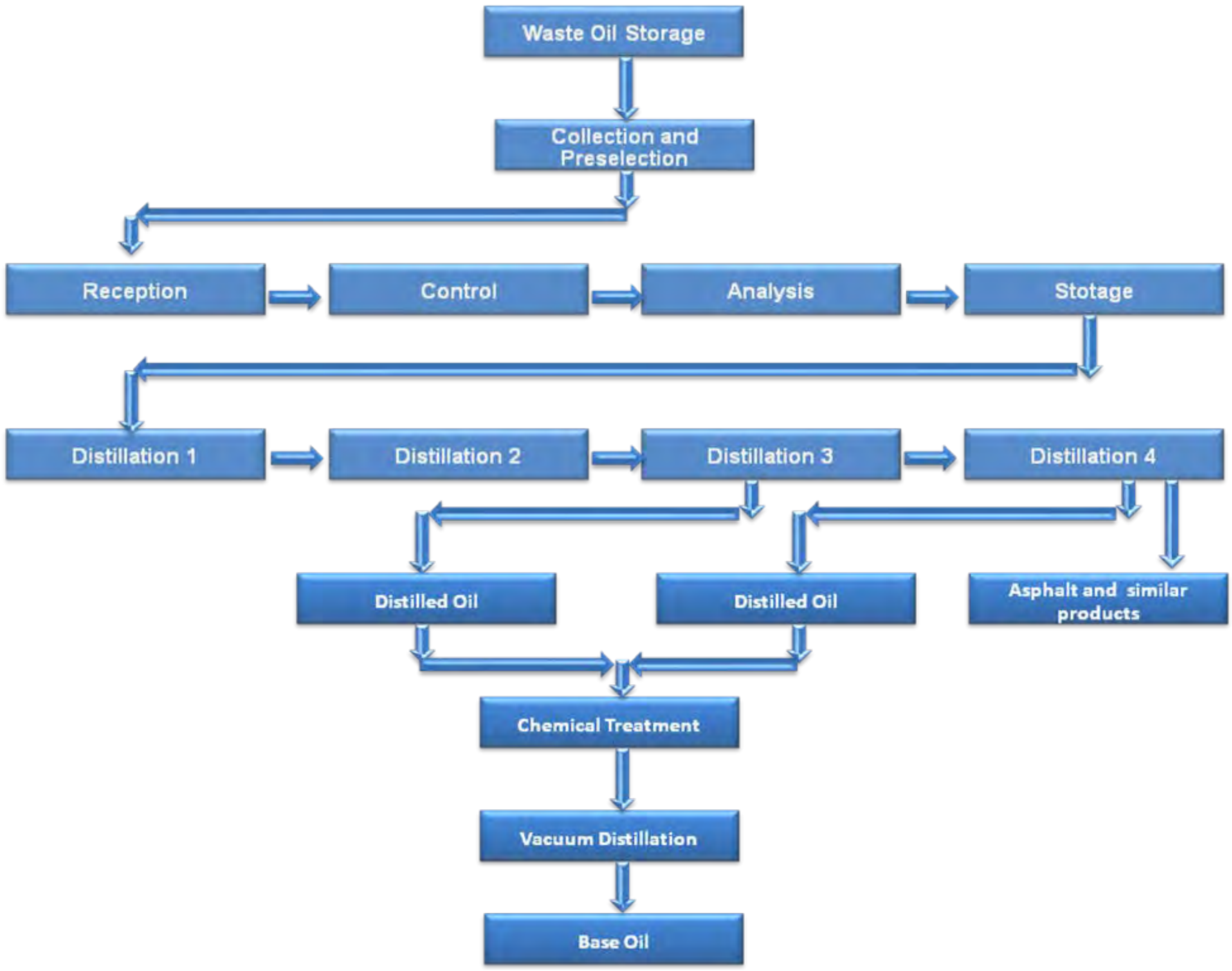


Figure 2.3.3.16.1: Vaxon Process (CATOR Process) flow diagram

2.3.3.17 MeinkenTechnology[83] ("OD")

2.3.3.17.1 Process Description

Meinken technology, based on acid clay treatment, is no longer used for economic reasons and because of the problems inherent to the treatment of acid clay/earth. It also involves problems of internal corrosion and disposal.

There are some refineries that work with modified Meinken technology at the present time. The inclusion of thin film and contact distillation techniques enables them to reduce the quantity of sulphuric acid to 3% and of clay/earth to 3.5%. Some of them also include hydrogenation.

[83] Regional Activity Centre for Cleaner Production, Mediterranean Action Plan (RAC-CP/MAP), Recycling possibilities and potential uses of used oils, November 2000

The main advantages of this process are the low investment and maintenance costs, the possibility of treating low quality used oils, and the flexibility and ease of handling the process itself.

2.3.3.18 Atomic Vacuum Distillation Technology[84] ("R&D")

2.3.3.18.1 Process Description

This technology is based on Shortpath vacuum distillation/clay treatment and is licensed by the Atomic Vacuum Company, Mumbai (India).

Used/waste oils are pre-treated to remove carbon sludge by flocculation using two natural polymers and separation by centrifugation and filtration. The pre-treated oil is passed through a TFE under medium vacuum and temperature for diesel, emulsified water and light hydrocarbon separation.

After this stage, the lighter oil fraction is separated by molecular distillation (high vacuum shortpath distillation). The residue from this process is high vacuum distilled under temperature over 350^{o}C and pressure 0.13 Pa.

The distilled oil is treated with Fuller's earth/clay for removing metals and producing base oils with the required viscosity and then mixed with additives.

Bottoms from high vacuum distillation and residue from filtration are used for producing soft asphalt, etc. Spent clay is reclaimed and reactivated 3 to 4 times by using solvent extraction and a high temperature activation process.

2.3.3.19 BlowDec Technology[85] ("R&D")

2.3.3.19.1 Process Description

The BlowDec process is a new technology developed from Slovak patent No. 279397. The basic goal is the separation of liquids and solids from the original waste material and the liquefying of the hydrocarbon based polymers by mechanical and thermal degradation of binding forces with simultaneous cracking of heavier hydrocarbons and inhibition of coke formation. The technology is proven for the recycling of waste materials with a high content of organic components, primarily waste mineral oils (waste oils), oil sludge and waste mixed plastics.

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[84] Giovanna, F.D., A. Lodola and S.Miertus, Compendium of Used Oil Regeneration Technologies, UNIDO, Trieste, 2003

[85] Mad'ar, I. and M. Juriga, A new method of the organic waste treatment concerning waste oil, mixed plastics waste, oil sludge and PCBs waste processing with simultaneous recovery of hydrocarbons, Petroleum and Coal, Vol. 45, 3-4, 187-192, 2003, http://www.vurup.sk/sites/vurup.sk/archivedsite/www.vurup.sk/pc/vol45_2003/issue3-4/pdf/20.pdf

The main principle is the processing of waste organic materials in a hot whirling bed created by solid particles, for example hot sand, in special equipment - the BlowDec reactor. The process is also suitable for the treatment of the different types of waste with organic content refinery sludge, oil-contaminated earth and similar materials polluted with hydrocarbons. During the BlowDec process, both physical and chemical activities occur, resulting in almost 100% separation (recovery) of the hydrocarbons from the waste stream.

2.3.3.20 Dunwell Process[86] ("R&D"/"C")

2.3.3.20.1 Process Description

The used oil re-refining process, which was developed by Dunwell Co., was pursued by Lubrico Co. beginning in 1990. The same process was developed in 1992 by the Estate Co. in Hong Kong. Both of these processes have a capacity of about 50 tonnes per day. In the first step, the feed is separated from solid impurities by filtering, centrifugation and settling or a combination of these processes, and then further dewatered. The dewatering is carried out at 150°C and atmospheric pressure. In the second step, the light hydrocarbons are separated by heating to 230°C. The residue oil is cleaned by vacuum distillation.

By 2008, Dunwell Engineering Company Ltd (DECL) had further improved upon its re-refining process using VMAT (Vibrating Membrane Used Lubricating Oil Recycling Technology), a state-of-the-art technology being adopted in various countries because of its advantages in energy efficiency (85°C), cost effectiveness, and ease of handling, unlike many other processes whose energy intensity is very high, requiring processing at 350°C.

VMAT can also be adopted through the retrofitting of existing used lubricant recycling plants, resulting in better economic returns.

2.3.3.21 Interline Re-refining Process ("R&D"/"C")

Figure 2.3.3.21 depicts a simplified Interline Process flow diagram. The used oil feed is mixed with propane and the mixture is then sent to a specific solvent extractor, a proprietary system. Most of the additives, water and other insolubles are separated from the propane/base oil mixture. The solids and water settle to the bottom and enter the residuum/water separator where water is separated from a tar-like material which goes to the asphalt blending tank. In this tank, the tarlike material is blended with the vacuum distillation residue to produce an asphalt extender/modifier product. The solvent/oil mixture is pumped to an oil/solvent separation system. The propane is vaporised at a pressure high enough to allow the propane to be condensed at the cooling water temperatures. The recovered propane is then returned to the solvent extractor to be re-used with incoming used oil. Propane-free oil is sent to a light hydrocarbon stripper where the last traces of propane and low-boiling hydrocarbons (gasoline) are removed. The flash-adjusted oil is then directed

[86] Ho, S.C., K. Ng: "Magic Behind the Re-refining of Spent Lubricating Oil," 1995/96 Annual Issue IIE (HK), 1996. (Cross reference of 'Possibilities for processing of used lubricating oils – part 2,' MOL group)

to a traditional vacuum distillation column. The distilled lubricating oil product is a high-quality base oil which, with a clay polishing step, can be blended and marketed as a virgin quality lubricating stock.
The extraction process removes the majority of additives. Propane extraction of the used oil results in a number of significant technical/economic advantages over traditional re-refining technologies that do not include a hydrogen treatment stage. Most importantly, it allows economic re-refining at volumes much lower than existing non-acid treatment technologies. The Interline technology eliminates the need for wiped-film distillation because the extraction phase removes most of the used oil impurities that cause problems in traditional distillation columns. As the process also eliminates the need for a hydrogen finishing stage, it cannot handle waste oil contaminated with PCBs.

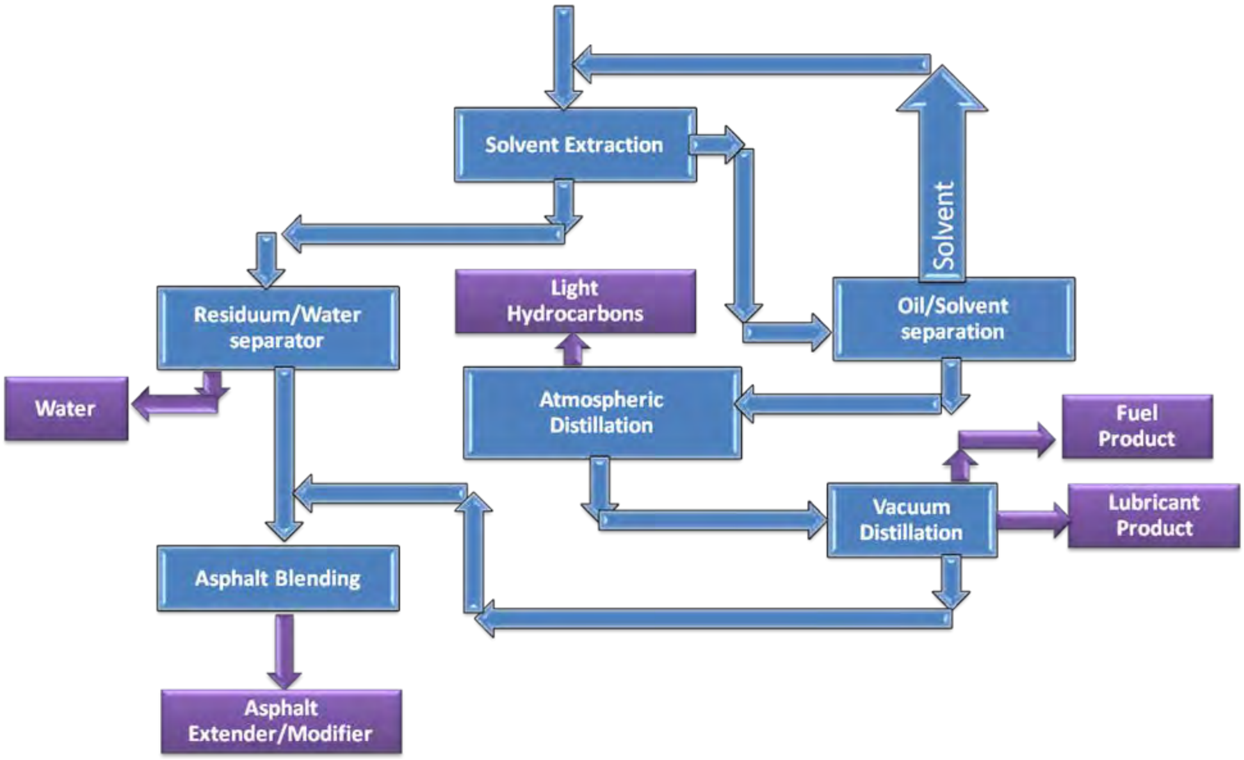


Figure 2.3.3.21: Schematic of Interline Process

2.4 Burning of Waste Oils

The burning of waste oil is generally done via two different routes, specifically, direct burning without any treatment or burning after some degree of treatment. Burning of waste oil could be with or without any heat recovery, depending on the quality of the waste oil and the type of system used. Generally speaking, to the extent feasible, the heat recovery approach should be preferred, in accordance with the hierarchy of waste management practices. Burning of waste oil with heat recovery enables utilisation of its calorific value. When used as a substitute fuel, principally in place of coal, diesel and light fuel oil, waste oil also has economic value. A number of different burning applications for used oil exist, distinguishable partly by the temperature at which they burn, and partly by the control technology they use to reduce adverse environmental effects.

Waste oils, as mentioned earlier, contain heavy metals such as arsenic, cadmium, chromium and lead. Low temperature burning of waste oil can result in gaseous emissions. The emissions from burning waste oils reflect the compositional variations of the waste oils. Potential pollutants in gaseous emissions can include carbon monoxide (CO), sulphur oxides (SOx), nitrogen oxides (NOx), particulate matter (PM), toxic metals, organic compounds, hydrogen chloride, and dioxins/furans.

2.4.1 Using Waste Oils as Fuel by Controlling Parameters[87]

Levels of contamination in waste oils varies widely, depending on how the oils were used or the length of use of the virgin lube oil. Recognising this fact, the US EPA has established a set of criteria, called used oil specifications, to control the potential hazards posed by used oil when burned for energy recovery. Table 2.4.1 provides these allowable parameters for the waste oil to be used as fuel.

