CRITICAL REVIEW OF EXISTING STUDIES AND LIFE CYCLE ANALYSIS ON THE REGENERATION AND INCINERATION OF WASTE OILS

FINAL REPORT

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Executive Summary

Context, Objectives and Methodology of the Project

- One of the main axes of the directive 75/439/EC on Waste Oils (WO), amended in 1987, is that, among the different options for recovery, priority is given to the regeneration of WO over their incineration.

  But several studies clearly demonstrate that Member States (MS) do not favour regeneration of WO, but on the contrary are widely using WO as fuel in industrial installations.

- Launched by the EC in the frame of the revision of this amended directive, the main objective of this study is to undertake a thorough technico-economic and environmental analysis of the literature available about the regeneration of WO and its comparison with their incineration.

- For that purpose, more than 75 studies have been analysed.

  In order to update some of the obsolete information, to overcome some of the inconsistencies, and to gather information about new subjects still poorly covered by the literature (such as new regeneration technologies and thermal cracking), a lot of experts have been interviewed.

  A critical assessment has been performed for the four Life Cycle Analysis (LCA) studies available:

  - Burning or Re-refined used lube oil? - The Norwegian environmental protection agency,1995,
  - WO - Fuel or lubricant? - Examination for precedence in accordance with the waste recycling act - Lower Saxony Minister of the Environment (Germany), post 1997,
  - Recyclage et Valorisation énergétique des huiles usagées - Atouts et faiblesses – ADEME (France), 2000,
  - Ökologishe Bilanzierung von AltölVerwertungswegen - Ökologisher Vergleich von vier wichtigen Altölwertungsverfahren – UBA (Germany), 2000.

  The first International Standard concerning LCA (ISO 14040) has been published in 1997: it describes the principles and framework for conducting and reporting LCA studies, and includes certain minimal requirements. Two studies (ADEME and Germany 2000) have been recognised as compatible with the ISO standards concerning LCA studies: in the both studies, a critical review has been carried out. These studies are correctly designed to compare the waste management options under consideration.

  The two other studies (Norway 1995 and Germany 1997) have been performed before the publication of the ISO standards concerning LCA.

  For different reasons detailed in the report, the results of the Germany 1997 study has not been taken into account to draw the conclusions presented below.

Current Situation of WO Management in Europe

- About 4 930 kt of base oils were consumed in Europe in 2000, among which about 65% of automotive oils and less than 35% of industrial oils.

  About 50% of consumed oils are lost during use (combustion, evaporation, residues left in the containers…). The remaining 50% represent the collectable WO.

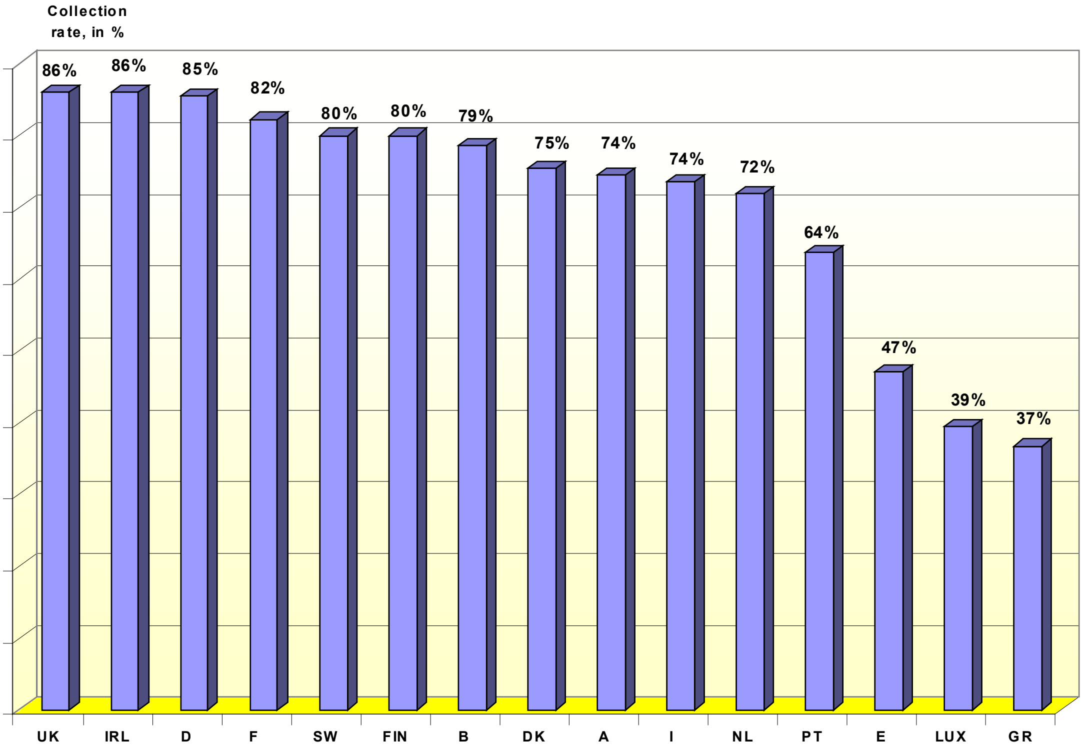
- Engine oils represent more than 70% of 2 400 kt of the collectable WO (black industrial oils about 5% and light industrial oils less than 25%).

  Engine oils (and to a lower extent black industrial oils) are potentially suitable for regeneration, whereas light industrial oils, clean, join an independent recovery circuit.

- The average WO collection rate reached about 70-75% in the E.U. in 2000. Approximately 1 730 kt of WO were collected. The remaining 675 kt (25-30%) are accounted as illegally burnt or dumped in the environment. It still vary from country to country.

  The efficiency of the WO collection systems is often very high for engine oils (more than 80%) and low for black industrial oils (less than 10%).

WO Collection Rate, in 2000



Appropriate collection and disposal arrangements for WO from industrial or automotive origin (garages…) are generally well established in Europe.
However, WO from 'Do-It-Yourself' (DIY) oil changes are less likely to be collected and so present the greatest risk of improper disposal.

Remark: It is well known that the national databases about collected quantities are still insufficiently developed and heterogeneous between the countries. The quality of the MS declarations could greatly benefit from the implementation of such databases with harmonised definition and calculation rules.

- A lot of treatment processes exist (or are under development) today in Europe. The most significant ones are listed below.

WO	*Type*	*Products*
Clean WO	RE-USE	**Hydraulic or cutting oil** • electricity companies • shipping industry • major engineering companies **Mould oil or base oil** for the production chain saw oil
Engine WO + clean WO	REGENERATION or RE-REFINING	**Lubricant base oil**
All types of WO including synthetic oils	THERMAL CRACKING	**Distillate gas oil products** • gas oil (also called heating oil, diesel oil, furnace oil…) • de-metallised fuel oil • marine gasoil (MGO) • re-refined light base oil
Mixed wastes	GASIFICATION	**Synthetic gas** • hydrogen • methanol
All types of WO, especially heavy polluted ones	SEVERE RE-PROCESSING	**De-metallised fuel oil** (or heavy distillate) • marine diesel oil (MDO) • fuel for heating plants…
	MILD RE-PROCESSING then burning	**Replacement fuel oil (RFO)** • road stone plants, cement kilns, large marine engines, pulverised power stations…
	DIRECT BURNING (waste incinerators, cement kilns, greenhouses, workshops…)	

- An average of 25% of the collectable WO (and 33% of the collected WO) would have entered a regeneration plant in the EU in 1999.

  About 50% of WO were energetically used in the E.U., in 1999.

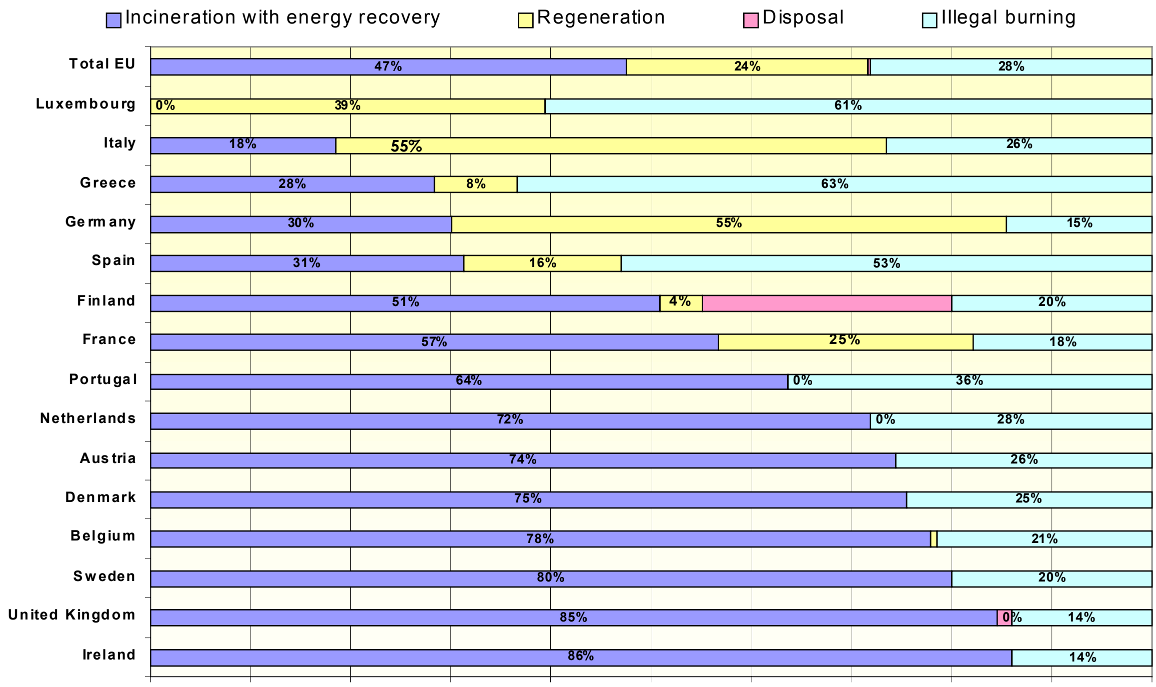
  Cement kilns play an important role in the energetic use of WO: about 400 kt of WO are burnt in cement kilns at the European level, which represents about 17% of the total WO and 35% of the WO burnt.