Table 2.4.1: Allowable parameters for using waste oil as fuel

Parameter	**Allowable limit**
Arsenic	5 ppm max
Cadmium	2 ppm max
Chromium	10 ppm max
Flash point	38^{o}C min
Lead	100 ppm max
Total Halogen	4,000 ppm max

Any waste oil which is tested and is not within these set parameters is termed off-specification used oil. Off-specification used oil may be burned for energy recovery, but it is strictly regulated. Such used oil may only be burned in:

- Boilers
- Industrial furnaces
- Hazardous waste incinerators

[87]US EPA, Hazardous Waste Recycling and Universal Wastes, http://www.epa.gov/osw/inforesources/pubs/orientat/rom32.pdf

- Space heaters

Once the specification determination is made, the on-specification oil is no longer subject to used oil management standards.

Conversely, used oil that meets all specification levels, otherwise known as on-specification used oil, is not subject to any restrictions when burned for energy recovery. In fact, on-specification used oil is comparable to product fuel in terms of regulation.

Another body, the Ohio EPA,[88] also allows the burning of waste oils under its rule 3745-279-11, provided that the oil meets the above mentioned parameters with an additional one, namely PCBs of less than 2 ppm.

The US EPA has also established rules that allow for the burning of waste oils for energy recovery and publishes the pertinent regulations in the Federal Register.[89] The section that pertains to the waste oil burning industry is covered in 40 CFR, part 279. Rather than monitoring air emissions, the EPA has written regulations about what is being burned. If the oil is acceptable then the emission will be acceptable. Waste oils are divided into two categories. Those that are relatively benign and create little concern when burned are called "on-specification oils," while those that contain more than the allowable limits of heavy metals, halogens, or the presence of low volatile fuels are called "off-specification oils."

The EPA regulations allow the burning of "on-specification" waste oils in equipment designed for energy recovery, generally without limitation. "Off-specification" waste oils are also allowed to be burned but are limited to devices that are 500,000 BTUs or less, vent to the outside and burn only oils generated on-site.

2.4.2 Generic Technologies for Burning Waste Oils

As discussed earlier, waste oils, depending upon the level of contamination, can either be burned directly or converted into fuels.

2.4.2.1 Direct Burning of Waste Oils

Burning waste oil without pre-treatment is one disposal option with several different methods of energy recovery. These vary in popularity depending on local economic and legislative circumstances. Direct burning is generally carried out in high temperature combustion systems to ensure complete combustion and avoid the release of harmful substances like dioxins/furans. Burning waste oil as a supplemental fuel in cement kilns is commonly used. In Europe, it is estimated that over 400,000 tonnes/year of waste oil is burned in cement kilns. On a smaller scale waste oil is also burned in space heaters. Heaters with specially designed combustion systems are used for this purpose. This method provides an economic source of heating and the waste oil can be disposed of at the point of generation. Care

[88] http://epa.ohio.gov/portals/32/pdf/Used_Oil_Burner_Guidance.pdf
[89] Waste Oil Burning Equipment: Burners, heaters (furnaces) and boilers. http://www.wasteoilheat.com/

needs to be taken to ensure that such systems do not contribute to air pollution. Accordingly, appropriate control systems need to be used. Waste oils that are too contaminated are also disposed of by burning in hazardous waste incinerators.

2.4.2.2 Burning after Mild Processing

In some applications waste oils may require a simple cleaning process before further use. Water and sediments are settled in tank after mixing used oil with a demulsifier. Settling is facilitated by heating the tank up to 70/80°C. The clear oil is decanted and passed through a series of filters as necessary. The waste and sediments are treated before disposal.

The processed oil may be blended into fuel oil. In this case the maximum amount of processed used oil which may be blended with other heavy oils is limited by a specification on ash content (generally about 0.1% max) and subject to meeting viscosity range specifications. The blended fuel may be sold as bunker fuel.

The processed oil can also be used as fuel in burners to dry limestone and hard stones being used as road surfacing materials. Waste oil has been an effective substitute for light gas oil in the road stone industry for several years, lowering operating costs and providing an easy disposal route. This process is commonly used in the UK, although in Italy this process is not permitted by environmental authorities. Where waste oil is used for drying limestone, some acid contaminants are likely to be captured by the limestone, thus making this option relatively more environment friendly. Waste oil can also be utilised in pulverised coal power stations, mainly as furnace start-up fuel, but also as an addition to the main fuel where heat input is restricted.

2.4.2.3 Burning after Severe Reprocessing

Severe reprocessing transforms waste oils into fuel oils which can be burned with similar emissions to those from burning other fuels.

The waste oils are treated in a process unit including:

- a flash column to remove water
- a distillation column operating under light vacuum to remove light ends and gas oil,
- a high vacuum distillation column to produce:
    - distillates
    - vacuum residue containing sediments, heavy hydrocarbons, metals and additives.

The efficiency of the vacuum column may enable the production of distillates with metal content of less than 1 ppm. Organic chloride compounds may still remain in the distillate.

To use waste/used oil as fuel, several cleaning or transformation treatments as discussed above are applied. These are summarised in Table 2.4.2.3.[90]

Table 2.4.2.3: Treatments applied to waste oils before their use as fuel

Type of treatment	Changes that occur in the waste oils after treatment	Fuel use	Industrial sector use
No treatment—used directly in a combustion process	No change	Directly used as fuel in kilns, furnaces etc.	Waste incinerators; cement kilns; marine oils; space heaters (garages, workshops etc.)*; on board ships (typically using marine oils); quarry stone industries
Mild reprocessing	Removal of water and sediments	Waste fuel blend to fuel oil (replacement of fuel oil)	Cement kilns; road stone plants; large marine engines; pulverised power plants
Severe reprocessing (chemical or thermal processes)	De-metallised heavy fuel oil (or heavy distillate)	Waste fuel blend to fuel oil (replacement of fuel oil)	Marine diesel oil; fuel for heating plants
Thermal cracking	De-metallised and cracked products	Distillate gas oil	Gas oil (also called heating oil, diesel oil, furnace oil, etc.); de-metallised heavy fuel oil; marine gas oil; re-refined light base oil not used as fuel
Hydrogenation	Reduction of sulphur and PAH contents		
Gasification	Converted to synthesis gas (H_2 + CO)	Fuel gas	Chemical production of methanol; large combustion plants (e.g. gas turbines)
*Forbidden in some countries			

[90] European IPPC Bureau, Institute for Prospective Technological Studies, Joint Research Centre, European Commission, 2006. Integrated Pollution Prevention and Control: Reference Document on Best Available Techniques for the Waste Treatments Industries. eippcb.jrc.es/reference/BREF/wt_bref_0806.pdf

2.5 Advanced Waste Oil Recycling Technologies

2.5.1 Thermal Cracking Based [91] [92]

Waste oil is recycled on a large scale into fuels (fuel oil, diesel) or fuel for energy recovery through a thermal conversion process, carried out under appropriate pressure temperature and residence time, particularly in the US, Australia and other European countries. Some of the technologies, commercial and non-commercial, based on the above concept are as follows.

2.5.2 Springs Oil Conversion (SOC)

Springs Oil Conversion (SOC) technology has been developed by Silver Springs Oil Recovery Inc, Canada. Two processes are available.

2.5.2.1 SOC1: Waste oil de-watering is followed by thermal cracking performed in fired heater coils with soaking drums or heated kettles. This process is suited to small plants in the 6 kt to 15 kt/yr range.

2.5.2.2 SOC2: The de-watering is followed by the thermal cracking performed in an indirectly fired rotary kiln. It is suited to large capacities and can process oils more refractory to thermal cracking (such as synthetic oils) and higher carbon residues (bunker fuels). While the quality of fuel products obtained from it is poor, like in the above technology, the technology is commercial on a relatively large scale. There are about 25 plants around the world with capacities ranging from 300 tonnes to 12,000 tonnes per annum.

Figure 2.5.2 depicts the schematic of the SOC process.

[91] http://medical.kellysearch.com/profile/springs+oil+conversion+inc/ca/ab/calgary/t3b+3t8/900525655, Canada, http://www.springsoil.com/

[92] Taylor Nelson Sofres Consulting, Critical review of existing studies and life cycle analysis on regeneration and incineration of waste oils , Final Report 2001, European Commission, DG Environment , A2 – Sustainable Resources Consumption and Waste

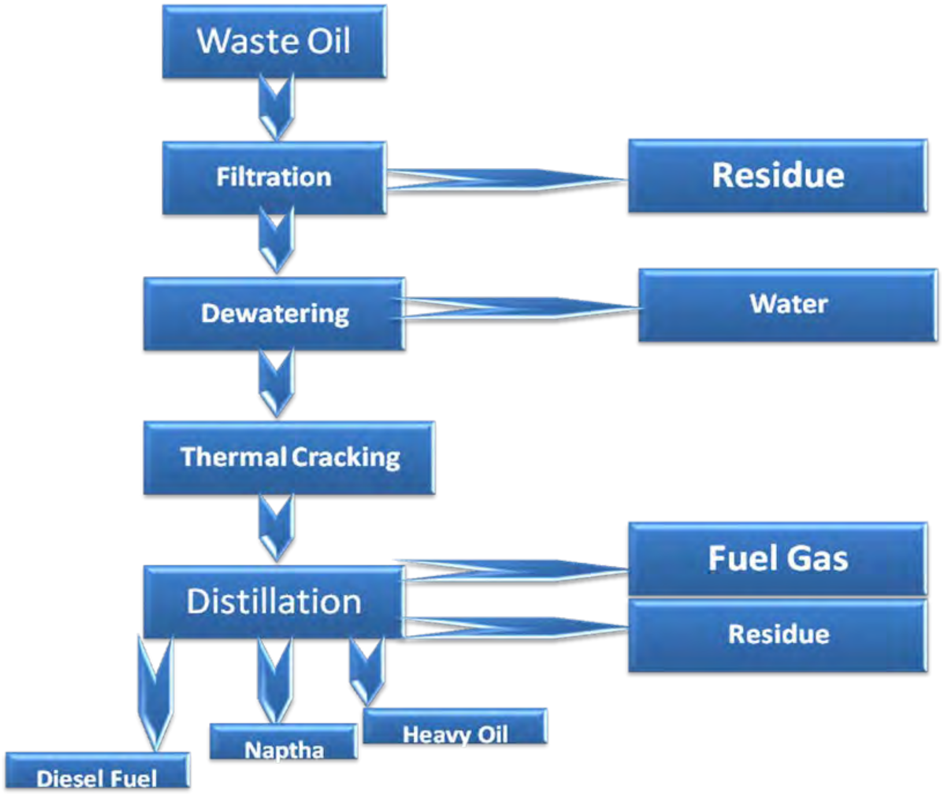


Figure 2.5.2: Schematic of SOC Process

2.5.3 Great Northern Processing Inc. (GNP) Thermal Cracking Process (Propak Process)

GNP technology was developed in the United States, offered under license by Propak Systems Ltd., Canada, and marketed by Par Excellence Developments, Canada. The thermal cracking of waste oil, utilising 'refinery calibre' systems and equipment, was developed in 1995-96 and was successfully re-applied in a 30 kt commercial operating plant by a US company to produce high quality gas oil distillate from a feedstock of waste oil. This technology was installed in Belgium by the end of 2001 with plant capacity of 40 kt/yr operated by WATCO.

The process consists of a screening and de-watering section, followed by a thermal cracking section, then separation or distillation, depending on the product slate desired, and finally a purification and stabilisation stage. This technology is characterised by substantial operational and product flexibility and adaptability to the changing market values of products. It can also be manipulated to maintain product quality with feed variability. Process operating conditions (temperature, pressure, residence time, etc.) can be varied to produce a primary product (be it heavy fuel oil, gas oil or base oil) to be maximised and secondary product streams (consumed in the process for calorific value or sold) to be minimised. Figure 2.5.3 depicts the schematic of the Propak Process.

The technology is limited to a few plants in Canada and Belgium.

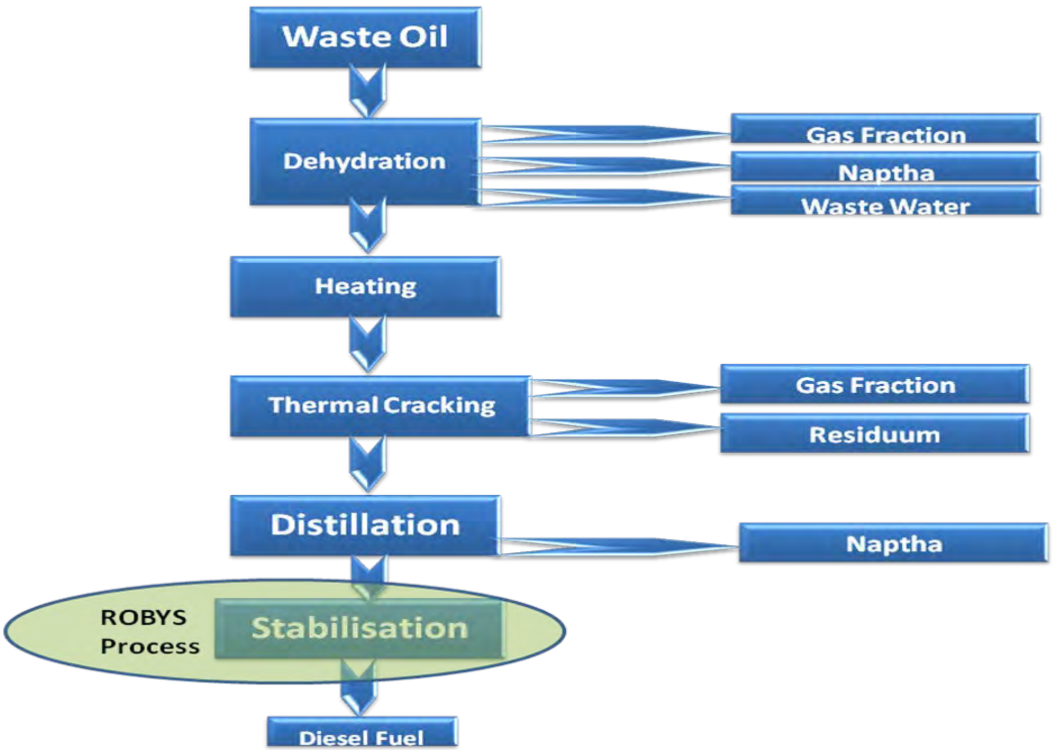


Figure 2.5.3: Schematic of GNP Thermal Cracking Process (Propak Process)

2.5.4 Environmental Oil Processing Technology [93]

EOPT (Environmental Oil Processing Technology) – Nevada, USA

The waste oil after dewatering is subjected to thermal cracking in a gas-fired tube heater. Long chain molecules are broken into smaller molecules. The cracked oil is fractionated for separation of marketable products: naphtha, diesel, residual fuel.