  But the importance of that route differs between the countries. It represents:

  - the major route in F, D, Sw,
  - only one of the routes in A, B, It and the UK.

  About 25% of WO were still illegally disposed of in 1999.

Management of Waste Oils in the E.U., in 1999



Remark: The data regarding the current situation of WO management in Europe are of very poor quality. In particular, we remain reserved about the reliability of the data regarding the regenerated quantities and regeneration rate.

- During the last years, a shrinking of the regeneration is noticeable in some countries which were precursors (such as France, Germany, Italy) and others (such as the UK).

  At the same time, 2 regeneration plants exist in Belgium today according to WATCO.

  The tendency regarding the regeneration development is uncertain for the near future. However, it seems that some projects emerge in several countries: France, Germany, Italy, Spain.

- Most of the MS do not subsidise the collection step.

  As far as the regeneration is concerned, it is subsidised only in Spain and now in Germany too.

  The situation in Italy is evolving. For instance, the partial exemption on the taxation on lubricants when they are produced from re-refined base oil will be suppressed at the end of 2001.

  As for the derogation on excise duty, it still applies for WO used as fuel in 11 of the MS.

Technico-Economic Analysis of WO Regeneration

- There is no major technical bottleneck for regeneration development:
  - the technologies exist,
  - the quality of base stocks produced is comparable to virgin base oils (Group I and even Group II when a severe hydro or solvent treatment is used for the finishing step).

  However, it remains to be seen whether the latest technical advances in regeneration prove to be sufficiently flexible to handle the changing composition of WO over the next 10 years and the possible increase of bio-lubricants consumption.

  This uncertainty generates risks for investors in regeneration facilities.

- The economic bottleneck is obvious.

  In most of the cases, a regeneration plant (with a 10% return on investment) is not economically self sufficient from the beginning, not only when the costs of collecting WO and delivery to the plant are included but even when they are not included. It would need to receive between 10 and 100 Euros for each tonne delivered to the plant, depending on the technology, the capacity and the market conditions.

  It is only after some years, once the capital cost are at least partly paid off, that the regeneration activity can be profitable.

  On the contrary, some large plants (but not all according to our analysis), located in countries where the re-refined base oil can be sold for a good price, can benefit from both scale advantages and high revenues, allowing them to purchase the WO, but at a relatively low price, between 15 to sometimes 50 Euros / t.

  In all the cases, the revenues of a regeneration plant are extremely sensible to the crude oil price fluctuations.

- The WO supplies often represent another bottleneck.

  Under free economic conditions, a regeneration plant is often unable to compete with untreated or re-processed combustion of WO (except in the case of some large plants with favourable local conditions).

  Even when the gate fee is negative, first the price that the plant can pay is not high enough to cover the overall collection and delivery costs (between 25 and 100 Euros/t depending on the country.

  Secondly, the regeneration plants suffer from the competition with industrial sectors buying the WO for an energetic use, such as cement kilns, brick kilns, power plants ...

  - As a matter of fact, due to the structure of their cost and the price of the fuels that the WO substitute, these companies are able to buy the collected WO often at a higher price than the regeneration plants (e.g. between 40 to 120 Euros per tonne when considering Italy, Germany and Spain). As a consequence, the market can often not guarantee the regularity of the supply of a regeneration plant. The situation may be improved a little bit for the regeneration activity when the new Directive on Incineration is implemented (in 2003 for new plants and 2005 for old plants), forbidding the burning of WO in many plants which are currently using WO as fuels and thus decreasing the financial interest of plants used to burn WO directly.

- The supplies of regenerators are also weakened by the WO excise duty derogation which are still in use in 11 Member States (A, B, D, E, F, Fin, Ire, It, Lux, Pt, UK): it consists in a derogation on the duty that has otherwise to be collected on WO which are used as fuel, either directly after recovery or following a recycling process. This fiscal measure, prolonged until 2006, encourages the use of WO as fuel.

  For instance, the UK excises are so high (43 Euros/t) that it brings the classic product (heating fuel) up to prices higher than the EU average. The total exemption for WO burnt as fuel makes WO very attractive for energetic use (that is why the UK is importing a large quantity of WO from other EU countries) and creates rarity of raw material for regenerators producing base oils.

- The vertical concentrations from collectors to processors which exist in some countries can create shortage of raw materials for regenerators because integrated companies would prefer to sell to cement kilns or other WO energetic users which offer higher prices (in particular in the case of crude oil price increase).

■ As for the outlet, potential users of re-refined base oils, in the automotive or industrial sector, are still reluctant to use regenerated products.

Besides, the size of the automotive lubricants is shrinking in a context of over-capacity of lubricant production and the demand progressively displaces from conventional mineral-based auto lubricants to 'synthetic' products with high performances. These tendencies are unfavourable to the increase of the re-refined base oils demand under free market conditions.

In any case, in this context of an increase of the quality required for lubricants, large regeneration plants will have to produce high quality re-refined base oil, even if niches will still absorb small quantities of lower quality.

■ To promote regeneration, it will be necessary to assist the regenerators with incentives (non financial in all cases and sometimes financial too).

Specific measures and arrangements have also to be taken by the regenerator himself.

All these measures aim at diminishing the risk profile of investment in regeneration projects by guaranteeing the existence and durability of the supply and outlets and, when the gate fee is positive, by covering it.

No spontaneous investment will occur unless clear signals regarding these issues are given to investors.

A set of measures and incentives is presented below, classified according to:

- the issue they are addressing: the supplies, the outlets and the profitability,
- the effect which is expected: to secure the feedstock, to secure the outlets, to cover a positive gate fee…

For instance:

Possible measures and incentives	Expected effect
Supplies	
• Medium or long term WO supply contracts and voluntary agreements between collectors and the regeneration plant • Participation (shares) taken by collectors in the regeneration activity	To secure feedstock supplies on which depends the profitability of the invested capital (to use the available regeneration capacity as much as possible)
• Collection and delivery costs covered, at least partly, by a disposal charge paid by generators / holders, a product charge on sold lubricants, a subsidy from governmental bodies…	To decrease the WO gate fee for regenerators Rem: This measure is necessary to improve the WO collection rate. Regeneration could then benefit from it.
• Application of the excise duty on WO that are used as fuel	To secure the supplies to regeneration plant
• Segregated storage and collection	To supply regeneration plants with regenerable WO to increase the quality of the outputs
Outlets	
• Marketing strategy of the regenerator to define the appropriate positioning of its products on the market (e.g. the distinction between products sold below the market price and those at the market price) • Medium or long term voluntary agreements between the regeneration plant and lube producers or large lube users • Financial incentives for blenders and lubricant manufacturers to purchase specified re-refined base oils	To secure the outlets and if possible to lighten the effect of the crude oil fluctuations
• Public procurement	To impose or at least encourage the use of lubricants containing or manufactured with re-refined base oils
Profitability	
• Stimulation of co-operation between the EU 15 countries	To obtain economies of scale and thus to decrease the WO gate fee
• Exemption of tax on sold lubricants (if any) for lubricants produced from re-refined base oil	To increase the re-refined base oil selling price (and the revenues) and thus to decrease the WO gate fee
• Subsidies (from a product charge on sold lubricants, a disposal charge paid by generators / holders, governmental bodies…)	To cover the residual positive WO gate fee of the regeneration plant (if any)

Technico-Economic Analysis of WO Thermal Cracking

- Thermal cracking can accept various types of hydrocarbon feedstock: WO, waste marine fuels, deep frying oils and, possibly with design considerations, waste plastics (e.g. DIY WO returned in their original container).

- The strategy of thermal cracking is to produce high quality products ranging from de-metallised heavy fuel oil to re-refined light industrial lube oil, including gasoil products.

- Thermal cracking is a common refinery process that is well known and proven.

  No plant already exists in Europe for WO: the first plant will be operational by the end of 2001 in Belgium.

- Experts agree that thermal cracking with its lower capital cost allows plants to be profitable at the 30 kt/yr plant size. No subsidies are necessary.

  The evaluation performed in the scope of this project on the basis of the Belgium plant being built confirms that point.

Critical Assessment of LCA Studies Comparing Regeneration and Incineration

- The results (more the tendencies than the absolute figures) from the four LCA assessed comparing regeneration and incineration can be considered sound and representative of a wide diversity of situations prevailing in Europe for the following environmental impacts categories:
  - Consumption of fossil energy resources,
  - Contribution to global climate change,
  - Contribution to regional acidifying potential,
  - Emission of Volatile Organic Compounds (VOC).

  As a matter of fact, three technologies have been considered, which can be considered being representative of a diversity of regeneration technologies existing in Europe, including modern processes:
  - Vacuum distillation + clay treatment,
  - Vacuum distillation + chemical treatment,
  - Hydrogen pre-treatment + vacuum distillation.

  And two of the incineration options existing in Europe are covered by the LCAs discussed:
  - Incineration in cement kiln,
  - Incineration in asphalt plant.

A large proportion of the collected WO in Europe are sent to one of these two types of plants. The environmental impacts of these two plants are different. The choice of two different types of plants reflect the fact that in reality there is a big variety of burning plants that use waste oils as fuel (e.g. power generation plants, tarmac production plants, cement kilns, asphalt plants, etc).

The following conclusions drawn from the LCAs analysed are those considered sound.

- From a local impacts perspective, when considering only the recovery treatments, the impacts generated by the regeneration plant are generally lower than those generated by the incineration plant.
- The environmental performance of an old regeneration process can be improved with a modern technology.
- The environmental impacts due to collection and transport of WO and primary materials are not significant within a life cycle perspective compared to the impacts of the industrial processes (this is often the case in LCAs performed for waste management options, e.g. packaging waste).
- The environmental burden of the recovery treatment (regeneration or incineration) by itself is generally less important than the one of the avoided process (virgin base oil production or traditional fuel or energy production).

  Within a life cycle perspective, the total contribution of the management system under consideration is indeed the result of the difference between two different quantities: the impact of the recovery treatment minus the impact of the main avoided system (this latter representing a bonus). The environmental impacts of WO recovery systems are mainly determined by this bonus and less by the direct impacts of the recovery processes themselves.
- All the WO recovery options under consideration are favourable in terms of environmental impacts (i.e. they contribute to avoid impacts) by comparison with a 'do nothing' system.
- The amount of the bonus brought by the avoided process is determined by the choice of the substituted process (this is also the case for other wastes with a high calorific value as plastic wastes).

  Especially in the case of the incineration of WO with energy recovery, the type of fuels that the WO replace is crucial: fossil fuel, hydroelectricity, thermal electricity, other wastes….

  This explains that, in the LCAs analysed:

  - for almost all environmental impacts considered, incineration in cement kilns (where WO replace fossil fuels) is more favourable than incineration in an asphalt kiln (where WO replace gas oil),
  - a modern regeneration may be, according to the impact considered, more favourable than or equivalent to incineration in an asphalt kiln,
  - compared to incineration in a cement kiln (where WO replace fossil fuels), WO regeneration has environmental advantages and drawbacks depending on the impact considered.

  It appears that regeneration would present advantages for all environmental impacts in all scenarios if the WO would replace non fossil fuels (e.g. hydroelectricity, nuclear electricity and maybe other wastes).

- According to the LCAs studied, as regards the comparison of regeneration to fuel and feedstock conversion:
  - Compared to thermal cracking, WO regeneration would have environmental advantages and drawbacks depending on the impact considered.
  - Regeneration would be preferable to gasification for all impacts except solid waste and water input.
  - A modern regeneration technology would become preferable to refinery recycling for some impact categories or equivalent for the others.

  Nevertheless these results ought to be validated by other studies in the future

- The following issues have not been addressed in the LCAs available and can be considered as gaps:
  - noise,
  - odour,
  - nature conservation (biodiversity, etc.),
  - land use,
  - toxic emissions.
  - the displacement of non fossil fuels by waste oils.

  As for toxic emissions (heavy metals, organic pollutants…), the LCA methodology is not currently relevant to quantify and compare reliable indicators with respect to human toxicity and ecotoxicity.

  An attempt to compute such indicators has been made in two LCAs but using different methods and obtaining highly uncertain results.

  More generally, few studies have been reported on the toxicity and potential health effects of re-refined base oils. And chronic impacts have not been studied.

  Nevertheless, it seems that re-refined base oil are not acutely toxic, nor are they skin or eyes irritant.

- The following considerations, which may have a significant influence on the environmental impacts have not been covered by the available studies as well:
  - the situations when WO replace other energy sources or wastes and not traditional fuels at the burning plants,
  - the influence of the base oil quality standard produced and / or regenerated on the environmental impacts of the different management options,

- Although one of the studies integrates the analysis of a modern regeneration technology under development, the main results from the reviewed LCA studies are based on today's situation and mean technology.

  In view of defining a waste management policy, this can just constitute a starting point**.** A prospective evaluation, taking into account the possible evolutions of technologies in the mid term, has to be integrated.

A.
Introduction and Current Situation

1 Presentation of the Project

1.1 Context and Objectives of the Project

- The first Community directive in the waste area was the Directive on waste oils (WO), 75/439/EC, adopted in 1975, and amended in 1987 by 87/101/EC. This directive sets the provisions for the environmentally sound management of WO.

  This directive primarily aims at ensuring that WO are collected and disposed of without causing any avoidable damage to man and the environment.

  One of the main axes of this directive is that, among the different options for recovery, priority is given to the regeneration of WO over their incineration.

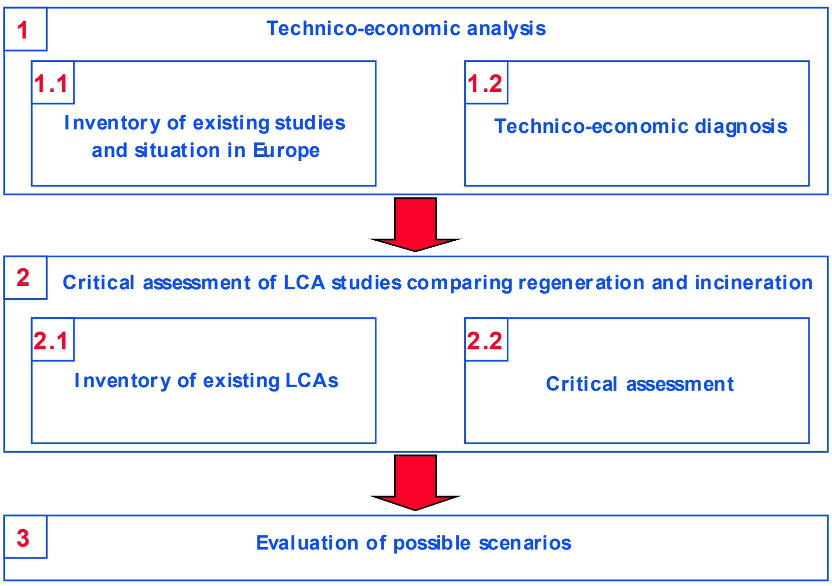
- Several studies, as well as the last report from the Commission to the Council and the European parliament on the implementation of community waste legislation for the period 1995-1997, clearly demonstrate that Member States (MS) do not favour regeneration of WO, but on the contrary are widely using WO as fuel in industrial installations.

- The present study has been launched by the EC in the frame of the revision of this amended directive.

  Its purpose is to bring a new set of arguments and facts to the debate which should serve to attain an environmentally sound management of WO in the revised directive.

  Its main objective is to undertake a thorough analysis of the literature available in the context of the regeneration of WO and a critical assessment of the comparisons carried out between regeneration and incineration of WO.

1.2 Content of the Project



1.2.1 Technico-Economic Analysis (Phase 1)

The objectives of Phase 1 was, from the literature, to address the following issues:

- collection schemes available for WO in the MS,
- regeneration: categories of WO that can be regenerated, new technologies available, cost analysis (break even point),
- subsidies and taxes applied in the MS to regeneration and incineration of WO,
- recovery options for WO other than regeneration and incineration.

For that purpose, the available literature has been analysed (more than 75 studies, which are listed in appendix 1):

- studies provided by the European Commission,
- studies indicated by Member States (as an answer to solicitation through E-mail),
- studies provided by the experts contacted in the frame of the project,
- information obtained through a research on Internet (research engines, Web sites).

Several synthetic documents have been elaborated which are included in the appendices section and which will be presented in the following chapters.

It has to be noted that, from a methodological point of view, the use of existing information and data not produced by the consultant constitutes an extremely difficult and time consuming exercise, because of the lack of consistency of the data and not enough transparency regarding the hypotheses.

As a consequence, in order to update some of the obsolete information, to overcome some of the inconsistencies, and to gather information about new subjects still poorly covered by the literature (such as new regeneration technologies and thermal cracking), a lot of experts have been interviewed (see appendix 2).

1.2.2 Critical Assessment of LCA studies Comparing Regeneration and Incineration (Phase 2)

The purpose of Phase 2 was to compile the different life cycle analysis (LCA) comparing recovery options for WO produced at the Community level, in order to identify:

- the conclusions which can be drawn at the European level,
- the conclusions which are site or country specific.

Six studies have been considered:

- Burning or Re-refined used lube oil? - The Norwegian environmental protection agency,1995 [16],
- WO - Fuel or lubricant? - Examination for precedence in accordance with the waste recycling act - Lower Saxony Minister of the Environment (Germany), post 1997 [18],
- Environmental and economic impact of re-refined products : a life cycle analysis - Centro Ricerche FIAT (Italy) [20],
- Collection and disposal of used lubricant – CONCAWE, 1996 [19],
- Recyclage et Valorisation énergétique des huiles usagées - Atouts et faiblesses – ADEME (France), 2000 [21],
- Ökologishe Bilanzierung von AltölVerwertungswegen - Ökologisher Vergleich von vier wichtigen Altölwertungsverfahren – UBA (Germany), 2000 [17].

A comprehensive bibliographic notice is delivered for every study (see chapter 10).

2 TYPES OF OILS AND TYPES OF WO DISPOSAL ROUTES

2.1 TYPES OF BASE OILS AND WO

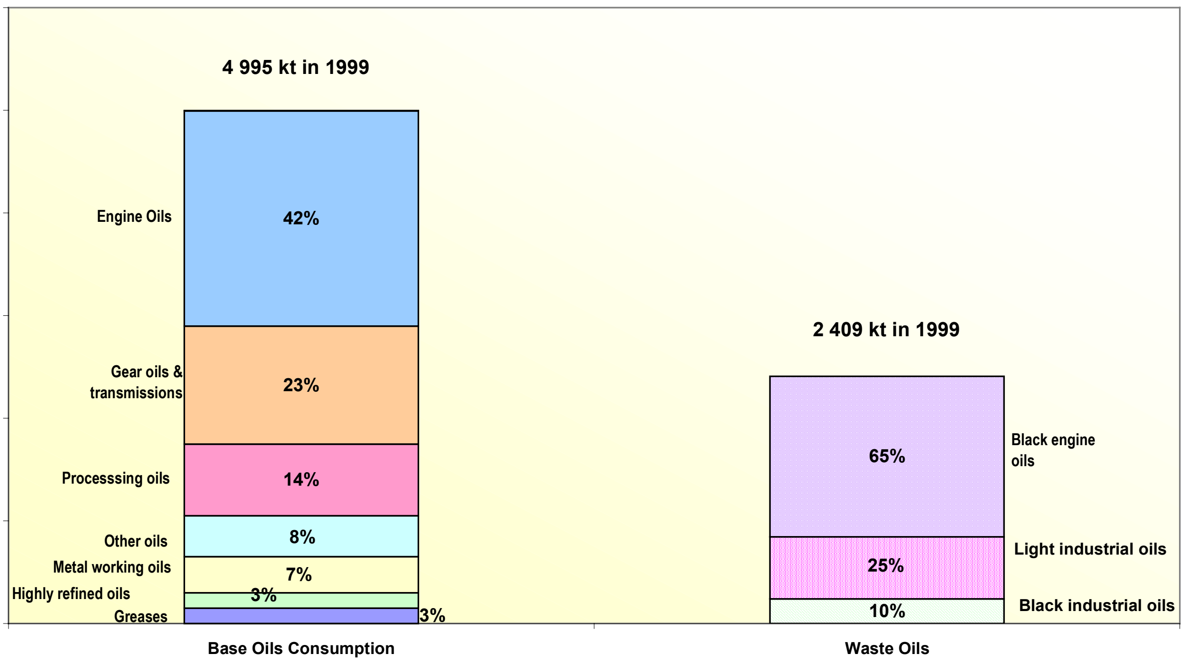
(See appendix 3 which presents a synthetic table)

- Automotive oils represent more than 65% of base oils consumption (industrial oils less than 35%).
- About 50% of consumed oils are lost during use (combustion, evaporation, residues left in the containers…).
- The remaining 50% represent the collectable WO.