One plant is operating with this technology in Nampa, Idaho, USA.

2.5.5 EADIEMAC Process for Recycling of Used Lubricating Oils [94]

Used/waste oil is thermally cracked into diesel or marine diesel (MDO). The impurities of the waste oil are concentrated into a tarry waste material. The technology is still under pilot scale (demonstration plant: 150-200 bbls/day).

[93] Glovanna, F.D. et al., United Nations Industrial Development Organisation, Compendium of Used Oil Regeneration Technologies, Trieste 2003
[94] Eadie, W., P.Eng. Eadie Oil Inc., http://eadie.com/used/used.pdf

2.6 Selection of Appropriate Technology

There is no single re-refining process that is perfect for every country. Much depends on the throughput and processing flexibility desired. However, it is worthwhile noting that current technology seems to be converging towards a two-step procedure, vacuum distillation of dehydrated waste oil, and subsequent hydrotreating of distilled stocks. Such technologies usually produce high-quality base oils and concentrate the contaminants in the distillation residue. Other re-refining technologies, for example, extraction based Interline technology and UOP Hylube, also show promise.

The criteria for selection of a particular re-refining technology are described in the following section. The users of this compendium are advised to consider the following important parameters before making a selection of any technology. For larger users, it would be perhaps necessary to undertake a comprehensive techno-economic evaluation of the project through an experienced consulting agency.

2.6.1 Criteria and Considerations for Technology Selection

2.6.1.1 Availability of Waste Oils

The cost of logistics plays a very important role in the overall economics of a recycling plant. As recurring costs are very high for both inward and outward transportation, substantial funding is also needed for the work in progress as well as the inventory of raw and finished stocks. This is the primary factor to be considered when establishing a re-refining commercial plant at a particular location. Large industrial cities with a greater population of vehicles are probably the best location, because of the high potential of waste oil generation and availability.

2.6.1.2 Potential for Pollution

Technology selection goes generally in favour of the technology that is least polluting or more environmentally friendly. For this very reason the acid-clay based technology has been mostly phased out in many countries. Between vacuum distillation and solvent extraction base technologies, the choice is generally for vacuum based technology, as it is relatively lower polluting and uses no hazardous chemicals in the process. Extraction based technologies widely use propane solvent which has hazardous characteristics (flammability) and this limits its adoptability.

2.6.1.3 Emissions and Emission Norms of the Possible Site

Any industrial activity launched at any place results in a certain amount of air, water emissions and solid wastes. In many highly industrialised cities, emissions and waste generation levels may already be alarming or higher than those allowed by the concerned regulatory bodies, such as those responsible for pollution control. Under such circumstances, eco-friendly technology with additional pollution abating equipment may be necessary.

2.6.1.4 Extent of Technology Commercialisation

This also is a major consideration when selecting a particular technology because of the large availability of data and experience regarding all aspects of the technology.

2.6.1.5 Other Considerations

Other considerations may include resource conservation, energy efficiency, high product yields, minimum waste generation and higher capacity (larger plants support better pollution control activities).

2.7 Issues Relevant to Developing Countries

In light of the realisation that waste oils have a high potential to cause air, water and land pollution, no distinction should be made between developing and developed countries when deciding whether or not to introduce environmentally sound technologies (EST). At the same time, a certain degree of leniency is worth considering in the case of developing countries. The regulations can be continuously strengthened as stringency is fortified gradually.

In developing/underdeveloped countries, there may be a lack of awareness among the general public or insufficient infrastructure to support a large or medium industry.

It is suggested that developing countries choose a simpler re-refining technology (e.g. vacuum distillation followed by clay treating), which has lower investment needs. The management of waste oils through such relatively less eco-friendly technologies may have a better effect than from not having any management system in place for waste oils.

Other generic technologies based on vacuum distillation and extraction followed by hydrogenation are capital intensive and are viable for lager capacities (say, above 10,000 MT per annum). Although waste oil may be available in large quantities, availability may be very thinly distributed over a larger geographic region, making it economically unviable to collect and transport. Most developing countries may not have enough raw material to support these large capacities. All hydrogen based technologies are out of context here as even some developed countries have not adopted these insofar as they are highly capital intensive and they also carry higher operating costs. Ultra-filtration based technologies at present have yet to gain a significant presence even in the developed world.

2.8 Comparative Evaluation of Process Sequence of Specific Technologies

Table 2.8 overviews various processes and technologies that permit the re-use and application of used oils, both mineral oils from the industrial sector and vegetable oils from restaurant activities. The numbers in the corresponding boxes indicate the sequence in which the process (shown in column 1) is carried out.[95]

Table 2.8: Comparative evaluation of process sequence of various technologies

	Meinken	KTI	Mohawk	Berc-Niper	Prop	Safety Kleen	IFP	Snamprogetti	UOP DCH	Viscolube	RTI	Interline	Rose Kellog	Entra	Recyclon	Vaxon	CEA	Krupp Koppers
Atmospheric distillation	1	1	2	1		1	1	1		1	2	3						NA
Chemical pre-treatment			1															NA
Demetalisation					1													NA
Separation											1							NA
Extraction of solvent				3			4	2, 5				1	1					NA
Recovery of solvent				4				3				2						NA
Acid and earth treatment	2									4								NA
Vacuum distillation		2	3	2	2		2	4	3	2	3, 4	4	2	1, 2	1	1		NA
Chemical treatment									2					3	2	2		NA
Hydrogenation		3	4	6	3	3	3, 5	6	1	3			3					NA
Thin-film distillation	3					2								4	3	3		NA
Fractioning		4	5	5	4				4				4					NA
Earth treatment				7								5						NA
Autoclave, ultrafiltration																	1	NA
Hydrocarbon fumes under hypercritical conditions			6															1

2.9 Socio-economic Implications of Recycling

As detailed in the following section, the destruction of waste oil has its own share of both brighter and darker sides. However, it must be said that notwithstanding the darker aspect of having to live with hazardous waste, recycling offers many times more advantages to individuals, communities and the globe as a whole. Though hazardous, the residues from all

[95] The Regional Activity Centre for Cleaner Production, Mediterranean Action Plan (RAC-CP/MAP)

the processes can be dealt with by adopting appropriate routes and processes for handling them, including secured landfill as a last resort.

Underdeveloped countries definitely have an advantageous position compared to advanced countries, because the energy intensity (specific energy consumption for recycling) can be brought down through the use of manual labour in most of the operations, e.g. handling drums and barrels, loading and unloading the products, labelling, maintaining records and other administrative procedures and so forth, which account for a major portion of energy in the processes. Even some of the technical operations like operating the filter presses can be undertaken using manual labour, through minor modifications and appropriate leveraging as well as indigenous designs using local skills.

The recycling operation opens up a large and vast canvas of opportunities, including those overviewed below.

2.10 Employment Potential of Waste Oil Recycling

The re-refining industry definitely has good potential for providing jobs in addition to the conservation of natural, quickly depleting petroleum resources. This industry therefore must be encouraged by the governments of the countries particularly the developing countries and they may even provide financial assistance by way of subsidies, tax rebates or other fiscal measures for environmentally friendly management of the waste oil.

All developing countries now have some rules and acts in force regarding the environment, water, air and soil to keep pollution under check. Local institutional and regulatory requirements do play a very major role in selecting and adopting appropriate technologies. The pros and cons are examined in light of all above points.

The labour requirement of any system is inversely proportional to the level of technology deployed. Irrespective of the level and complexity of the technology, a major portion of the activities in recycling is common to all technologies. These are:

- Collection of the waste oils;
- Transportation or the oils to the recycling plant;
- Storage before recycling;
- Transporting waste oils to individual processing equipment between stages; and
- Periodic mechanical upkeep of different equipment like reactors, pipelines, motors and pumps, etc.

In addition, while assessing the employment potential of such projects, one must keep in mind that the manpower required is a function of the methods adopted and tools and tackles available for the same, irrespective of which activities are being carried out. By way of example, if we consider the contrast between two different situations for the same technology with different levels of mechanisation, we might find that one plant has installed a well laid out grid of pipelines to flow the oil from stage to stage, whereas the second plant has adopted fully manual operations. In the first case, the plant would perhaps need only one skilled and trained person to operate the pump, which could be controlled by appropriate sensors and indicators for the monitoring and control of the fluid, whereas the second plant would require a fleet of perhaps fifty unskilled persons to manually fill the barrels, move them, lift them, transfer the fluid manually into the reactors, transfer the products into finished product containers, load the products into trucks, and so on.

Hence it would be prudent to consider the socio economic conditions of the specific location under consideration and then take appropriate decisions about the level of technology to be deployed. Even if one is deciding to adopt a state of the art process, the supporting activities can be carried out manually, which would be beneficial to a region in which unemployment is a problem.

2.11 Categories of Jobs Offered by the Recycling Industry

The waste oil recycling industry offers a wide range of job opportunities for the local population. A few jobs generated would be of a managerial capacity, while most will be in the operations and supervision category. A few specific types of job opportunities include works manager, manager, shift supervisor, process operator, electrician, maintenance fitter, welder/plumber, stores assistant, accounts assistant, administrative assistant, plant security, procurement assistant, vehicle driver, unskilled worker (materials handling and logistics helpers), laboratory chemist, laboratory assistant, and various others (such as jobs in equipment maintenance).
All the above-mentioned jobs are of a primary nature, which would provide regular, full-time employment.

In addition, a considerable number of secondary jobs will be created, including positions for transport operators, oil tanker drivers, oil tanker helpers, employees' canteen operators, suppliers of consumables and various other positions (such as contract workers).

The exact number of such jobs entirely depends upon three basic parameters, namely, the level of technology, the number of shifts in a day's operations, the level of mechanisation, particularly with regard to materials handling, and socio-cultural conditions and work habits.

2.12 Skills Requirements

Waste oil recycling opens up opportunities spanning the whole spectrum of skills from totally unskilled labour to positions demanding the highest level of skill, including chemical analysis in the laboratory and operation of a fully automated process plant. Recycling also requires both a physically strong labour force and intellectually strong persons having substantial educational background. As mentioned earlier, some types of jobs, e.g. laboratory assistant or vacuum pump operator, are required in each plant irrespective of the level of technology employed. Similarly, in cases in which the plant does not have its own set of employees for general maintenance of the plant and equipment, local youth can be trained either by the technology provider or by any other appropriate agency. This would demand some basic level of education, such as industrial training in typical engineering skills for positions including welder, electrician, mechanic, plumber, mason, fitter, etc.

The process of involving various stakeholders in the initial stage of the project (as explained in the section of this compendium dealing with SAT) would also help raise social and environmental awareness levels.

2.13 Operation and Maintenance Requirements

It is suggested here that information on operation and maintenance, investment and operating costs regarding any particular re-refining technology can best be provided by the selected technology licensor.

The equipment needing maintenance is classified into two broad categories, specifically, (A) a general category and (B) a special category.

2.14 Equipment in a Recycling Plant

2.14.1 General Category Equipment

In general, irrespective of the technology adopted, the equipment used in the recycling processes is similar to that used in any other process industry. Typical examples of such equipment include:

a. Fluid transfer pumps
b. Vacuum pumps
c. Filter presses
d. Pressure vessels
e. Storage tanks
f. Firefighting equipment
g. Automobiles (cars and truck/tankers)
h. Conventional lifting tackles, cranes
i. Laboratory equipment like Bunsen burners, muffle furnaces, distillation equipment, small rated pumps and compressors, etc.
j. Non return valves
k. Electrical system control panels

2.14.2 Special Category Equipment

The typical equipment in the unit is dependent upon the particular technology adopted. Some examples of such equipment are;

a. Solvent storage devices (for propane, hydrogen, etc.)
b. Thin film evaporators
c. Falling film evaporators
d. Vacuum distillation columns

2.15 Contact Addresses of Selected Re-refining Technology Licensors

Table 2.15 provides some ready reference contact details of known technology providers. As this is not an exhaustive list, readers may probe further to identify other providers.

Table 2.15: Contact addresses of selected re-refining technology licensors

Technology	Licensor	Address	Email/web address
Safety Kleen	Safety Kleen Systems Inc.	Corporate Headquarters 5360 Legacy Drive, Building 2, Suite 100 Plano, TX 75024, USA	www.safety-kleen.com
Viscolube/ IFP	IFP, France	Viscolube Italiana SpA Via Tavernelle 19 26854 Pieve Fissiraga Lodi, Italy Phone +39-0371 2503.1 (Switchboard) Fax +39-0371-98030	viscolube@viscolube.it
STP Process	S.T.P. (Studi Tecnologie Progetti S.r.l.)	STP Studi Tecnologie Progetti S.r.l. Piazzale Ezio Tarantelli, 97 00144 - Rome, Italy	stp@stpitaly.eu
CEP Process	Chemical Engineering Partners (CEP)	Chemical Engineering Partners 2415 Campus Drive, Suite 225 Irvine, CA 92612, USA Phone +1-949-440-8317 Fax: +1-949-440-8383	cepinfo@ceptechnology.com
Interline	Interline Resource Corporation	Interline Resource Corp. 160 West Canyon Crest Road Alpine, UT 84004, USA	ircinfo@interlineresources.com
UOP Hylube	UOP Honeywell	175 West Oakton Street Des Plaines, IL 60018, USA +1-847-391-2000	www.uop.com
Vaxon	Avista Oil Group	Bahnhofstr. 82 31311 Uetze, Germany 05177 85-0	www.avista-oil.com

Atomic Vacuum Distillation	Atomic Vacuum Company Mumbai, India	Atomic Vacuum Company W-146B, MIDC, Taloja, Navi Mumbai-410208, India	www.atomicvacuum,com
ProTerra Process	Probex Corporation	One Galleria Tower 13355 Noel Road, Suite 1200 Dallas, TX 75240, USA	www.probex.com

2.16 Treatment and Disposal of Residual Hazardous Wastes after Recycling of Waste Oils

While the useful products from the process are handled as any of their counter parts, it is the hazardous residues from the process that call for very special attention and the utmost care in handling and disposing them. As this is the end of the line output, there is very little or no value attached to it, and hence it needs to be safely disposed of. The well-accepted ways of incineration and subsequent disposal in secured landfills are the route to be followed.

2.16.1 Incineration[96]

2.16.1.1 About Incinerators

In parlance of destruction of hazardous components of recycled waste oils, an incinerator is a device capable of destroying all the hazardous components through the process of burning. Incinerator design should necessarily have a provision for scrubbing and ensure that no hazardous components escape from the system into the atmosphere.