  Engine oils represent more than 70% of the WO stream (black industrial oils about 5% and light industrial oils less than 25%).

  Engine oils (and to a lower extent black industrial oils) are potentially suitable for regeneration, whereas light industrial oils, clean, join an independent recovery circuit.

Base Oils Consumed and WO Generated

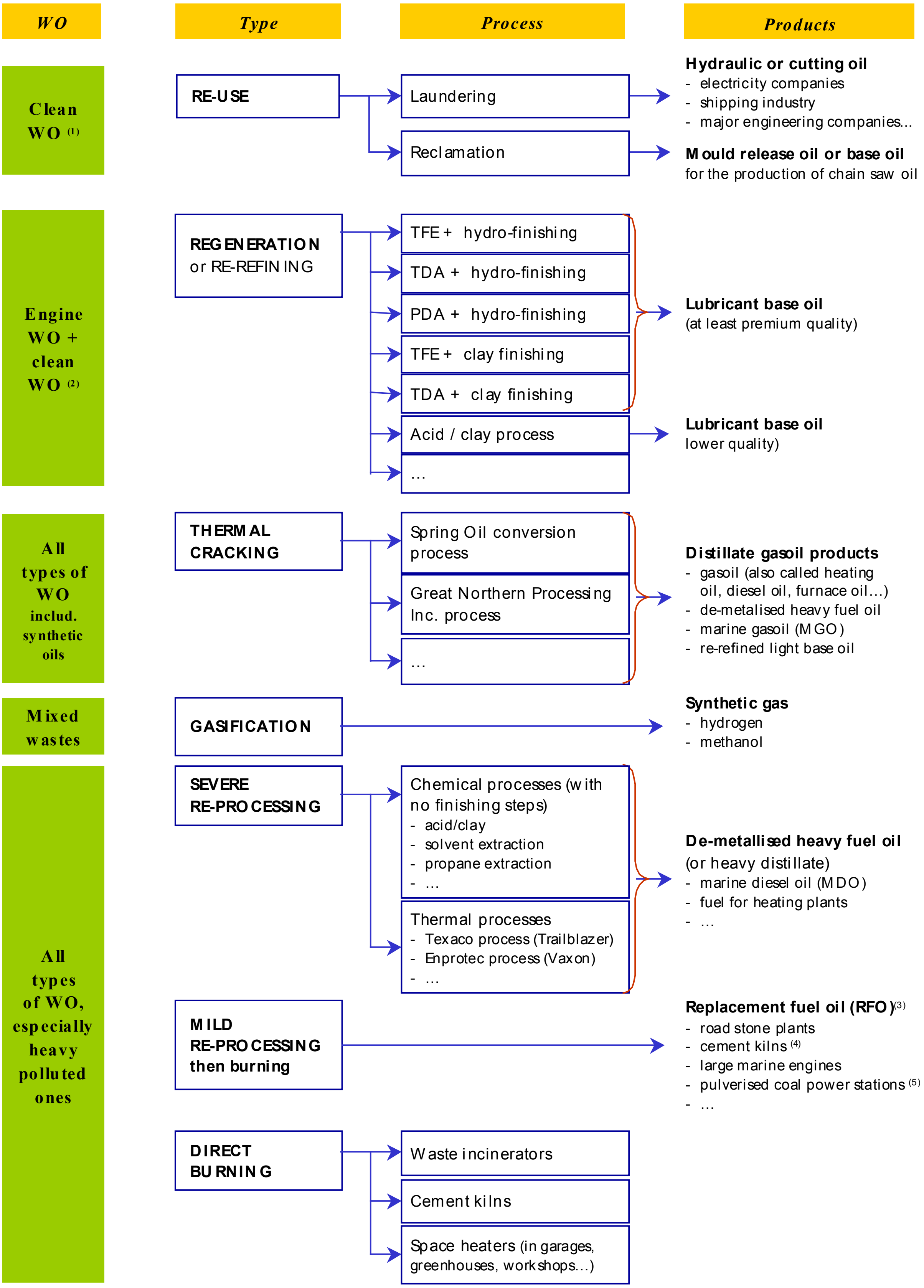


Sources: [6], [27], [29], [37]

2.2 TYPES OF WO DISPOSAL ROUTES

A lot of treatment processes exist (or are under development) today in Europe. The most significant ones are listed below. Although dumping and illegal burning exist in most of the European countries (see chapter 3.1), they are not mentioned here as they are forbidden.

The Different WO Disposal Routes



(1) especially hydraulic or cutting oil
(2) engine oils without chlorine + hydraulic oils without chlorine + hydraulic mineral oils + mineral diathermic oils (according to the API classification)
(3) still containing the heavy metals, halogen and sulphur contained in the WO
(4) substitutes other secondary liquid fuel (SLF) or heavy fuel or coal or petroleum coke
(5) as a furnace start up fuel

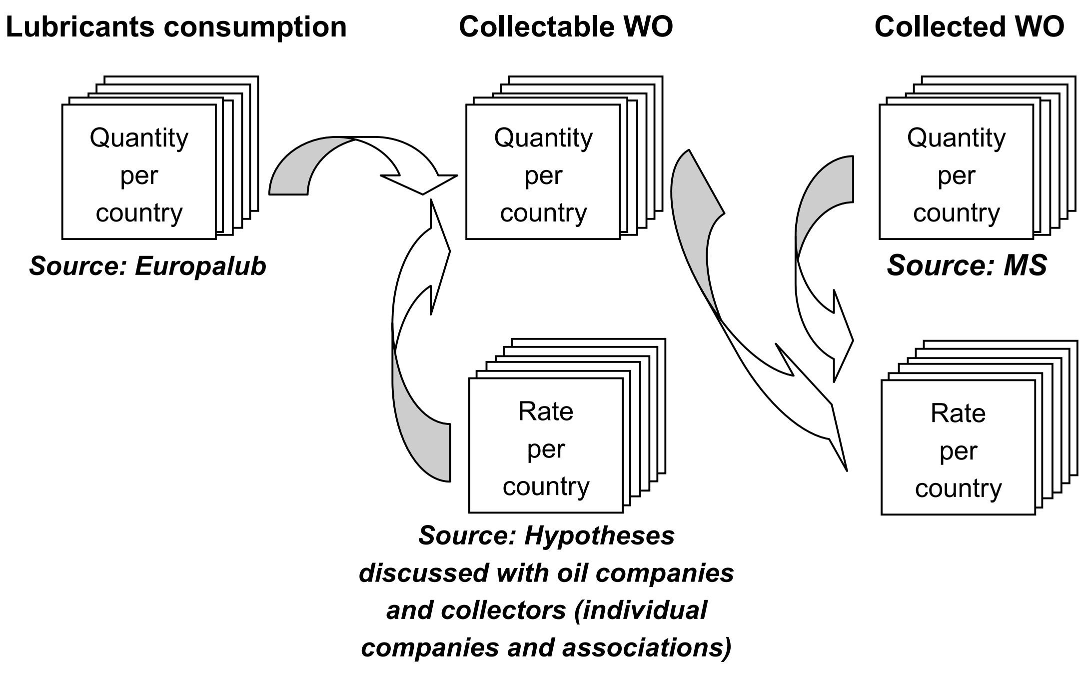
3 Current Situation of WO Management in Europe

3.1 WO Quantities in the European Union

3.1.1 Situation in the European Union

3.1.1.1 Lubricants Consumed, WO Generated and Collected

- The source of information selected for that section is the GEIR data corresponding to the 2000 year[1], because:
  - the data cover all the MS,
  - the data are among the most recent ones,
  - a methodology has been defined and implemented in co-operation with experts.



[1] Except for France where the ADEME data communicated to TN SOFRES Consulting in the scope of this study have been considered [65]

It should be mentioned that this first methodology could be improved in the future, in order to bring confirmation and clarification about several issues:

- the evaluation of the WO generated is based on hypotheses regarding the percentage of WO collectable per country, which is the difference between the quantity of lubricant consumed and the loss during its use.

  This attempt to address that issue on a country basis is fully justified by the fact that the percentage of lubricants that disappear during use (about 50% in average) varies between the countries, according to the proportion of the various activities involving the use of lubricants. In its evaluation, the GEIR has attempted to take into account that reality by choosing, for each country, a specific percentage of loss.

  This percentage thus varies between 68% and 40% according to the country.

  However, it is still based on hypotheses and not on an in-depth analysis.

- it is well known that the national databases about collected quantities are still insufficiently developed and heterogeneous between the countries. The quality of the MS declarations could greatly benefit from the implementation of such databases with harmonised definition and calculation rules.