There are different ways of incinerating this type of waste. Some of the contemporary features of such incinerators are, (i) open burning (open fire burning), (ii) a single-chamber, oven-type brick incinerator, and (iii) a small dual-chamber brick incinerator with no air pollution control. These designs are also commonly used in developing countries. Temperatures in the primary combustion chamber with supplementary fuel can reach about 800ºC but temperatures in the small secondary chamber are generally at about 600ºC. The combustion chamber may have a steel grate leading to a small bottom ash compartment. The secondary chamber does not have an afterburner and has a very short residence time (usually less than 0.2 seconds). The incinerator has a metal chimney of about 4 meters in length. Wood, kerosene or diesel may be added as supplementary fuel to the primary chamber. These incinerators have no temperature or pollution controls and they are sometimes used to burn only safety boxes containing sharps.

2.16.1.2 Multi-chamber Incinerators

[96] UNDP (n.d.), Guidance on Estimating Baseline Dioxin Releases for the UNDP Global Healthcare Waste Project

A multi-chamber excess air incinerator has two or more combustion chambers and may be of the retort type (see.2). The first chamber generally burns the waste at around 760ºC. A burner in the second chamber burns the flue gas. These incinerators typically use more than double the amount of air in the primary chamber than that needed for complete combustion.

Picture 2.16.1.2 A typical retort type multi-chamber incinerator

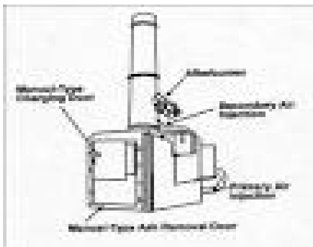


Figure 2.16.1.2 Diagram of a typical retort type multi-chamber incinerator

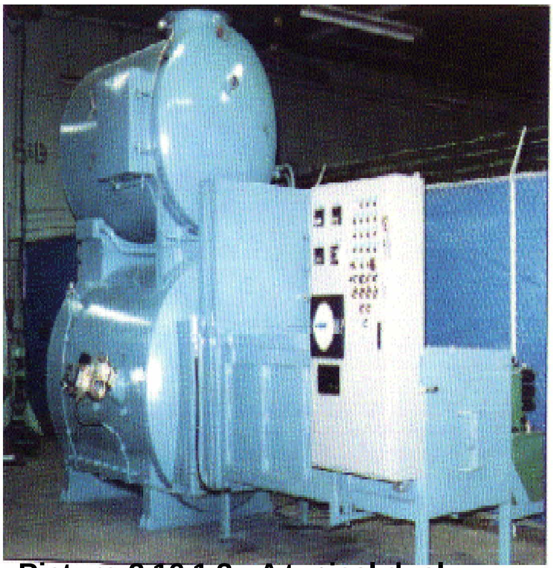
A dual-chamber controlled-air incinerator with a small secondary chamber, an afterburner and no air pollution control is also used in low to medium income countries. A controlled-air incinerator is sometimes called a starved-air incinerator, pyrolytic incinerator, or modular incinerator. Such incinerators have an internal refractory lining in the primary combustion chamber and have a small secondary chamber on top of or beside the primary chamber. Because they have auxiliary burners burning diesel, gas or other fuel in the primary chamber, they can reach combustion temperatures of 750ºC and higher. They have an afterburner in the secondary chamber capable of reaching 900 to 1000ºC with a short residence time of about 1 second. Temperatures are maintained by a simple controller. The primary chamber has a steel grate through which ashes fall into a bottom ash compartment accessible through an ash removal door. These incinerators have metal chimneys that are about 10 meters high. Except for the afterburner, there are no pollution controls.

A tubular incinerator is a single-chamber incinerator (having an internal diameter less than 0.6 meters and no more than 2 meters in height) with a bell-shaped system connecting the tubular chamber to the stack. The bell-shaped system allows air dilution of the exhaust gas. They are controlled by two burners and have no air pollution controls. Waste is loaded manually and the incinerator operates in a batch mode.

2.16.1.3 Suitable Incinerators for Hazardous Wastes from Recycled Waste Oils

With a view to ensuring that no hazardous components escape into the atmosphere, it is suggested that a dual-chamber controlled-air incinerator with a large secondary chamber, an afterburner, and a degree of air pollution control be used for this purpose.

A controlled-air incinerator is also called a starved-air incinerator, pyrolytic incinerator, or modular incinerator. Such incinerators have an internal refractory lining in the primary combustion chamber and has a large secondary chamber on top of or beside the primary chamber. Because such systems have auxiliary burners (using diesel, gas, or other fuel) in the primary chamber, the primary chamber can reach combustion temperatures of about 750 to 850ºC. The primary chambers have steel grates leading to an ash pit or ash sump. The secondary chambers have one or two afterburners capable of reaching temperatures up to 1000ºC with a residence time of between 1 to 2 seconds. The incinerator may have a low-efficiency air pollution control device such as a cyclone separator. These incinerators have chimneys that may be as high as 20 meters.



Picture 2.16.1.3 A typical dual-chamber controlled air incinerator

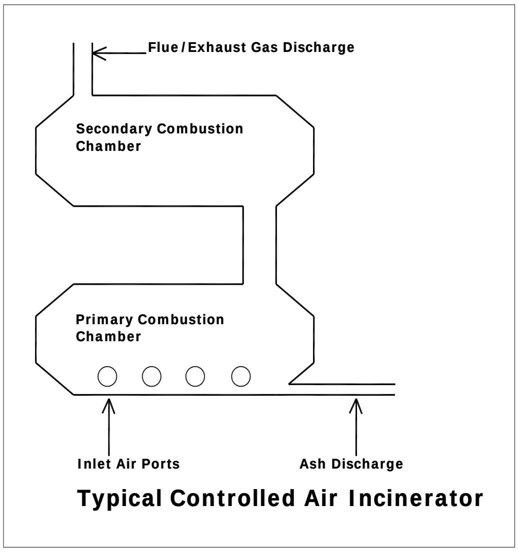
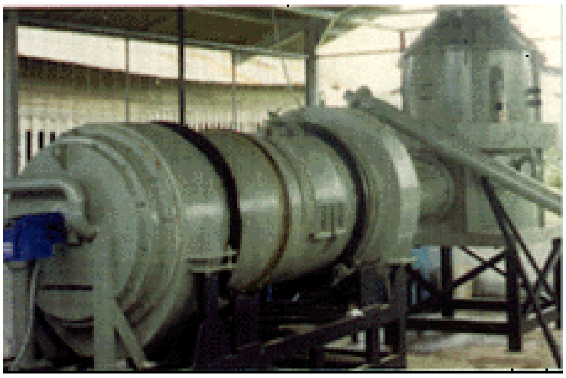


Figure 2.16.1.3 Diagram of a typical controlled-air incinerator

2.16.1.4 Rotary Kiln Incinerators

Rotary kiln incinerators are similar to the rotary kilns used by cement plants. They have a cylindrical primary combustion chamber (kiln) which slowly rotates horizontally (at a slight inclination of about a 1 to 2 degree angle) at about one full rotation per minute. The tilt helps in moving the waste away from the charging door such that by the time the waste reaches the opposite end, only ash remains. Depending on the design, the temperatures in the kiln range from 700 to 1000°C. Burners in the secondary chamber maintain high temperatures.



Picture 2.16.1.4 A typical rotary kiln incinerator

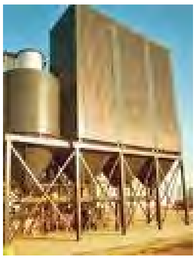
2.16.1.5 Air Pollution Control Devices

2.16.1.5.1 Many well designed incinerators use a set of air pollution controlling devices in line with the incinerator. Such devices are cyclones, bag filters, electrostatic precipitators and scrubbers. A bag house is an assembly of filter bags or fabric filter tubes suspended inside a large enclosure. The exhaust gas has to pass through these bags to exit the unit. The suspended solid particulates are trapped by the bag fabric.

2.16.1.5.2 Fly ash and other particles collect on the filter bags to form a dust cake. Different methods are used to dislodge the dust cake, such as reverse air flow, mechanical shakers, or a pulse jet. Electrostatic precipitators use high-voltage fields to apply electrical charges to the particles, causing the charged particles to move toward an oppositely charged collection surface, where they accumulate. Generally, before the gases reach the bag house or the electrostatic precipitators, they pass through a series of cyclone separators. The cyclone separator is a funnel-shaped device that creates a vortex to remove coarse particles from the gas.

Picture 2.16.1.5.2 A typical cyclone separator

2.16.1.5.3 A dual chamber controlled air incinerator with high residence time (2 seconds) in the secondary chamber, good temperature control, and a cyclone separator is one of the most effective incinerators. In the cyclone, the vortex spirals downward, carrying most of the coarse particles. As the gas reaches the conical section at the bottom, it turns and moves upward to exit. The dust particles fall and are collected in a hopper below. Similarly, dry or wet type scrubbers are generally used in such systems with the dual objective of absorbing harmful gases and also capturing solid particulates to avoid escape from the system. In a dry or semi-dry scrubber, sorbent material is added into the gas stream to react with the acid gases formed in the incinerator. The bag house filter or other dust removal device then captures the reaction products, excess sorbent and other particulates in the gas. Alkaline material (such as soda ash) or activated carbon is commonly used.



Picture 2.16.1.5.3 A typical bag house filter

2.16.1.5.4 A wet scrubber uses water or an alkaline solution to remove particulates and acid gases from the exhaust gas. The device may use a set of spray nozzles at the top of the scrubber tower to release droplets of water that impact the particles as the gas moves upwards towards the exit of the scrubber tower. Some wet scrubbers may use a packed bed or a series of horizontal impingement plates to increase contact between the water or alkaline solution and the gas. Picture 2.16.1.5.3 shows a typical arrangement for a scrubber.

Picture 2.16.1.5.4: A typical scrubber

2.16.1.6 Disposal of Hazardous Wastes in Secured Landfills

2.16.1.6.1 Disposal in Secured Landfills [97]

A secured landfill is a carefully engineered depression in the ground (or built on top of the ground, resembling a football stadium) into which wastes are put. The aim is to avoid any hydraulic (water-related) connection between the wastes and the surrounding environment, particularly groundwater. Basically, a landfill is like a bathtub in the ground; a double-lined landfill is like one bathtub kept inside another, with spacers.

The most crucial issue in a secured landfill is ensuring that they don't leak and that the leached products don't mix up with the ground water or percolate in to the water table. Landfills are known to leak in two different ways: leakage out the bottom or leakage over the top.

Figure 2.16.1.6.1 depicts a cross section of a typical model sanitary landfill. [98]

[97] Pellerano, M.B., B. Parkhurst, A.K. Fearneyhough, March 1995. (Extracted from http://www.ejnet.org/landfills/)
[98] http://www.bra.org/curriculum/G04.pdf

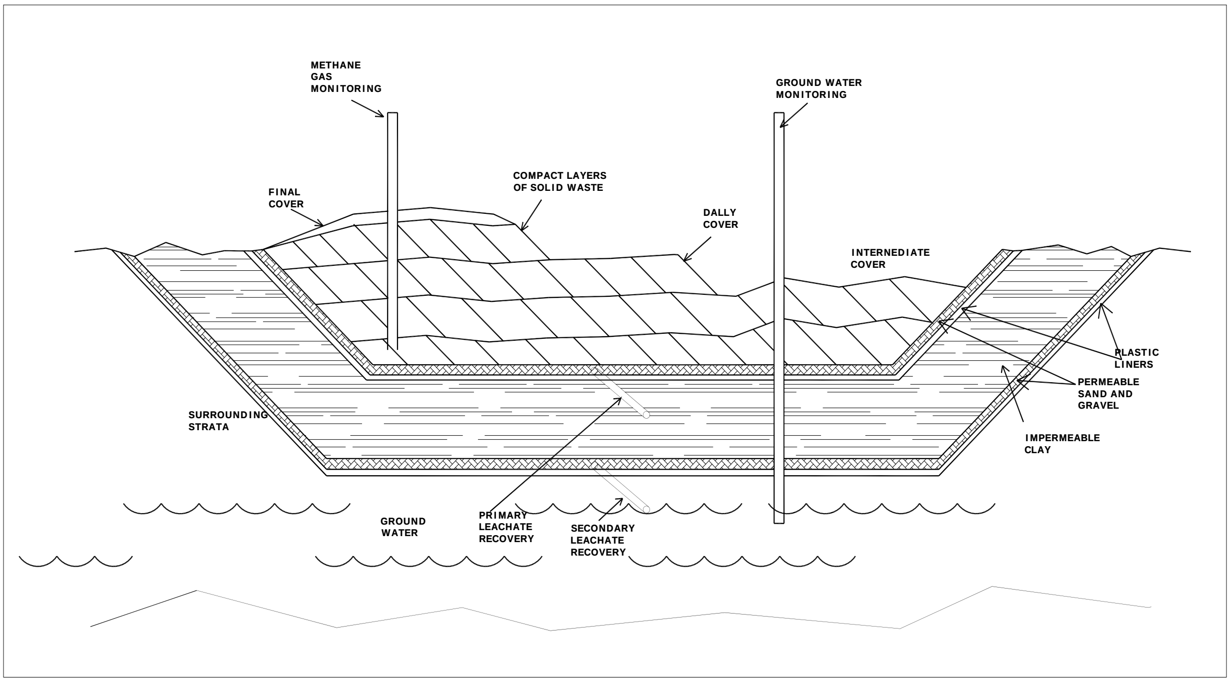


Figure 2.16.1.6.1: Cross section of a model sanitary landfill

2.16.1.6.2 Composition of a Landfill: Critical Elements of Secured Landfills

There are four critical elements in a secured landfill: a bottom liner, a leachate collection system, a cover, and the natural hydrogeologic setting. The typical hydrogeologic setting of a given location makes it imperative to tailormake the design of a landfill suited to the site's particular circumstances. Given this situation, each landfill is engineered according to the specific characteristics of its physical and geographical setting.

The natural setting can be selected to minimise the possibility of wastes escaping to groundwater beneath a landfill. The three other elements must be engineered. Each of these elements is critical to success.

2.16.1.7 The Natural Hydrogeologic Setting

In landfill design, two major considerations are (a) preventing the wastes themselves from escaping, which calls for rocks located as tightly together (waterproof) as possible, and (b) selecting an area having geology as simple as possible so that should any leakage occur, one can easily predict where the wastes will go. Then the location of wells is designed to capture escaped wastes by pumping. Fractured bedrock is highly undesirable beneath a landfill because the wastes cannot be located if they escape. Abandoned mines and quarries are avoided as landfill sites because they frequently contact the groundwater.

The crucial part of the secured landfill is the leachate collection and treatment system. Leachate is water that becomes badly contaminated through its contact with wastes. It seeps to the bottom of a landfill and is collected by a system of pipes. The bottom of the landfill is sloped; pipes laid along the bottom capture contaminated water and other fluid (leachate) as they accumulate. The pumped leachate is treated at a wastewater treatment plant (with the solids removed from the leachate during this step either returned to the landfill or sent to another landfill). If leachate collection pipes clog up and leachate remains in the landfill, fluids can build up in the 'bathtub.' The resulting liquid pressure becomes the main force driving waste out the bottom of the landfill when the bottom liner fails.

A well designed secured landfill is then approved by the local administration responsible for environmental issues. These landfills are certified and approved landfills. Across the world, most countries have adopted this practice and it is possible to locate the nearest secured landfill where the new recycling facility is planned. It is important to have a basic understanding of the landfill being proposed for the community concerned. It is suggested that proper information be gathered from the landfill operator and the local governing boards that will be giving the permits to the landfill operator. The following pictures provide views of some prominent landfill sites in various countries.

Landfill site in Western Australia

Landfill site in Poland

A section of a landfill located in Barclay,

South East New Territories Landfill, Hong Kong

Ontario. This landfill is one of several landfills used by Dryden, Ontario.

Former city dump in New Jersey, now a golf course

Landfill operation. Note that the area being filled is a single, well-defined "cell" and that a rubberised landfill liner is in place (exposed on the left) to prevent contamination by leachates migrating downward through the underlying geological formation.

Picture 2.16.1.7 Examples of landfill sites

CHAPTER 3: SUSTAINABILITY ASSESSMENT OF TECHNOLOGIES (SAT)

3.1 Introduction

The paradigm of sustainability has evolved through various global deliberations and conferences over the past few years, most notably the Rio Earth Summit of 1992/Agenda 21 and the World Summit on Sustainable Development in Johannesburg in 2002. The concept of sustainability emphasises integration of economic, environmental and social interests and concerns.

The economic consideration has conventionally overruled the other criteria in decision making for investments. Decisions that imply least costs have normally been preferred without much consideration given to factors such as environmental impacts or related social aspects of the decision. Rising public concerns about environmental aspects, health, water and sanitation have been underpinned by awareness campaigns by social environmental groups. Increasing emphasis is being placed on environmental and social concerns, resulting in a need to consider the sustainability aspects of any new project. In recent years, an increasing number of plants and establishments have come to close down due to public resistance based on such environmental and health hazard factors.[99]

The need for developing and promoting Environmentally Sound Technologies (ESTs) in the context of sustainability has been the primary consideration in investment projects, starting in the early 1990s. In particular, at the United Nations Conference on Environment and Development (UNCED) in 1992, the need to promote ESTs was highlighted in Agenda 21. Chapter 34 of Agenda 21 defines ESTs as those technologies that “protect the environment, are less polluting, use all resources in a more sustainable manner, recycle more of their wastes and products and handle residual wastes in a more sustainable manner than the technologies for which they were substitutes.” ESTs include a variety of cleaner production processes and pollution prevention technologies, as well as end-of-pipe monitoring technologies. Apart from just technologies, they can be considered as total ‘systems’ that may include knowledge and skills transfer, operating procedures, goods, services and equipment, and also organisational and managerial procedures[100]. Many initiatives have been developed in relation to the promotion of ESTs in developing countries and countries with economies in transition.

The International Environmental Technology Centre of the United Nations Environment Program (IETC-UNEP) has developed a methodology known as Sustainability Assessment of Technologies (SAT), which has received commendation internationally[101]. The focus of

[99] India Business Insight, 06/13/2002, http://www.fluoridealert.org/Pollution/Phosphate-Industry/Oswal-Phosphate-Plant-facing-Closure-due-to-Fluoride-Contamination.aspx, http://www.energyboom.com/emerging/dominion-closing-new-england-coal-fired-plant-due-pending-regulations, US set for wave of coal plant closures, http://www.guardian.co.uk/environment/2010/dec/14/us-coal-plant-closures (Accessed 10.10.2011)
[100] DTIE-UNEP EST Assessment Methodology and Implementation - Training Kit prepared for the support of the project on Environmental Management of the Iraqi Marshlands.
[101] Chandak, S.P. (2009). Sustainable Assessment of Technologies: Making the Right Choices. IETC-UNEP- Presented at the 1st Stakeholder Consultative Workshop/Training Program of the Project on Converting Waste Agricultural Biomass to a

this methodology is on both the process and the outcome, with an interest towards informed and participatory decision making. In this document the SAT methodology has been adapted to suit the assessment of technologies as applicable to the recycling and/or destruction technologies for waste oils.

3.2 Basic Steps of SAT

The first step in the SAT methodology is to define the problem explicitly. Below are some examples of problems related to management of waste oils:

- Lack of proper management of waste oils has resulted in public health problems in communities as people are exposed to water and soil contaminated with waste oils as well as air emissions due to indiscriminate burning.
- Improper waste oil management practices pose a risk to the health and safety of workers, waste collectors and the community at large.
- Poor waste oil recycling/destruction methods have created a serious environmental problem in local communities, causing resentment among neighbors affected by foul odours, smoke, air pollutants, and contaminated water and soil.
- Inadequate waste management practices are putting a strain on oil resources and undermine the potential for material recovery and recycling.

As part of the first step, a situation analysis is undertaken involving collection of baseline data and stakeholder consultations. On a strategic or macro level, baseline data could refer to policies concerning waste oils, current pathways of waste oils and environmental impacts related to improper waste oil management. This information is helpful in defining the problem in concrete terms during stakeholder consultations with local governments, NGOs and waste generators. The information could also be used in comparative evaluations of scenarios.

During the collection of baseline data, preliminary information could also be obtained on the waste generators as well as the material characteristics, the composition and the rates of generation of waste oils. A methodology for collecting such information is described in the compendium.

The next step is the setting of targets for each issue identified during the stakeholder consultations. A “target” specifies how a particular issue can be mitigated. Table 1.1 gives a few examples of some possible strategic-level issues and targets that might arise in the course of stakeholder consultations.

Fuel/Resources in Moneragala District, Sri Lanka funded by UNEP and coordinated by the National Cleaner Production Centre, 21 August 2009.

Table 3.1 Examples of issues and targets at the strategic level

Waste Oils	
Issue	Target
Not all waste oil generators in the area have a way to segregate or collect their waste for recycling or treatment	Implement a large-scale central recycling/destruction facility to treat waste oils from all generators in the area; promulgate policies requiring treatment of all waste oils
Long distances and poor roads between districts preclude one central treatment facility for the province	Designate a cluster treatment hub in each district and deploy technology at each hub
Collection and transportation of waste oils to a central facility is rather expensive, as the waste oils are generated by a large number of garages that each generate only a small quantity	Implement a decentralised treatment scheme that utilises a technology appropriately sized for each facility
Strong public opposition to open burning and air pollution	Deploy technology generating few or no air emissions
Inadequate space in the secured landfill for disposal of hazardous waste such as waste oils	Use technology that allows material recovery and recycling; expand existing recycling infrastructure
Lack of information and training among waste oil generators	Develop training programs and policies that require training in waste oil management as part of facility accreditation and/or professional licensing

3.3 Key Features of SAT

3.3.1 Addressing Strategies as Well as Operational Levels

The SAT methodology incorporates both strategic level and operational level assessments. The methodology is however flexible enough to allow users to directly commence with operational level assessment if desired. This is likely to be needed in situations where strategic assessment is either not relevant or not feasible.

3.3.2 Addressing Sustainability through a Specially Designed Methodology and Criteria

The criteria and indicators are probably the most important components of the SAT methodology. In order to develop more robust sets of criteria and indicators, the following aspects were considered during the development of the SAT methodology:

- Criteria and indicators proposed under other similar methodologies;
- The need to consider the life cycle perspective, keeping in mind parallel approaches like the World Bank's Input-Output-Outcome-Impact (IOOI) framework[102];
- Risks and restrictions associated with technology choices (Ref. Box 1).

Box 1: Need to Address Risks and Restrictions Associated with Technology Choices

In any decision-making process, special attention needs to be given to the risks and restrictions associated with each choice, since these become crucial deciding factors in many instances. Typically, risks and restrictions that need to be considered in making a technology choice include:

- Stability or resilience
- Size/scale of operation and scalability
- Flexibility for using different types of raw materials
- Adaptability by the neighborhood and other stakeholders
- Hazards to the community and the employees
- Required special skill levels (if any) and any other pre-requisites (such as availability of space)
- Other important considerations such as availability of skills and local capacity (supply, operation, maintenance and repairs, and training of the local population).

3.4 SAT Criteria

3.4.1 Arriving at a Set of Criteria

Considering all the above-mentioned aspects, the SAT methodology offers a set of generic criteria and indicators under the following broad categories:

- Technological suitability;
- Environmental considerations (in terms of resources and emissions, risks etc.);
- Economic/financial concerns; and
- Socio-cultural considerations.

A list of generic technical and economic criteria and indicators has been provided in Annex 1. It should be noted that these generic criteria are indicative. It is recommended that each user group develop their own set of customised criteria and indicators depending on their specific circumstances. This can be better done through consultative meetings in the presence of an expert moderator and with the support of relevant stakeholders, as well as domain-/sector-specific experts.

[102] http://www.communitiescommittee.org/fsitool/AppendixB.html.

3.4.2 Involvement of Relevant Stakeholders

To ensure the sustainability of a project, it is necessary that all the stakeholders associated, whether directly or indirectly, be formed into a coherent decision making team. The various stakeholders in a project of this nature may include representatives and spokespersons from:

- The municipality office;
- Political parties in the local region;
- Women's groups;
- Community development groups;
- Local youth groups;
- The district development committee;
- The district industry office;
- Chambers of commerce and industry;
- Industry associations;
- Present and/or past mayors of the town; and
- Social workers and persons from prominent local NGOs.

3.4.3 Stakeholders' Workshop

A stakeholder consultation workshop could be conducted to receive feedback on the data collected and planned activities as well as to identify stakeholder needs and technologies worth exploring.

The workshop is essentially a means for discussing the defined problems and possible solutions with the stakeholders, with a view to sketching out a roadmap for the technology assessment process and obtaining the participants' opinions.

The stakeholder consultation workshop is aimed at identifying the issues of concern regarding the technology options for converting the waste oils into a resource. Key points to be discussed during the workshop may include:

- Environmental aspects of different technology options;
- Finance and profitability aspects;
- Waste oil generators and the quality and quantity of available waste oils;
- Space requirements;
- Manpower and skill requirements;
- Commercial availability of technology options
- Level of improvement over currently used processes, e.g. burning as fuel, filtering and centrifuging for use as second-grade lubricants, using as dust suppressants etc.
- Availability, enforcement and impact of regulations and economic tools for various technology applications;
- Current efficiency and effectiveness of collection, treatment, usage and disposal technologies and associated infrastructure;
- Roles of various stakeholders at different levels regarding the current practices within the waste oil management chain.

3.4.4 Constraints and Limitations

It is very likely that a majority of these stakeholders are not in a position to contribute much on the technology front. However, some of the primary concerns raised by them during such an intervention could make or mar the success of the project. Examples of issues that may be raised during such interventions are:

- **Social**
  Job creation potential
  Acceptability to local culture
  Improvement of quality of life of the nearby community
  Occupational safety and health conditions
  Improvement of local technical skills and knowledge base

- **Environmental**
  Additional support services/utilities (water/energy) requirements
  Environmental emissions
  Noise, vibration and odour
  Space and infrastructure requirements
  Contributions to waste oil management
  Net carbon emissions

3.5 Adopting a Progressive Assessment

It is advisable to approach the issue through different tiers of hierarchy. A tiered approach is both effective as well as efficient, as it does not require exhaustive data collection for all technology systems under consideration. It is possible to eliminate the obviously infeasible options, from a long list, at an early stage (screening) and then focus on select qualified technology systems. In this way, detailed information collection becomes essential only for short-listed technology systems, thereby saving substantial time and effort.

3.6 Choosing from Options

Arriving at the final choice from a number of available options can be done through the following steps or tiers.

Tier 1 - Screening:
Firstly, technology systems are screened against logical operators (i.e. 'yes/no' type) for EST criteria. This is essentially a broad-level qualitative analysis with respect to overarching criteria.

Tier 2 - Scoping:
The ESTs that pass through the screening stage are then subjected to a second round of assessment. Scoping uses select criteria that require a greater amount of qualitative or readily available quantitative information. In doing so, a number of less competitive options are likely to be discarded, thus leaving stakeholders with a more limited but more relevant number of technology system options.

Tier 3 - Detailed Assessment:
Technology systems shortlisted from the scoping tier are then subjected to a more rigorous evaluation, using additional criteria specially drafted for this purpose and that demand a greater extent of quantitative information. At the end of the detailed assessment, the stakeholders will understand which technology systems are the most sustainable for their situation, in ranked order.

3.6.1 Use of Quantitative Techniques

Experiential and judgmental gut feeling is generally used while taking major decisions. However, the use of quantitative procedures that allow more objective assessment, sensitivity analyses and the incorporation of alternate scenarios are expected to give much better and more objective solutions.

In drafting the SAT methodology, a quantification and aggregation framework was proposed to facilitate objective decision-making, while at the same time overcoming the limitations of qualitative assessment. The key elements for this approach are:

- Weights to be assigned to a criteria; and
- Scores to be assigned to indicators.

A range of aggregation techniques can be applied, depending on the complexity and sensitivity of the decision to be made as well as the competence and the capability of stakeholder groups. These range from a simple weighted sum method to more sophisticated approaches such as the Analytic Hierarchy Process (AHP). These are explained in more details in the "Techniques for evaluation of alternatives" in the following pages.

3.7 Processing the Alternatives and Ranking

Once identified, the technology options need to be evaluated in order to facilitate the optimum decision to choose a particular technology. The following approach can be adopted to evaluate the alternatives. They are listed in increasing order of complexity:

Techniques for evaluation of alternatives:

- Weighted sum matrix or decision matrix;
- Sequential elimination by lexicography;
- Sequential elimination by conjunctive constraints;
- Goal programming;
- Delphi Method for consensus building; and
- Analytic Hierarchy Process (AHP).

Additionally, advanced methods such as Expert Systems and Neural Networks may be applied for decision making and evaluation. However, this section considers and discusses only the commonly applied methods.

All the techniques are explained below in brief.