Lubricants Consumption and WO Production and Collection in the E.U. - Year 2000

	Consumption	Collectable		Collected (dry waste oil)	
	A	B/A	B	C/B	C
	Tons	%	Tons	%	Tons
Austria	102 400	44%	45 000	74%	33 500
Belgium	173 608	44%	76 388	79%	60 000
Denmark	71 416	65%	46 420	75%	35 000
Finland	89 194	54%	48 165	80%	38 532
France	888 771	49%	435 498	56%	242 500
Germany	1 076 149	50%	538 075	85%	460 000
Greece	88 000	68%	60 000	37%	22 000
Ireland	38 900	*51%*	*19 839*	*86%*	*17 062*
Italy	681 100	40%	272 440	74%	200 395
Luxembourg	10 150	*50%*	*5 075*	*39%*	*2 000*
Netherland	154 685	54%	83 530	72%	60 000
Portugal	113 200	55%	62 260	64%	39 620
Spain	496 141	45%	223 263	47%	105 000
Sweden	146 847	*54%*	*79 297*	*80%*	*63 438*
U.K.	803 667	51%	409 870	86%	352 500
E.U.	4 934 228	49%	2 405 120	72%	1 731 546

Source : IHMB - GEIR
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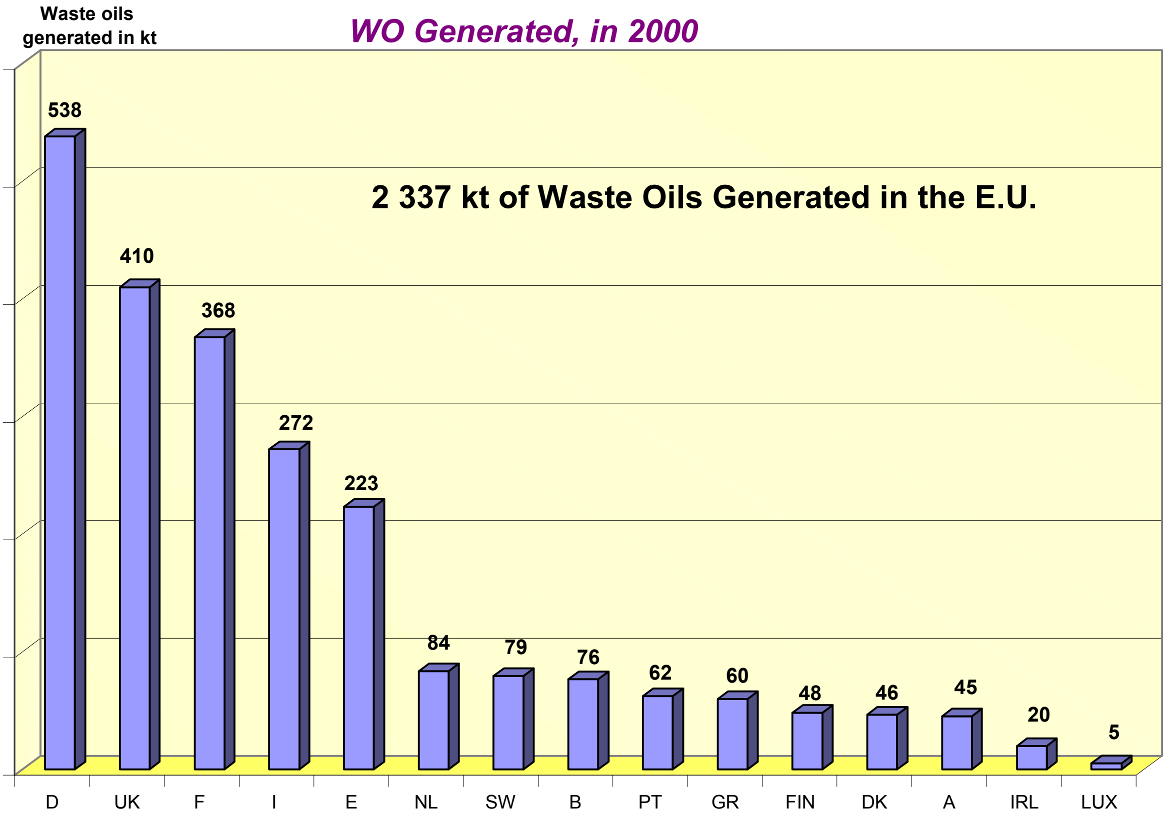
mail : geir@fedichem.be

Figures in italics are yet to be confirmed by respective member state

- In the European Union, approximately 4 930 kt of lubricants were consumed in 2000. It is assumed that about 2 400 kt of WO were generated in 2000, i.e. 49%.



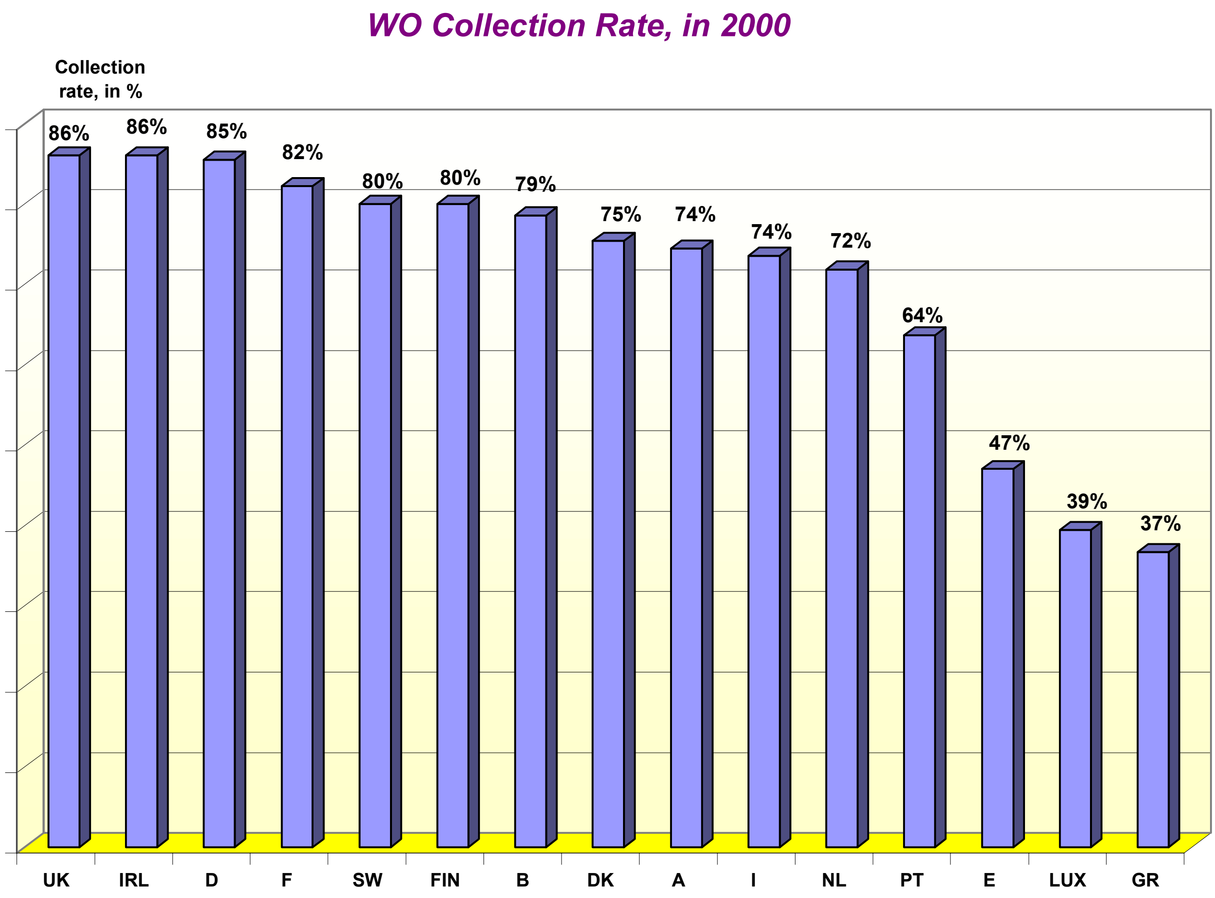
Source: IHMB – GEIR [75] (table above) (except for France [65])

■ The average WO collection rate reached about 70-75% in the E.U. in 2000.

Approximately 1 730 kt of WO were collected. The remaining 675 kt (25-30%) are accounted as illegally burnt or dumped in the environment.

The efficiency of the WO collection systems is often very high for engine oils (more than 80%) and low for black industrial oils (less than 10%).

It still vary from country to country, between more than 85% in the most advanced countries to less than 40% in the less advanced ones.



Source: IHMB – GEIR [75] (table above)(except for France [65])

3.1.1.2 WO Disposal Routes

- The data regarding the current situation of WO management in Europe are of very poor quality, particularly those concerning the regeneration route:
  - the official data, reported by the MS to the EC, are old (1995 for some countries, 1997 for the others) and often obsolete,
  - regarding the regeneration route, several difficulties occur which impact greatly on the quality of the data:
    - no up-dated synthetic information, even within the profession,
    - in that sensitive political context, the accuracy of the information is not guaranteed. For instance, some data incorporate the capacity of plants which could produce re-refined base oil but which are currently operated to produce demetallised fuel oil.

      As a result, we had to deal with contradictory information coming from different sources.
    - most of the sources indicate the quantity entering regeneration plants.

      But the yield of a regeneration plant varies between 55 to 75% depending on the process. In addition, regeneration plants can adjust the quantity of re-refined base oil and fuels produced according to the international and local situation (crude oil prices, market demand, subsidies...). For these reasons, a huge difference might exist between the quantities entering the regeneration route and the quantities of re-refined base oil actually produced.

      For instance, in Germany, 298 kt would be sent to the regeneration, out of which less than 90 kt of re-refined base oil would be produced.
    - the situation of the regeneration route is facing a rapid evolution. Some of the plants close whereas others are built. It is very difficult to gather precise information about these evolutions.

- An attempt to synthesise the available information as well as those gathered during the current study has been made (see the next two pages).

  The results are presented below with charts. The tendencies indicated and the figures mentioned are only indicative and would necessitate to be confirmed in the framework of a dedicated study.

  In particular, once again, we remain reserved about the reliability of the data regarding the regenerated quantities and regeneration rate.