3.7.1 Weighting Method or Weighted Sum Matrix or Decision Matrix

Upon listing all the parameters for decision making, it may be noted that not all of them have equal importance or impact. Hence, it is necessary to assign them their due weightages or degrees of importance. This helps in arriving at a decision matrix. A decision matrix evaluates and prioritises a list of options. First a list of weighted criteria is established and then each option is evaluated against those criteria. The following procedure is involved in a decision matrix:

- Brainstorm the evaluation criteria appropriate to the situation.
- Discuss and refine the list of criteria. Identify any criteria that must be included or excluded. Reduce the list of criteria to those that are most important.
- Assign a relative weight to each criterion, based on how important that criterion is to the situation. This can be done by distributing 10 points among the criteria. The assigned values may be arrived at through discussion and consensus. Alternatively, each member can assign weights, then the numbers for each criterion would be added for a composite team weighting, by weighted averaging.
- Draw an L-shaped matrix. Write the criteria and their weights as labels along one edge and the list of options along the other edge. Usually, whichever group has fewer items occupies the vertical edge.
- Evaluate each choice against the criteria.

3.7.2 Sequential Elimination by Lexicography

The steps followed in Sequential Elimination by Lexicography are:

- Each attribute is given a ranking from most important (1) to least important (e.g. '5');
- Each of the alternatives is given a score for each attribute (1 to 10);
- The alternatives are sorted according to rank;
- Alternatives are gradually eliminated according to their scores.

3.7.3 Sequential Elimination by Conjunctive Constraints

The steps followed in Sequential Elimination by Conjunctive Constraints are:

- Each attribute is given a constraint ("must be greater than X," "must be less than X");
- Each alternative is rated according to the constraints;
- If there is more than one "survivor", tighten the constraints;
- If there are no survivors, slacken the constraints.

3.7.4 Goal Programming

This method is similar to Linear Programming. The attributes are converted to mathematical variables and incorporated into equations. These equations are then resolved to find the optimal solution. The typical application of Linear Programming and similar Operations Research models for maximising, minimising or optimising are applied, as appropriate.

3.7.5 Delphi Method for Consensus Building

In this approach, a number of cycles of discussion and argument, corrections, suggestions, and modifications are undertaken. It is advised that the process be monitored by an expert facilitator who controls the process and manages the flow and consolidation of information. Following are the steps for consensus building using the Delphi Method:

i. The issue or problem to be solved is clearly defined;

ii. A facilitator or chairperson having the skills needed to manage the process properly and impartially is identified and nominated;

iii. A panel of all concerned stakeholders is constituted. The members of this panel must have the depth and breadth of knowledge and proven good judgment needed for effective analysis of the problem;

iv. The panel members brainstorm on the problem from their point of view and provide feedback to the facilitator, anonymously;

v. The facilitator consolidates the individual responses and then resubmits them to the panel;

vi. Based on this resubmission, new responses are gathered. It is quite likely that some of the members may change their mind in the light of new insights and may decide to go with the majority. In other cases, those whose views differ from the prevailing group position may provide some new information which may influence the group decision in the next round;

vii. This process continues until a consensus on alternatives has been reached.

3.7.6 Analytic Hierarchy Process (AHP)

This method is applied when there are complex relationships among criteria. It requires decision makers to make judgments regarding the importance of criteria. The alternatives are compared in pairs to one another.

AHP is a structured technique for dealing with complex decisions. Rather than prescribing a "correct" decision, AHP helps decision makers find the one that best suits their needs and their understanding of the problem but which may have initially appeared to be a sub-optimal solution. The approach is not to maximise or minimise but to optimise.

AHP has been extensively studied and refined since its origin in the 1970s. AHP provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals and for evaluating alternative solutions.

AHP involves the mathematical synthesis of numerous judgments about the decision problem at hand. It is not uncommon for these judgments to number in the dozens or even the hundreds. While the math can be done by hand or with a calculator, it is far more common to use one of several computerised methods for entering and synthesising the judgments. The simplest of these involve standard spreadsheet software, while the most complex use custom software, often augmented by special devices for acquiring the judgments of decision makers gathered in a meeting room.

The main steps involved in the AHP process are;

Step 1: Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it, and the criteria for evaluating the alternatives.

Step 2: Establish priorities among the elements of the hierarchy by making a series of judgments based on pair-wise comparisons of the elements. For example, when comparing potential real estate purchases, the investors might say they prefer location over price and price over timing.

Step 3: Synthesise these judgments to yield a set of overall priorities for the hierarchy. This would combine the investors' judgments about location, price and timing for properties A, B, C, and D into overall priorities for each property.

Step 4: Check the consistency of the judgments.

Step 5: Come to a final decision based on the results of this process.

CHAPTER 4: GUIDELINES FOR APPLYING THE SAT METHODOLOGY FOR ASSESSMENT OF TECHNOLOGIES FOR RECYCLING/DESTRUCTION OF WASTE OILS

4.1 Introduction

Using the steps of the suggested SAT methodology, an approach for applying SAT to the destruction of waste oils has been prepared. These guidelines relate to the identification, assessment and selection of ESTs for the recycling/destruction of waste oils. The process depicted in Figure 2.1 leads to a solution for the issue of waste oil destruction.

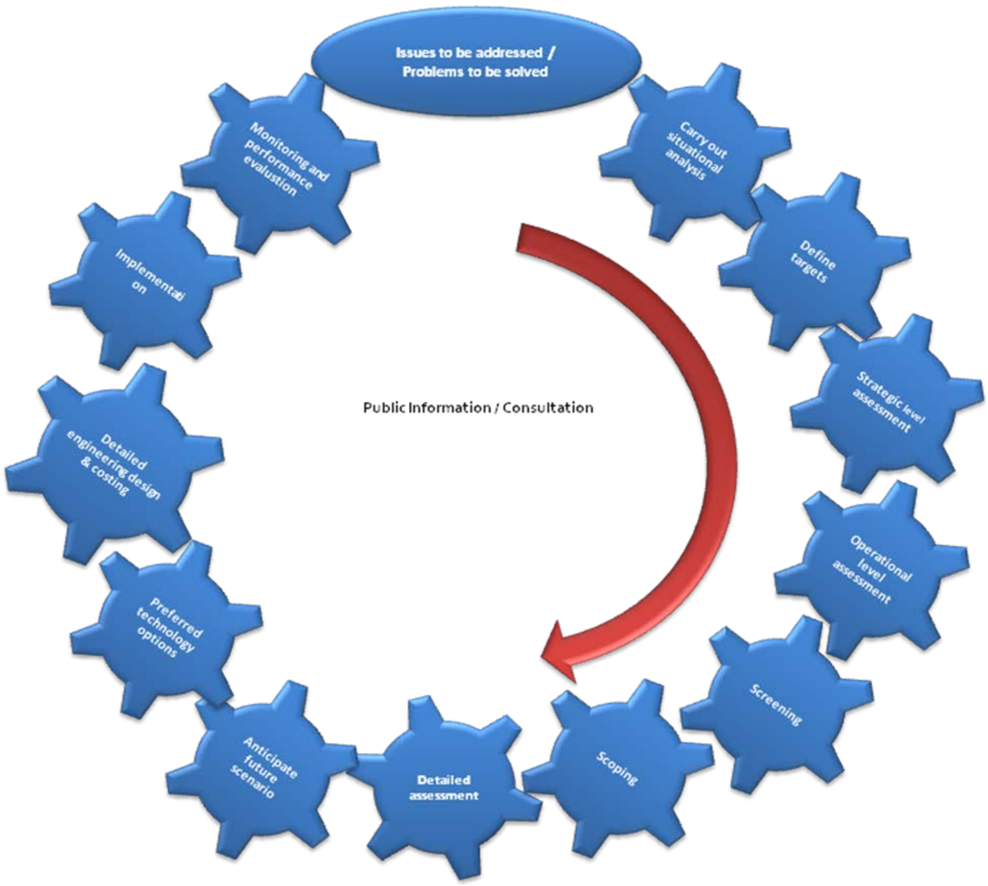


Figure 4.1 Steps for arriving at the selection of appropriate feasible technology for recycling/destruction of waste oils

4.2 Defining Problems/Issues

This SAT methodology for recycling/destruction of waste oils has been developed based on a selected resource-technology combination as a means of managing waste. Given their

inherent properties, it is prudent to consider the waste oils as a resource rather than dispose of them in an unsustainable manner. This effort is therefore intended to explore the most appropriate ways of recycling waste oils or converting them into value-added products or energy, thereby minimising the environmental and social issues which have traditionally arisen due to improper management practices. In doing so, every effort needs to be made to explore and enable the generation of additional income to the local community.
The process of defining problems and issues requires a focused approach. Perhaps the most common problem in this case is the failure to identify the real problems/issues. The result is that the "wrong problem" or just a symptom may be solved while the original problem/issue remains. To avoid this pitfall, some useful diagnostic questions to ask are noted below[103]:

- Explicitly state the problem. Are you sure it is a problem? Is it important? What would happen if the "problem" were left alone? Could attempts to solve the "problem" result in unintended consequences?
- Why is it a problem? Is there a "gap" between the actual performance and desired performance? For whom is it a problem and why?
- Is this problem masking a deeper systemic problem?
- Is there a deviation from relevant standards?
- What is the current situation? What are the ideal outcomes?
- How do key people or stakeholders feel about the problem and current outcomes?
- How urgent is the problem? How important is the problem relative to other problems?
- How high are the stakes? Factors include costs and profits as well as environmental and social concerns.
- What information is lacking?

Issues concerning waste oils are defined below.

- Improper waste management practices may lead to health and environmental and perhaps even social problems.
- Disposal of these wastes may also be considered as a loss of useful resources.
- The inability to utilise waste oils for useful applications (energy source, lubricants for reuse etc.) puts a strain on the already overburdened fossil fuels depletion issues.

4.3 Situation Analysis

The situation analysis includes the following activities:

- Baseline data collection through the involvement of stakeholders; and
- Mapping, analysis and setting targets.

[103] Adapted from Teaching and Learning with technology: Pennsylvania State University, http://tlt.its.psu.edu/suggestions/cases/studenttips/define.html

4.3.1 Baseline Data Collection

Baseline data is defined as the initial collection of data which serves as a starting point for project analysis as well as a basis of comparison with subsequently acquired data. Baseline data therefore helps to assess the impact of any actions taken for a project (in this case, the selection of a technology).
Baseline data should be robust enough to assist in the analysis and interpretation of data in the context of the problem.
A step-by step methodology for collecting baseline data on waste oils is described in detail in the publication "Compendium of Recycling and Destruction Technologies for Waste Oils" available at: http://www.unep.org/ietc/wastemanagement/publications

4.3.2 Mapping, Analysis and Setting Targets

At this stage, targets are set for each problem/issue based on the data collected and feedback received from the stakeholders. In the context of this guideline, a target is intended to specify the mitigation of a defined problem/issue. For example, one defined issue could involve an anticipated change in the amount of waste oils generated of a particular type which may or may not be either available at all at present, or whose generation may increase or decrease drastically in the future. In this case, the target would be to identify and implement a technology that can be easily duplicated or which may be easily scaled up or down in order to tackle the potential future issues of either changing waste oil quantities or technological advancements in lubricants manufacturing.

4.4 Strategic Level Assessment

As the next step, planners, decision-makers, mayors/elected representatives should brainstorm and study various options at the policy and planning levels. An appropriate methodology must be chosen for carrying out a strategic assessment, given the local context.

The strategic level assessment provides guidance on issues such as preferred strategies for waste oil management (i.e. recycling or conversion into fuel or incineration), centralised vs. decentralised systems and facility ownership (i.e. public, private or public-private partnership etc.). The use of planning tools such as Logical Framework Analysis, Participatory Project Planning with vision mapping, and the like can help in strategic level assessment.

4.5 Operational Level Assessment

Once the strategic level assessment is carried out and the broad types of options are finalised, the methodology moves on to the operational level where engineers, technical staff and executives take over to assess available technology systems. Expert opinions and technology-related information are highly necessary in this step.

In case the SAT methodology is to be applied only at a community or enterprise level, the earlier stage of strategic assessment may be skipped and stakeholders can start with the operational level SAT as the first step.

The following tiered approach is used.

- Tier 1 – Screening: Technology systems are screened against basic criteria which are often in the form of logical operators (i.e., 'yes'/'no' type).
- Tier 2 – Scoping: The technologies that pass through the screening stage are then subjected to a second round of elimination by means of the scoping tier. Scoping uses select criteria that require a greater amount of qualitative or readily available quantitative information. This results in a more limited but more relevant number of technology system options.
- Tier 3 – Detailed Assessment: Technology systems shortlisted from the scoping tier are then subjected to a more rigorous evaluation specially drafted for the purpose that demands a greater extent of quantitative information. Additional criteria could be added. This results in a ranking of the top three to five technology systems.

The outcome of the operational level assessment is a number of technology system options ranked in the order of their performance relative to the principles of sustainability. However, the selected "best" technology system choice based on current information may later turn out to be inadequate or inappropriate for future circumstances due to changes in the situation, local requirements, legislation or advances in technology. Hence, before making a final decision, the SAT methodology can be used for a second cycle to simulate possible future scenarios and ensure that the outcome of the first cycle is robust enough to stand the test of time.

The final decision on a particular technology system is then made from among the preferred technology options. The next steps involve detailed engineering design, tendering, construction and commissioning. Continuously monitoring and evaluating the technology system during its operational phase is an essential next step. This ensures that the technology system is meeting the desired objective vis-à-vis the criteria considered in the SAT methodology. The outcomes of the monitoring and evaluation should be reported to the stakeholder group to inform future decisions at both strategic and operational levels and to serve as input to the situational analysis of a similar future project. This cycle of continuous improvement coupled with public information and consultation distinguishes the SAT methodology.

4.5.1 Screening (Tier 1)

At this stage, the short-listed system options first undergo screening using criteria in Tier 1. The criteria considered in Tier 1 screening should ideally be taken from the outcomes of the stakeholder consultation workshops. It is recommended to develop customised criteria and indicators specific to the situation through consultative meetings. Examples of some commonly referred areas for developing criteria are given below.

- Compliance with local environmental laws
- Compliance with Multilateral Environmental Agreements (MEAs)
- Availability and deployment of local expertise
- Extent of local materials usage
- Risk levels for workers
- Environment friendliness – air, water pollution propensity
- Capital intensiveness

While designing the criteria, two aspects should be given particular attention:

a) It should be possible to respond to each criterion with a ‘yes’ or ‘no’ answer. For example, a criterion such as ‘Level of investment’ is not a good criterion as the response cannot be ‘yes’ or ‘no.’ Instead the criteria should be rephrased as, ‘Is the technology capital intensive?’
b) The ‘yes’ response should always be the acceptable response. For example, for a criterion such as, ‘Are special skills and a high degree of education required to operate this technology?’ an answer of ‘yes’ may not be the preferable answer in the context of developing countries. The criterion should therefore be rephrased as, ‘Is the technology simple and easy to operate?’