The methodology used to compile the information is as follows:

- The source considered for oils consumed, WO collectable and WO collected is GEIR [75] as indicated above.
- The quantities regenerated after collection (i.e. entering the regeneration plants) are those reported to the EC in 1995 or 1997 [10].
- The quantities of re-refined base oil (i.e. output of the regeneration plants) are those reported by GEIR [9].
- The quantities disposed of after collection have been taken equal to those reported to the EC in 1995 or 1997 [10].
- The quantities collected for energetic use have been calculated by difference (collected - regenerated - disposed).
- The quantities illegally burnt have also been calculated by difference (waste - collected).
- What precedes concerns all the countries except France [65] for which available national data have been used and partially UK [40] (oils consumed, WO collectable and WO collected is GEIR [75] and the other data are national data presented in the UK report).

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Coopers & Lybrand [30] 1993

Country	Consumption	Waste (collectable)	Collected	Collection rate	Energetic use (illegal burning inside it, after a mixture or a service)	Energetic use rate (%)	Regenerated (input) (model)	Regeneration rate out of waste (%)	Regeneration rate out of collected WO (%)	Disposal	Disposal rate (%)	Non-collected / illegal burning	Non-collected rate (%)
	P1	W1	C1	C1/W1	E1	E1/W1	R1	R1/W1	R1/C1	D1	D1/W1	N1=W1-...	N1/W1
Austria	85	45	38	84%	38	84%	0	0%	0%	0	0%	7	16%
Belgium	100	95	50	53%	50	53%	0	0%	0%	0	0%	45	47%
Denmark	80	43	40	93%	40	93%	0	0%	0%	0	0%	3	7%
Finland	100	50	40	80%	34	68%	2	4%	5%	0	0%	10	20%
France	690	325	225	69%	130	40%	95	29%	42%	0	0%	100	31%
Germany	1 200	690	600	87%	240	35%	360	52%	60%	0	0%	90	13%
Greece	120	60	5	8%	0	0%	5	8%	100%	0	0%	55	92%
Ireland	80	40	14	35%	14	35%	0	0%	0%	0	0%	26	65%
Italy	525	208	180	87%	30	14%	150	72%	83%	0	0%	28	13%
Luxembourg	5	2.5	2.3	92%	2.3	92%	0	0%	0%	0	0%	0.2	8%
Netherlands	170	85	60	71%	60	71%	0	0%	0%	0	0%	25	29%
Portugal	89	45	13	29%	13	29%	0	0%	0%	0	0%	32	71%
Spain	500	250	110	44%	75	30%	35	14%	32%	0	0%	140	56%
Sweden	200	110	90	82%	90	82%	0	0%	0%	0	0%	20	18%
United Kingdom	775	400	360	90%	350	88%	10	3%	3%	0	0%	40	10%
Total EU	**5 109**	**2 449**	**1 827**	**75%**	**1 166**	**48%**	**657**	**27%**	**36%**	**0**	**0%**	**621**	**25%**

Data reported to EC [10] 1995 for Greece, Italy, Portugal and Spain; 1997 for others

Country	Consumption	Waste (collectable)	Collected	Collection rate (%)	Energetic use	Energetic use rate (%)	Regenerated (input)	Regeneration rate out of waste (%)	Regeneration rate out of collected WO (%)	Disposal	Disposal rate (%)	Non-collected / illegal burning	Non-collected rate (%)
	P2	W2	C2	C2/W2	E2	E2/W2	R2	R2/W2	R2/C2	D2	D2/W2	N1=W2-C2	N2/W2
Austria	86	45	34	75%	37	83%	0	0%	0%	0	0%	8	18%
Belgium	n.a.	230	202	88%	202	88%	1	0%	0%	0	0%	28	12%
Denmark	86	n.a.	36	n.a.	29	n.a.	0	n.a.	0%	0	n.a.	n.a.	n.a.
Finland	97	50	47	94%	33	66%	2	4%	4%	12	24%	3	6%
France	875	373	242	65%	169	45%	81	22%	33%	0	0%	131	35%
Germany	1 168	760	485	64%	187	25%	298	39%	61%	0	0%	275	36%
Greece	120	60	5	8%	0	0%	5	8%	100%	0	0%	55	92%
Ireland	42	14	8	59%	7	51%	0	0%	0%	n.a.	n.a.	6	41%
Italy	625	208	180	87%	30	14%	150	72%	83%	0	0%	28	13%
Luxembourg	n.a.	3	3	100%	0	0%	3	100%	100%	n.a.	n.a.	0	0%
Netherlands	187	85	49	58%	49	58%	0	0%	0%	0	0%	36	42%
Portugal	89	45	13	29%	13	29%	0	0%	0%	0	0%	32	71%
Spain	500	250	110	44%	69	23%	35	14%	32%	n.a.	n.a.	140	56%
Sweden	144	n.a.	72	n.a.	49	n.a.	0	n.a.	0%	n.a.	n.a.	n.a.	n.a.
United Kingdom	873	477	422	89%	390	82%	32	7%	8%	55	11%	0	0%
Total EU	**4 892**	**2 601**	**1 909**	**73%**	**1 254**	**48%**	**687**	**23%**	**32%**	**67**	**3%**	**742**	**29%**

IEC Consulting [25] 1999

Country	Consumption	Collected	Re-refined base oil (output)	Re-refined base oil out of collected WO (%)
	P3	C3	R3	R3/C3
Austria	108	38	0	0%
Belgium	186	45	0	0%
Denmark	77	40	0	0%
Finland	102	35	0	0%
France	875	236	53	22%
Germany	1 115	453	52	11%
Greece	88	18	25	139%
Ireland	38	10	0	0%
Italy	666	166	80	48%
Luxembourg	10	4	0	0%
Netherlands	161	53	0	0%
Portugal	109	20	0	0%
Spain	601	158	12	8%
Sweden	148	55	0	0%
United Kingdom	790	230	8	3%
Total EU	**4 565**	**1 561**	**230**	**15%**

GEIR [9] 1998 (except for France 1999 data)

Country	Consumption	Collected	Regeneration output	Of which re-refined base oil	Of which fuel	Re-refined base oil out of collected WO (%)
	P4	C4	R4= B4+F4	B4	F4	R4/C4
Austria	86	38	n.a.	n.a.	n.a.	n.a.
Belgium	150	80	40	2	38	51%
Denmark	80	34	n.a.	n.a.	n.a.	n.a.
Finland	100	40	n.a.	n.a.	n.a.	n.a.
France	890	236	90	63	27	38%
Germany	817	473	436	257	179	92%
Greece	110	15	4	4	0	29%
Ireland	80	14	n.a.	n.a.	n.a.	n.a.
Italy	600	180	127	84	43	71%
Luxembourg	5	2	n.a.	n.a.	n.a.	n.a.
Netherlands	170	60	n.a.	n.a.	n.a.	n.a.
Portugal	89	13	n.a.	n.a.	n.a.	n.a.
Spain	570	130	25	25	0	19%
Sweden	200	83	n.a.	n.a.	n.a.	n.a.
United Kingdom	800	350	33	26	7	9%
Total EU	**4 746**	**1 748**	**756**	**462**	**295**	**43%**

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'Best' mix of the various data

Yr 2000 Source: GEIR [75] (5) (Consumption to Collection rate); Yr 1999 or 2000 or 2001 according to the countries. Calculations (formulas above) and various sources (other columns)

Country	Consumption	Waste (collectable)	Collected	Collection rate (%)	Energetic use	Energetic use rate (%)	Regeneration: Regenerated (input)	Regeneration: Regeneration (input) rate out of waste (%)	Regeneration: Regeneration (input) rate out of collected WO (%)	Regeneration: Re-refined base oil	Regeneration: Re-refined base oil out of waste (%)	Regeneration: Re-refined base oil out of collected waste (%)	Disposal	Disposal rate (%)	Non-collected / illegal burning / deposit	Non-collected rate (%)	Sources
formula	P=P6	W=W6	C=C6	C/W	E=C-R-D	E/W	R=R2	R/W	R/C	B=B4	B/W		D=D2	D/W	N=W-C	N/W	
Austria	102	45	34	74%	34	74%	0	0%	0%	n.a.	n.a.	n.a.	0	0%	12	26%	formula
Belgium	174	76	60	79%	60	79%	1	1%	1%	1	1%	2%	0	0%	16	21%	formula
Denmark	71	46	35	75%	35	75%	0	0%	0%	n.a.	n.a.	n.a.	0	0%	11	25%	formula
Finland	69	48	39	80%	25	51%	2	4%	5%	n.a.	n.a.	n.a.	12	25%	10	20%	formula
France	718	368	302	82%	208	57%	94	25%	31%	37	10%	12%	0	0%	66	18%	[65] (1)
Germany	1 076	538	460	85%	162	30%	298	55%	65%	257	48%	56%	0	0%	78	15%	formula
Greece	88	60	22	37%	17	28%	5	8%	23%	4	7%	18%	0	0%	38	63%	formula (2)
Ireland	39	20	17	86%	17	86%	0	0%	0%	n.a.	n.a.	n.a.	n.a.	n.a.	3	14%	formula
Italy	681	272	200	74%	50	18%	150	55%	75%	84	31%	42%	0	0%	72	26%	formula
Luxembourg	10	5	2	39%	0	0%	2	39%	100%	n.a.	n.a.	n.a.	n.a.	n.a.	3	61%	formula (3)
Netherlands	195	84	60	72%	60	72%	0	0%	0%	n.a.	n.a.	n.a.	0	0%	24	28%	formula
Portugal	113	62	40	64%	40	64%	0	0%	0%	n.a.	n.a.	n.a.	0	0%	23	36%	formula
Spain	496	223	105	47%	70	31%	35	16%	33%	25	11%	24%	n.a.	n.a.	118	53%	formula
Sweden	147	79	63	80%	63	80%	0	0%	0%	n.a.	n.a.	n.a.	n.a.	n.a.	16	20%	formula (4)
United Kingdom	804	410	353	86%	347	85%	0	0%	0%	0	0%	0%	6	1%	57	14%	[40]
Total EU	**4 763**	**2 337**	**1 791**	**77%**	**1 187**	**51%**	**586**	**25%**	**33%**	**462**	**20%**	**26%**	**6**	**0%**	**546**	**23%**	-