Once the criteria for screening have been finalised, technologies should be assessed at Tier 1 in the following manner:

- Assume that the technology to be screened is acid-clay treatment, which might look to be the easiest and most economic option. The first screening criterion to be tested against is whether or not there exist any restrictions against such treatment at the policy level.
- The next question is whether or not the said technology passes the test for screening criteria #2; i.e. whether the said technology using waste oils is aligned with Ministry of the Environment and/or national plans.
- Continue this process with the remaining screening criteria, with the stakeholders entering either ‘yes’ or ‘no’ against that technology in the relevant column.
- A particular technology is said to pass the screening provided it scores a favorable outcome for at least seven of the listed screening criteria. The technologies that

score a favorable outcome for all eight screening criteria are selected for the Tier 2 scoping analysis.

The results of the technology screening may be like what appears in sample Table 4.1.

Table 4.1 Sample solution for screening technologies (Tier 1)

	Criteria for screening										
Technology	Does the technology comply with international regulations?	Does the technology comply with national and local regulations?	Is the technology technically suitable in the local context?	Does the technology use indigenous materials and is it non-dependent on imports?	Is the technology generally safe?	Is the technology generally environmentally friendly?	Are the capital Investment costs low?	Is the technology simple to operate?	Does the technology have flexibility in use of raw material?	Are there domestic suppliers of the technology?	Outcome (Selected/not selected)
Thin film evaporation	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Selected
Acid activated clay process	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Selected
Falling film evaporation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Selected
Acid-clay process	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Selected
Vacuum distillation	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Selected
Extraction based	Yes	Yes	No	No	No	Yes	No	No	No	No	Not selected
Membrane based	Yes	Yes	No	No	Yes	Yes	No	No	No	No	Not selected

The outcomes of the stakeholder consultation would help in identifying certain issues of concern regarding the technology to be installed for converting the waste oils into a resource. Accordingly, these issues can be converted into screening criteria for the given problem. There may not be "right" or "wrong" solution, given that the SAT methodology caters to situation-specific issues. However, a particular solution may be "appropriate" or "inappropriate" in the given context and the advisor to the stakeholders should ensure that inappropriate solutions are detected.

Some or all of the generic technologies referred in the compendium, or any other developed technologies may be short-listed for Tier 1 assessment.

4.5.2 Scoping Analysis (Tier 2)

Now, the appropriate criteria for the scoping analysis must be developed and selected. A suitable method for assessment should be applied from among the available alternatives, with the technologies then ranked, based on the assessment results.

Criteria may be assigned as per different categories – technical, financial, social and environmental. Essentially, the weight assigned to each criterion within a category is based on the importance given to it by the stakeholders undertaking the assessment. The number or rating assigned to the technology reflects how well the technology complies with each defined criterion, as per the stakeholders' judgment. The ratings within each category are then added up to arrive a score for that category.

A sample list of some commonly used criteria is given below. Depending upon local conditions and the views of stakeholders, the development of additional criteria is encouraged.

- Technical suitability
  - Compatibility with local natural conditions (geographical, climate)
  - Extent of local materials usage
  - Availability of local expertise
  - Track record on performance
  - Compatibility with existing situation (technology, management systems)
  - Level of automation/sophistication

- Environment, health and safety aspects
  - Emissions
  - Odour
  - Extent of use of hazardous materials
  - Risk levels for workers
  - Risk to the environment, e.g. to biodiversity

- Economic / financial aspects
  - Capital investment
  - Operation and maintenance costs

- Benefits (re-refined lubricating oil, fuel, energy)

- Social/cultural aspects
  - Extent of necessary resettlement and rehabilitation of people
  - Income generation potential

In some instances, it is possible that the rating of the technology systems may change due to the new scoring based on available information. Using the information, the stakeholder group should once again prepare a new weighted sum matrix or revise the existing one.

The team members have to first agree upon and list up a set of criteria for scoping analysis of the screened technologies. The weighted score method may be used for the ranking of these technologies. The results of the scoping analysis of the technologies may be like sample Table 4.2.a, while the end result may be like sample Table 4.2.b.

Table 4.2.a Results of Scoping Analysis with Weighted Sum Method

Criterion	Weight	**Thin film evaporation**		**Acid activated clay process**		**Falling film evaporation**		**Vacuum distillation**		**Extraction based**	
		Score	Weight x score	Score	Weight x score	Score	Weight x score	Score	Weight x score	Score	Weight x score
Low degree of air pollution	10	3	30	3	30	8	80	10	100	9	90
Low odour emissions	20	8	160	2	40	9	180	5	100	7	140
Proven technology	10	8	80	8	80	7	70	7	70	9	180
Can use all types of waste oil	10	5	50	5	50	5	50	8	80	6	60
Provides additional economic benefits	20	8	160	3	60	6	120	8	160	3	60
Social acceptance	20	3	60	3	60	5	100	6	120	8	160
Additional processing needed	10	4	40	4	40	6	60	8	80	8	80
TOTAL	100	-	520	-	360	-	640	-	710		770

Note: Scoring is done on a scale of 1 – 10.

Table 4.2.b Ranking of Technologies (After Scoping Analysis – Tier 2)

Ranking	Score	Technology
1	770	Extraction based
2	710	Vacuum distillation based
3	640	Falling film evaporation
4	520	Thin film evaporation
5	360	Acid activated clay process

4.5.3 Detailed Assessment (Tier 3)

Now that a number of unfeasible or unqualified EST options have been eliminated after the scoping analysis, in this final tier exercise, the remaining options with the best overall ratings are subjected to further detailed assessment of their technical, financial, social and environmental feasibility. This level of assessment is rather situation-specific and the suggested criteria at this stage demand significantly more detailed and quantitative information to facilitate decision making.

Using all the information available up to this point, the stakeholder group should once again prepare a new weighted sum matrix or revise the existing one. In some instances, the rating of technology systems may change due to new scoring based on available information. Note that the logic and calculations for detailed assessment are similar to those used in the scoping analysis.

In this tier, we need to investigate in more detail and with greater intensity the relevant factors for the relative ranking of different technologies, while also identifying critical or important criteria needing more elaborate consideration. Presenting the results in tabular form as in the earlier two tiers may be quite complex, and with the number of numerical values in the table it may not be very convenient for decision-makers. One effective method is to employ a graphical representation of the results using what is known as a star diagram.

Star diagrams are diagrams that condense and organise data about multiple traits, facts or attributes associated with a single topic. For the purposes of the SAT methodology, the various criteria under the chosen categories, viz. technical, financial, social and environmental, translate into these multiple traits.

The star diagram is created by drawing a circle and dividing it into sectors. The number of sectors depends on the number of criteria to be reflected in the decision making. One criterion is assigned to each line.

In the next step, concentric circles are drawn within the main circle to reflect a scale for the scores assigned to the criteria. The score for each technology in question is marked as a point on the line representing each criterion. Once this is done for all criteria, the points are joined using straight lines for all the criteria belonging to the same technology, forming a multi-polar star-like shape. The number of sets of lines will be equal to the number of alternatives under consideration. Each set of lines can be coloured differently in order to demarcate them more clearly. These different sets of lines represent the composite star diagram for the technologies. The area under each star is then calculated to give a combined score (in a numerical value) of all the criteria for each technology.

Continuing with the earlier example the following criteria were selected for detailed assessment:

Table 4.3 Criteria for detailed evaluation

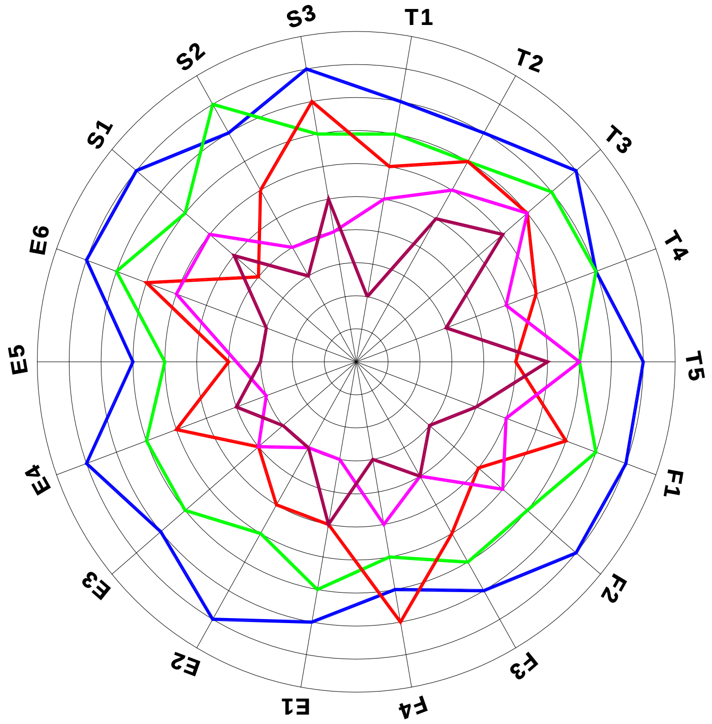
Considerations	Code	Criteria
Technical	T1	Compatibility with local natural conditions (geographical, climate)
	T2	Extent of local materials usage and suitability of local expertise
	T3	Proven technology and track record on performance
	T4	Compatibility with existing situation (technology, management systems)
	T5	Process stability and adaptability to future situations
Environment, health and safety considerations	E1	Risk levels for workers, communities and beneficiaries
	E2	Risk to the environment, e.g. to biodiversity
	E3	Resource usage, space requirements
	E4	Specific energy consumption per unit
	E5	Specific water consumption
	E6	Emissions and odour
Social/ cultural aspects	S1	Acceptability
	S2	Extent of necessary resettlement and rehabilitation of people
	S3	Income generation potential
Financial and economic considerations	F1	Capital costs
	F2	Operation and maintenance costs
	F3	Benefits (energy, fertiliser, reclaimed land, enhanced biodiversity, carbon credits)
	F4	Economic viability

The stakeholders then assigned consensus weightages to various criteria as given in Table 4.4

Table 4.4 Consensus weightages to criteria

Technology option	T1	T2	T3	T4	T5	F1	F2	F3	F4	E1	E2	E3	E4	E5	E6	S1	S2	S3
Extraction based	8	8	9	8	9	9	9	8	7	8	9	8	9	7	9	9	8	9
Vacuum distillation based	5	6	7	5	7	5	6	4	5	3	3	4	3	6	6	6	4	4
Falling film evaporation	6	7	7	6	5	7	5	6	8	5	5	4	6	4	7	4	6	8
Thin film evaporation	2	5	6	3	6	4	3	4	3	5	3	3	4	3	3	5	3	5
Acid activated clay process	2	5	6	6	3	7	2	1	8	2	2	1	3	1	1	3	3	5

The scores for composite criteria for these five top-ranking technologies can be drawn as shown in sample Figure 4.2. Using this diagram, the team may identify the strong and weak areas of the criteria. It is quite likely that some environmental aspects and social aspects may show poor scores. In order to optimise the benefits of these technological interventions, a more detailed analysis and further analytical probing are required, firstly to identify the root causes of these weaknesses, and secondly to develop remedial measures to tackle them. Otherwise, purely technological and financial aspects alone may not be able to achieve the overall objective and expected outcome for the project.



LEGEND: Extraction based
Falling film evaporation
Vacuum distillation based
Thin film evaporation
Acid activated clay process

Figure 4.2 Sample star diagram showing scores for composite criteria for five technologies

4.6 Verifying Continued Sustainability

A three-tiered detailed SAT analysis assists decision-makers in making a more informed decision. It should be pointed out that SAT analysis by itself does not yield a decision – it only facilitates decision-making. Thus the option with highest option is not necessarily the best option. Often the result of the SAT analysis indicates that there are several options within a close range of scores. In such cases, the management's prudence and knowledge take over in selecting one option.

Additionally, it is important to continuously monitor and evaluate the technology system during its operational phase to ensure that it continues to meet the desired objective vis-à-vis the various criteria considered during the SAT process.

Finally, the outcomes of the monitoring and evaluation should be reported to the stakeholder group – especially government agencies, planners and other decision makers, in order to help in situational analysis for similar future projects, and thus making better informed decisions.

ANNEX 1

Lubricants Consumption in Different Countries, 1997-1999 (Thousand tonnes)[104]

Country	1997	1998	1999	% Change	
				98/97	99/98
Austria	108	106	107	-1.9	+0.9
Belgium	211	196	210	-7.1	+7.1
Czech Republic	128	195	191	+52.3	-2.1
Denmark	85	81	77	-4.7	-4.9
Finland	97	94	92	-3.1	-2.1
France	900	931	919	+3.4	-1.3
Germany	1,159	1,142	1,158	-1.5	-1.4
Greece	(3) 122	(3) 114	(3) 118	-6.6	+3.5
Hungary	175	235	169	+34.3	-28.1
Ireland (2)	(3) 39	(3) 39	(3) 39	-	-
Italy	713	726	727	+1.8	+0.1
Luxembourg	(3) 10	(3) 10	(3) 10	-	-
Netherland	279	288	289	+3.2	+0.3
Norway	90	82	82	-8.9	-
Poland	217	291	295	+34.1	+1.4
Portugal	110	124	117	+12.7	-5.6
Spain (2)	451	490	501	+8.6	+2.2
Sweden	142	143	148	+0.7	+3.5
Switzerland	72	70	72	-2.8	+2.9
U. K. (2)	872	813	790	-6.8	-2.8
E.U.	5,298	5,297	5,302	-	+0.1
C.I.S. (1)	3,233	3,125	3,164	-3.3	+1.2
Other Europe	1,655	1,825	1,675	+10.3	-8.2
United States	8,423	8,754	8,578	+3.9	-2.0
Canada	981	939	951	-4.3	+1.3
Other America	3,296	3,403	3,369	+3.2	-1.0
Japan	2,187	2,101	2,039	-3.9	-3.0
Other Asia	10,363	10,380	11,112	-0.1	+7.1
Africa	1,907	1,961	2,018	+2.8	+2.9
Oceania	530	529	519	-0.2	-1.9
World*	37,903	38,314	38,727	+1.1	+1.1

*World, 1994: 36,625,000; 1995: 36,766,000; 1996: 37,536,000 tonnes

(1) Domestic market & bunkering (2) Excluding bunkering (3) Estimates

104 Giovanna,F.D., O. Khlebinskaia, et al., 2003. Compendium of Used Oil Regeneration Technologies, International Centre For Science And High Technology, UNIDO, Trieste