The more recent data collected in the scope of that study — Various sources

Country	Consumption	Waste (collectable)	Collectable rate (%)	Collected	Collection rate (%)	Re-use	Energetic use	Energetic use rate (%)	Regeneration: Regenerated (input)	Regeneration: Regeneration (input) rate out of collected (%)	Re-refined base oil	Disposal	Disposal rate (%)	Non-collected / illegal burning / deposit	Non-collected rate (%)	Sources & reference date for the data
	P5	W5	W5/P5	C5	C5/W5		E5	E5/W5	R5	R5/C5	B5	D5	D5/W5	N5= W5-...	N5/W5	
Austria																
Belgium		70		70	100%		35	50%	35	50%						GEIR - 2001
Denmark																
Finland																
France	892	368	41%	257	70%	8.4	175	48%	82	32%		0	0%	110	30%	[65] - 1999
Germany											590					GEIR - 2001
Greece	130	65	50%	63	97%	8	15	23%	40	63%		0	0%	2	3%	[67] - 2000
Ireland																
Italy																
Luxembourg																
Netherlands																
Portugal		60		36	60%											[66] - 2000
Spain				200												[71] p4
Sweden																
United Kingdom	730	390	49%	350	90%		347	44%	0	0%		6	2%	40	10%	[40] - 1999
Total EU											221.5					GEIR - 2000

GEIR [75] - 2000 (5)

Country	Consumption	Waste (collectable)	Collectable rate (%)	Collected (dry WO)	Collection rate (%)
	P6	W6	W6/P6	C6	C6/W6
Austria	102	45	44%	34	74%
Belgium	174	76	44%	60	79%
Denmark	71	46	65%	35	75%
Finland	69	48	54%	39	80%
France	889	435	49%	243	56%
Germany	1 076	538	50%	460	85%
Greece	88	60	68%	22	37%
Ireland	39	20	51%	17	86%
Italy	681	272	40%	200	74%
Luxembourg	10	6	60%	2	39%
Netherlands	195	84	54%	60	72%
Portugal	113	62	55%	40	64%
Spain	496	223	45%	105	47%
Sweden	147	79	54%	63	80%
United Kingdom	804	410	51%	353	86%
Total EU	**4 934**	**2 485**	**49%**	**1 732**	**72%**

(1) clean and heavily polluted industrial WO are included [65]
(2) Greece regenerated 25 kt of WO, but only 5 kt are Greek WO, 20 kt came from Algeria and Saudi Arabia
(3) Hypothesis (it has not been possible to consider the quantity reported by the EC as for most of the other countries, because it is higher than the collected quantity reported by the GEIR)
(4) The collected quantity reported to the EC has been considered instead of the GEIR data because the latest is higher than the quantity of WO assessed
(5) Except for France for which the source is ADEME [65]

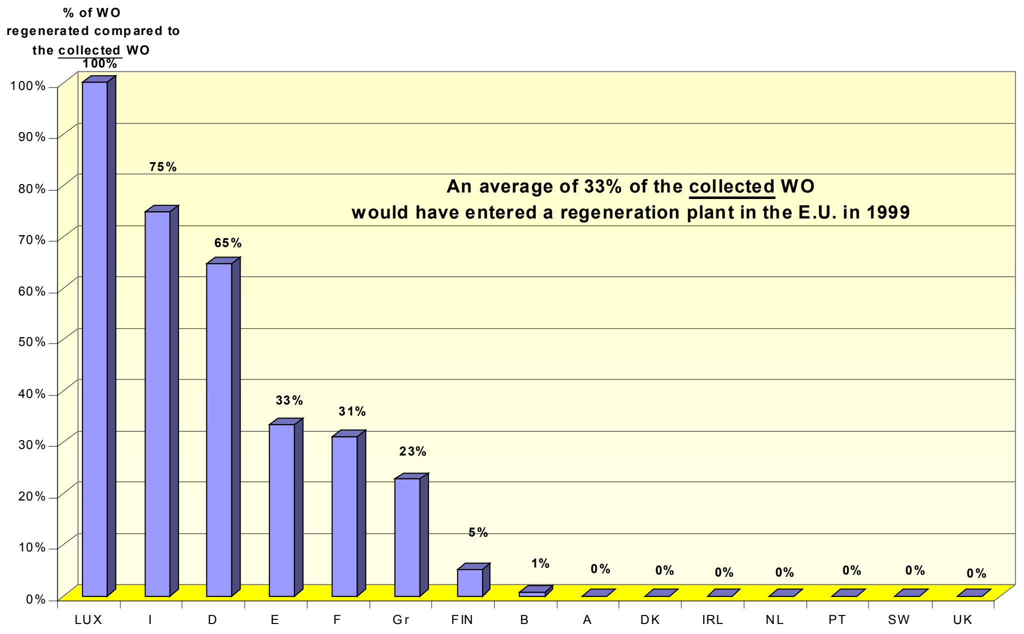
(5) Figures in italics are yet to be confirmed by respective MSs

ktonnes	'Best' mix of the various data																
formula	*P=P6*	*W=W6*	*C=C6*	*C/W*	*E=C-R-D*	*E/W*	*R=R2*	*R/W*	*R/C*	*B=B4*	*B/W*		*D=D2*	*D/W*	*N=W-C*	*N/W*	
	Yr 2000 Source: GEIR [75] (5)				**Yr 1999 or 2000 or 2001 according to the countries Calculations (formulas above) and various sources**												
							Regeneration										
Country	**Consumption**	**Waste (collectable)**	**Collected**	**Collection rate (%)**	**Energetic use**	**Energetic use rate (%)**	**Regenerated (input)**	**Regeneration (input) rate out of waste (%)**	**Regenerated (input) rate out of collected WO (%)**	**Re-refined base oil**	**Re-refined base oil out of waste (%)**	**Re-refined base oil out of collected waste (%)**	**Disposal**	**Disposal rate (%)**	**Non-collected / illegal burning / deposit**	**Non-collected rate (%)**	**Sources**
Austria	102	45	34	74%	34	74%	0	0%	0%	n.a	n.a.	n.a.	0	0%	12	26%	formula
Belgium	174	76	60	79%	60	78%	1	1%	1%	1	1%	2%	0	0%	16	21%	formula
Denmark	71	46	35	75%	35	75%	0	0%	0%	n.a	n.a.	n.a.	0	0%	11	25%	formula
Finland	89	48	39	80%	25	51%	2	4%	5%	n.a	n.a.	n.a.	12	25%	10	20%	formula
France	718	368	302	82%	208	57%	94	25%	31%	37	10%	12%	0	0%	66	18%	[65] (1)
Germany	1 076	538	460	85%	162	30%	298	55%	65%	257	48%	56%	0	0%	78	15%	formula
Greece	88	60	22	37%	17	28%	5	8%	23%	4	7%	18%	0	0%	38	63%	formula (2)
Ireland	39	20	17	86%	17	86%	0	0%	0%	n.a	n.a.	n.a.	n.a.	n.a.	3	14%	formula
Italy	681	272	200	74%	50	18%	150	55%	75%	84	31%	42%	0	0%	72	26%	formula
Luxembourg	10	5	2	39%	0	0%	2	39%	100%	n.a	n.a.	n.a.	n.a.	n.a.	3	61%	formula (3)
Netherlands	155	84	60	72%	60	72%	0	0%	0%	n.a	n.a.	n.a.	0	0%	24	28%	formula
Portugal	113	62	40	64%	40	64%	0	0%	0%	n.a	n.a.	n.a.	0	0%	23	36%	formula
Spain	496	223	105	47%	70	31%	35	16%	33%	25	11%	24%	n.a.	n.a.	118	53%	formula
Sweden	147	79	63	80%	63	80%	0	0%	0%	n.a	n.a.	n.a.	n.a.	n.a.	16	20%	formula (4)
United Kingdom	804	410	353	86%	347	85%	0	0%	0%	0	0%	0%	6	1%	57	14%	[40]
Total EU	**4 763**	**2 337**	**1 791**	**77%**	**1 187**	**51%**	**586**	**25%**	**33%**	**462**	**20%**	**26%**	**6**	**0%**	**546**	**23%**	-

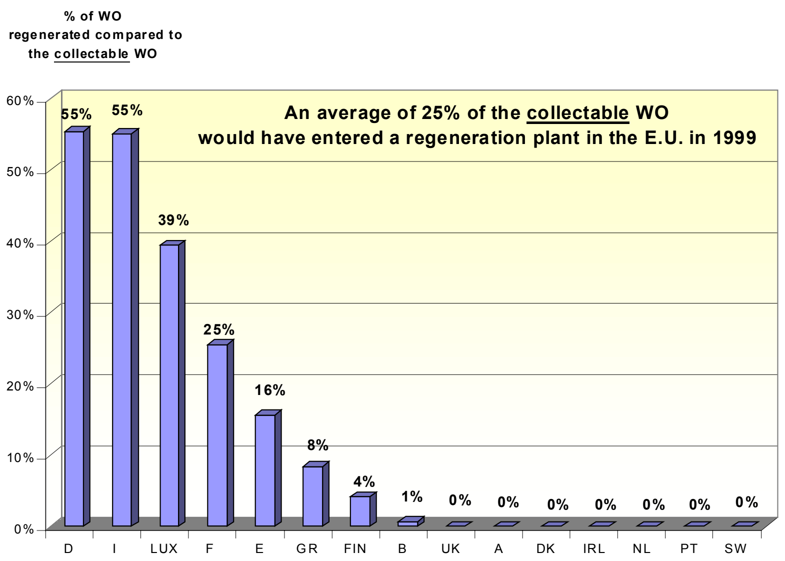
(1) clear and heavily polluted industrial WO are included [65]
(2) Greece regenerated 25 kt of WO, but only 5 kt are Greek WO, 20 kt came from Algeria and Saudi Arabia
(3) Hypothesis (it has not been possible to consider the quantity reported by the EC as for most of the other countries, because it is higher than the collected quantity reported by the GEIR)
(4) The collected quantity reported to the EC has been considered instead of the GEIR data because the latest is higher than the quantity of WO assessed
(5) Except for France for which the source is ADEME [65]

- The quantities estimated as entering a regeneration plant have been compared:
  - first to the WO actually collected.
    This indicator, commonly used by the MS, reflects the efficiency of the regeneration policy.
  - then to the WO potentially collectable.
    The indicator reflects the efficiency of both the collection policy and the regeneration policy.