ANNEX 4

Sample Generic Criteria and Indicator System

Group heading	**Criteria**	**Indicators**	**Guidance notes/verification requirements**
Tier 1: Screening Criteria			
Compliance	Compliance with local environmental laws	Yes/no	This is a very fundamental requirement and rather a simple check. If this requirement is not met, then any further consideration of the option would become meaningless. The proposed technology system must be in compliance with local as well as national legislation. Supporting information to make this decision can be found using technology fact sheets as well as expert opinions and information from vendors when necessary.
Compliance	Compliance with Multilateral Environmental Agreements (MEAs)	Yes/no	Check if the proposed technology system results in violation of MEAs. For instance, the use of ozone depleting substances (ODS) can result in such a violation and hence must be avoided. It is necessary to rely on expert opinion for this, since this is rather a specialised area requiring careful scrutiny.
Yields and process efficiency	Meeting objectives (e.g. the '3Rs' of remediation, restoration and redevelopment**)**	Yes/no	An assessment of the probable yields, products that can be retrieved from the waste oils and promised levels of yields by suppliers of technology is highly useful in this initial stage. At the same time, if the proposed technology offers remediation, restoration and redevelopment, it is much more likely to pass through the later stages of assessment. A decision on this criterion can be made using information such as technology fact sheets, expert opinions and information from vendors.
Technical suitability	Availability and deployment of local expertise	Low/ medium/ high	Local expertise is necessary for commissioning a new technology system as well as for operating and managing it. A rating of low, medium or high is given in accordance with the expertise requirements vis-à-vis availability. Use vendor information and technology fact sheets vis-à-vis available local expertise to make the decision on this criterion.
Use of indigenous materials and	Extent of local materials	Low/ medium/ high	Technology intervention should give preference to the use of local materials in light of both cost and social considerations. Reference to vendor

Group heading	Criteria	Indicators	Guidance notes/verification requirements
non-dependence on imports	usage		information and technology fact sheets may assist in making this decision.
Environment, health and safety risks	Risk levels for workers	Low/ medium/ high	Before making the decision on the proposed technology system, it is essential to assess the potential environmental, health and safety risks to the workers and to communities/beneficiaries as well as to the environment/biodiversity. Depending on the scale and sensitivity of the proposed technological interventions, a full-fledged risk assessment exercise may be necessary in some instances, while in others, this decision can simply be made by referring to expert opinions supported by technology fact sheets and vendor information. When assigning scores for the ratings in the weighted sum matrix, it is important to note that higher scores should be assigned for lower risks. This is different from many other criteria, in which high ratings correspond to high scores.
Non-polluting/ environmentally friendly	Resource usage		This criterion assesses how the residues from the process will be disposed. If it involves disposal in local water streams, the process will not be considered.
Financial inclusion of the technology providers			To ensure inclusive growth, it is useful to assess whether or not the technology provider is amenable to working under the principles of ESCO (Energy Service Company) models. This model provides an opportunity for the technology providers to prove their systems, invest upfront and then offer a Save and Share formula.
Level of capital investment	Initial investments in the facility	Low/ medium/ high	As financial aspects play a dominant role in any decision making, a technology system requiring a low amount of capital is normally preferred.
Level of operating costs: Imparting economic value	Running costs	Low/ medium/ high	As a system's break even point is one of the most important parameters in decision making, a technology system that offers low operating/running costs is preferred even when its initial capital investment is higher than that of other options.

Simple technology	Can be understood and operated by local talent		A complicated technology system often warrants various systems and consumables that are not readily available in the vicinity of the plant. At the same time, a technology offering limited stages of processing will be more acceptable.
Flexibility in use of raw materials	Allowing various types of waste oils	Only one type/ limited types/ any type	A technology system that can handle a wide range of waste oils is preferable to systems that can handle only limited types of waste oils.
Land space requirement	Area of land	Low/ medium/ high	Land availability has always been a consideration. It is often found to be the most critical factor in decision making regarding the location of the facility. Hence, any technology requiring less land is preferable.
Domestic suppliers	Usage of local industry expertise	Very low/low/ medium/ major	This criterion assesses the extent to which the system can be fabricated using local resources, materials and skills, even if the technology itself has to be imported from advanced countries. A higher portion of the system able to be fabricated and commissioned using local resources is preferable.
Special skills and high education required to operate	Educational and special skill levels	Low/ medium/ high	One issue is the mobility of the population and difficulties in relocating to newer places. This results in the need to utilise local talent and skills. A technology that can be successfully employed despite low levels of education commonly found in developing countries is preferable to those requiring high levels of education or special technical skills.

Tier 2: Scoping Criteria			
Technical suitability	Compatibility with local natural conditions (geographical , climatic, topological)	Low/ medium/ high	To ensure optimal performance of the technology system, it is necessary to check the compatibility with local natural conditions (e.g. Is the proposed technology system suitable for geographical, climatic and topographical conditions? Will it result in any secondary impacts such as groundwater contamination?). To make this decision, refer to technology fact sheets, expert opinions and information from vendors.
Technical suitability	Extent of local materials	Low/ medium/	Technology intervention should give preference to the use of local materials in light of both cost and social considerations. Reference to vendor

	usage	high	information and technology fact sheets may assist in making this decision.
Technical suitability	Availability of local expertise	Low/ medium/ high	Local expertise is necessary for commissioning a new technology system as well as for operating and managing it . A rating of low, medium or high is given in accordance with the expertise requirements vis-à-vis availability. Use vendor information and technology fact sheets vis-à-vis available local expertise to make the decision on this criterion.
Technical suitability	Performance -related track record	Low/ medium/ high/not available	Before making a decision about any technology system option, it is essential to check the track record of both the technology and the vendor. Technology fact sheets, market intelligence, and site visits to similar installations all assist in assigning a rating to this aspect.
Technical suitability	Compatibility with existing situation (technology, management systems)	Low/ medium/ high	A new technology system may in some cases build upon an existing system. Therefore, the new system must be compatible with existing infrastructure/technology systems as well as the organisation's management systems. This decision can be made with the help of expert opinions supplemented by technology fact sheets and vendor information.
Technical suitability	Adaptability to future situations	Low/ medium/ high	In order to get the maximum benefit from the technology intervention, it is essential to check the technology system's flexibility or adaptability to future scenarios. This may, for instance, include the possibility of a scaling-up/expansion or an upgrade in the technology that improves efficiency in order to meet changing needs. Ratings can be assigned for this criterion by referring to technology fact sheets and expert opinions. It may also be essential to revisit the situation analysis and undertake some simulation or scenario building exercises to be able to decide on this aspect.
Technical suitability	Process stability	Low/ medium/ high	The stability of the proposed technology system during its operation phase is a very important consideration in bringing about the desired results. The technology system must perform in a stable manner under a variety of scenarios/situations during the operation phase, such as shock loads or sudden variations in process parameters. When assessing stability, it is essential to rely on expert opinions while also

			referring to technology fact sheets, past similar case studies and vendor information.
Technical suitability	Level of automation/ sophistication	Low/ medium/ high	The level of automation and the sophistication of the proposed technology system can be assessed by referring to vendor information, technology fact sheets and expert opinions.
Environment, health and safety risks	Risk levels for workers	Low/ medium/ high	Before making the decision on the proposed technology system, it is essential to assess the potential environmental, health and safety risks to the workers and to communities/beneficiaries as well as to the environment/biodiversity. Depending on the scale and sensitivity of the proposed technological interventions, a full-fledged risk assessment exercise may be necessary in some instances, while in others, this decision can simply be made by referring to expert opinions supported by technology fact sheets and vendor information. When assigning scores for the ratings in the weighted sum matrix, it is important to note that higher scores should be assigned for lower risks. This is different from many other criteria, in which high ratings correspond to high scores.
Environment, health and safety risks	Risk levels for communities/ beneficiaries	Low/ medium/ high	
Environment, health and safety risks	Risk to the environment, e.g. to biodiversity	Low/ medium/ high	
Environment: Resources and emissions	Resource usage		
Environment: Resources and emissions	Space requirement	Low/ medium/ high	Various aspects related to resource usage can be assessed by referring to vendor information, technology fact sheets and expert opinions. When assigning scores for the ratings in the weighted sum matrix, it is important to note that higher scores should be assigned for lower space requirements and lower energy, water and raw material consumption. This is different from many other criteria, in which high ratings correspond to high scores.

Environment: Resources and emissions	Energy consumption per unit	Low/ medium/ high	
Environment: Resources and emissions	Extent of use of renewable energy	Low/ medium/ high	
Environment: Resources and emissions	Extent of use of waste materials as input	Low/ medium/ high	
Environment: Resources and emissions	Water consumption	Low/ medium/ high	
Environment: Resources and emissions	Raw material consumption	Low/ medium/ high	
Environment: Resources and emissions	Resource augmentation capabilities	Low/ medium/ high	The proposed technology intervention may result in the remediation or recovery/augmentation of resources as a side effect/additional benefit and must be considered when deciding on a technology system. For this decision, one can rely on expert opinions while also referring to technology fact sheets, past similar case studies and vendor information.
Environment: Resources and emissions	Emissions	Low/ medium/ high	Various aspects related to emissions, odour and usage of hazardous materials can be assessed by referring to vendor information, technology fact sheets and expert opinions. When assigning scores for the ratings in the weighted sum matrix, it is important to note that higher scores should be assigned for lower emissions, odour etc.
Environment: Resources and emissions	Odour	Low/ medium/ high	
Environment: Resources and emissions	Extent of use of hazardous materials	Low/ medium/ high	
Economic/ financial	Capital	Low/ medium/	Various aspects related to costs and benefits can be assessed by referring primarily to vendor

aspects	investment	high	information and technology fact sheets as well as to expert opinions in certain cases. When assigning scores for the ratings in the weighted sum matrix, it is important to note that higher scores should be assigned for lower costs (and higher benefits). This is different from many other criteria, in which high ratings correspond to high scores.
Economic/ financial aspects	Operation and maintenance costs	Low/ medium/ high	
Economic/ financial aspects	Benefits (energy, fertiliser, reclaimed land, enhanced biodiversity)	Low/ medium/ high	
Social/ cultural aspects	Acceptability	Low/ medium/ high	Criteria related to social aspects can be assessed by using information collated through relevant socio-economic surveys, census data etc. In addition, reference to vendor information and expert opinions may be critical. When assigning scores for the ratings in the weighted sum matrix, it is important to note that higher scores should be assigned for a lower extent of resettlement required. This is different from many other criteria, in which high ratings correspond to high scores.
Social/ cultural aspects	Extent of necessary resettlement and rehabilitation of people	Low/ medium/ high	
Social/ cultural aspects	Income generation potential	Low/ medium/ high	
Tier 3: Detailed Assessment Criteria			
Environment: Resources and emissions	Land/space requirements	Area of land occupied by the installed technology (including	In this tier of assessment, detailed information is collected for the listed criteria for this assessment level using information from vendors and technology fact sheets.

		surrounding buffer margins) vis-à-vis availability	Expert opinion is essential in studying and analyzing the collected information and in assigning the ratings for each criterion accordingly.
Environment: Resources and emissions	Energy consumption		
Environment: Resources and emissions	Fuel	Type of fuel; quantity per unit operating hours or unit output	
Environment: Resources and emissions	Electricity	Quantity per unit operating hours or unit output	
Environment: Resources and emissions	Steam	Quantity per unit operating hours or unit output	
Environment: Resources and emissions	Raw materials consumption	Quantity per unit output or production	
Environment: Resources and emissions	Water consumption	Quantity per unit output or production	
Environment: Resources and emissions	Emissions	Quantity per unit output or production	
Environment: Resources and emissions	Noise and vibrations: Noise levels near installation during operation	Intensity in decibels	

About the UNEP Division of Technology, Industry and Economics

Set up in 1975, three years after UNEP was created, the Division of Technology, Industry and Economics (DTIE) provides solutions to policy-makers and helps change the business environment by offering platforms for dialogue and co-operation, innovative policy options, pilot projects and creative market mechanisms.

DTIE plays a leading role in three of the six UNEP strategic priorities: climate change, harmful substances and hazardous waste, resource efficiency.

DTIE is also actively contributing to the Green Economy Initiative launched by UNEP in 2008. This aims to shift national and world economies on to a new path, in which jobs and output growth are driven by increased investment in green sectors, and by a switch of consumers' preferences towards environmentally friendly goods and services.

Moreover, DTIE is responsible for fulfilling UNEP's mandate as an implementing agency for the Montreal Protocol Multilateral Fund and plays an executing role for a number of UNEP projects financed by the Global Environment Facility.

The Office of the Director, located in Paris, coordinates activities through:

> The International Environmental Technology Centre - IETC (Osaka), which implements integrated waste, water and disaster management programmes, focusing in particular on Asia.
> Sustainable Consumption and Production (Paris), which promotes sustainable consumption and production patterns as a contribution to human development through global markets.
> Chemicals (Geneva), which catalyses global actions to bring about the management of chemicals and the improvement of chemical safety worldwide.
> Energy (Paris and Nairobi), which fosters energy and transport policies for sustainable development and encourages investment in renewable energy and energy efficiency.
> OzonAction (Paris), which supports the phase-out of ozone depleting substances in developing countries and countries with economies in transition to ensure implementation of the Montreal Protocol.
> Economics and Trade (Geneva), which helps countries to integrate environmental considerations into economic and trade policies, and works with the finance sector to incorporate sustainable development policies. This branch is also charged with producing green economy reports.

DTIE works with many partners (other UN agencies and programmes, international organizations, governments, non-governmental organizations, business, industry, the media and the public) to raise awareness, improve the transfer of knowledge and information, foster technological cooperation and implement international conventions and agreements.

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Waste oil is a growing waste stream closely linked with rapid industrialization and increased automobile use. In many developing countries only a small amount of waste oil is recycled and that too using primitive and obsolete technologies which not only yields poor quality of recycled oil but also gives rise to toxic air emissions and hazardous solid waste. The market of such low grade recycled oils is usually limited. Remaining waste oil is usually burnt in the open or disposed of indiscriminately.

This compendium provides information on recycling and destruction technologies for waste oils. The compendium describes five generic technologies and twenty six specific technologies for recycling waste oils. It also describes three generic technologies for burning and recovering energy from non-recyclable waste oils. A step-by-step methodology for assessing the quantity and characteristics of waste oil from different sources of generation is also described. In addition the compendium describes a methodology for sustainability assessment of technologies to help in assessing different technologies for a particular application and selecting the most appropriate technology.

We hope that the compendium will be useful to government authorities, business and all those engaged in the task of treatment and recycling of waste oils.

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