WO Regenerated (1999) Compared to WO Actually Collected (2000)



WO Regenerated (1999) Compared to WO Potentially Collectable (2000)



- Regarding the output of regeneration, about 220 kt of re-refined base oil would have been produced in 2000 according to the GEIR.

  Remark: this figure significantly differs from the 460 kt announced for 1998. This could be explained by a combination of two main effects: the closure of plants and the modification of the operating plants' outputs (more fuel and less base oil).

- About 50% of WO were energetically used in the E.U., in 1999.

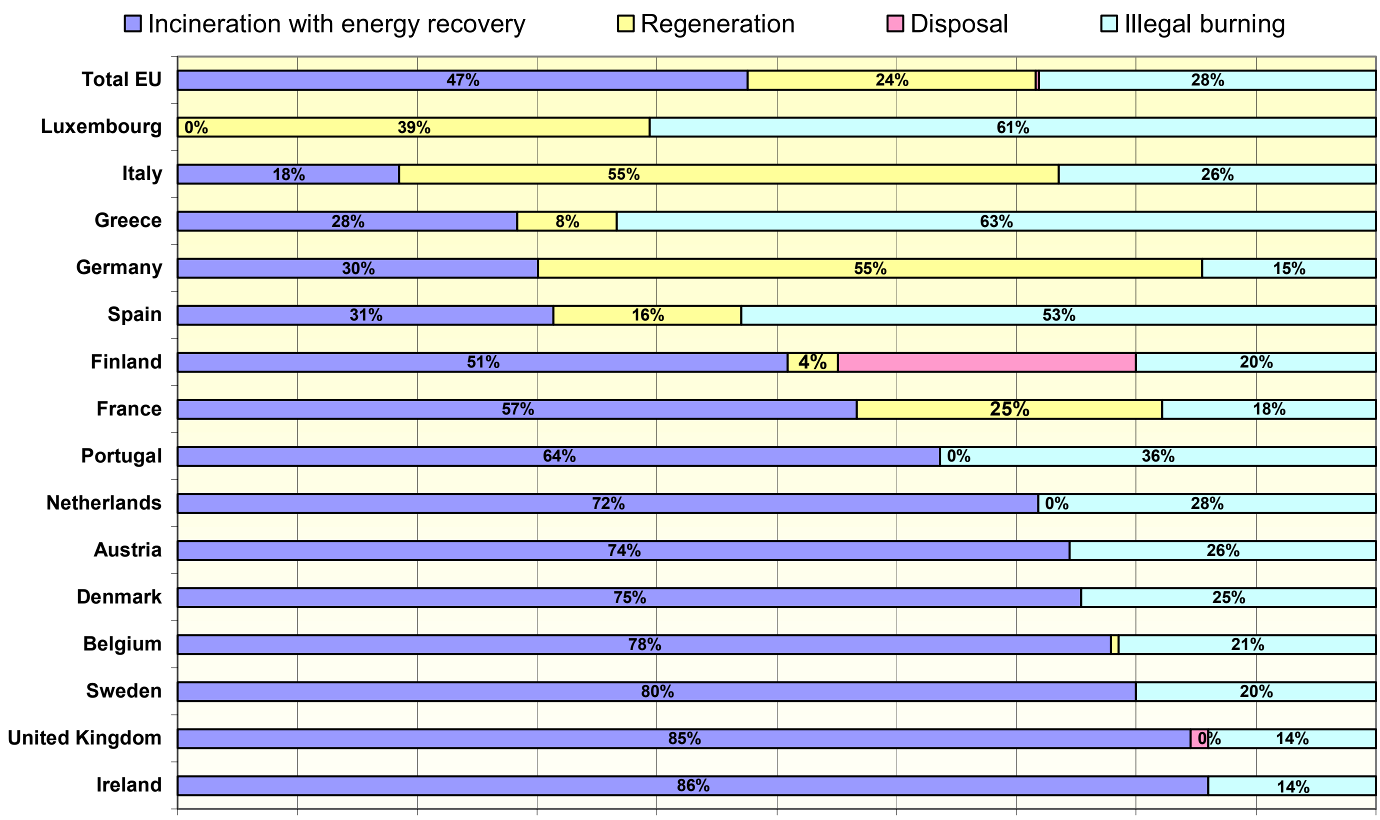
- Cement kilns play an important role in the energetic use of WO: about 400 kt of WO are burnt in cement kilns at the European level, which represents about 17% of the total WO and 35% of the WO burnt.

  But the importance of that route differs between the countries. It represents:

  - the major route in F, G, Sw,
  - only one of the routes in A, B, It and the UK.

- About 25% of WO were still illegally eliminated in 1999.

Management of Waste Oils in the E.U., in 1999



3.1.2 Evolutions Occurred Recently and Projects

- It would be interesting to compare the current situation with the past and to describe the evolutions that have occurred recently on a country basis.

  It is not possible, in the framework of this study, to perform a detailed analysis of these historic evolutions (not enough comprehensive and reliable information is available) but some tendencies can be given.

- Compared to the 1994 situation described in the Coopers & Lybrandt report [30], the efficiency of the collection would have been stable, between 70 and 75% of the WO.

  However:

  - the less successful countries seem to have greatly improved their collection efficiency during that period: B, Gr, Irl and Pt.
  - on the contrary, it appears that some of the very successful countries reach a lower performance today compared to 1994: A, Dk, F, It and Lux. It is likely that these differences reflect only the fact that the 1994 figures were over-evaluated.

Evolution of the Collection Rate[2]

	1994 Coopers & Lybrandt	2000 GEIR
Austria	84%	74%
Belgium	53%	79%
Denmark	93%	75%
Finland	80%	80%
France	69%	56%
Germany	87%	85%
Greece	8%	37%
Ireland	35%	86%
Italy	87%	74%
Luxembourg	92%	39%
Netherlands	71%	72%
Portugal	29%	64%
Spain	44%	47%
Sweden	82%	80%
United Kingdom	90%	86%
Total EU	**75%**	**72%**

- During the last years, a shrinking of the regeneration is noticeable in some countries which were precursors (such as France[3], Germany, Italy) and others (such as the UK).

  In the same time, 2 regeneration plants exist in Belgium today according to WATCO [76]:

  - Watco Oil Services - Hautrage – 40 kt,
  - Mottay & Pisard - Vilvoorde – 5 kt.

2 82% and not 56% according to ADEME in France [65]

3 2 out of the 3 plants have been closed in 1994 (see appendix 4)

- The tendency regarding the regeneration development is uncertain for the near future. However, it seems that some projects emerge in several countries: France, Germany, Italy, Spain.

  It has not been possible to gather comprehensive information on that subject but the following projects can be mentioned:

  - the British Petrus Oil is moving its plant from the UK to Germany.

    The 85 kt plant will be located in the town of Eisenhuttenstadt and will have 2 parallel front end processes:

    - unit 1): a TFE / distillation process (60 kt/yr),
    - unit 2): a solvent extraction / distillation (25 kt/yr).

    Unit 1) base oil distillate will be processed through an hydro finishing plant which has 45 kt capacity.

    To secure feedstock supplies, WO suppliers will accrue a minority stake in Petrus Oils Germany GmbH and enter into WO supply contracts.

    The plant will receive 40% of subsidised loans and grants, financed by the capital investment subsidy schemes in the State of Brandenburg, Germany, such as the Investitionszuchus and Investitionszulage.

  - In France, a 100 kt regeneration plant is in project, under the initiative of the SARP company (Vivendi Group). It will be located in Rouen.

    This project will be characterised by a high level of stakeholders integration to secure the overall process. The supplies of WO will be guaranteed by the fact that the largest WO collector in France, the SRRHU (Société de Ramassage pour la Régénération des Huiles Usagées) belongs to the Vivendi group too. Agreements are being discussed with the petroleum companies to secure the outlets. For that reason, this project might not require financial subsidies.

3.2 Some Elements about the WO Management in the E.U.

3.2.1 Methodology implemented

- A multi-criteria analysis

  A multi-criteria analysis has been performed in order first to describe the organisation and the actors in each country on a common basis and secondly to make easier the comparison between countries.

  Different indicators have been selected to describe the collection step (number of licensed collectors, collection circuits, favourable / unfavourable factors…), the recovery routes (number and capacity of plants for regeneration and energetic use, technologies…), the taxes (tax on fuel, tax on lubricants, tax exemptions), the subsidies (to collection, to regeneration) and some economic data (cost of collection, transport, treatment…).

  The same difficulties as those mentioned above have been faced: the lack of up-dated information, the lack of homogeneity in the available information, the difficulty to gather accurate data.

The main sources of information have been:

- for taxes and subsidies: IBC [25] (1999 data) and more recent data directly provided by MS (D, F, It),
- organisation and actors: the Coopers & Lybrand report [30] (1993 data), except for some countries for which more recent information was available (B [76], D [76], F [65], It [76], UK [40]).

The detailed information is presented in appendix 4 as a first basis. It will need to be completed and up-dated in the scope of a dedicated study.

- The analysis of the financial flows between actors

A systematic financial flow diagram has been elaborated for each country, aiming at:

- describing who pay for what and what is the situation in terms of financial incentives and taxes,
- allowing an easy comparison between the countries.

This constitutes a first basis to be completed and up-dated in the scope of a dedicated study.

The main sources of information have been:

- for B, D, F, I and the UK: recent data from either the MS (F [65]) or the GEIR (B, D, I [76]) or a report (UK, [40]),
- for the other countries: IBC [25] (1999 data for taxes and subsidies) and Coopers & Lybrand report [30] (1993 data for costs and prices).

The detailed diagrams per country are presented in appendix 5.

- Some elements concerning the collection, the subsidies and the taxes are summarised below on a multi-country basis.

3.2.2 Collection

- Appropriate collection and disposal arrangements for WO from industrial or automotive origin (garages…) are generally well stabilised in Europe.

However, WO from 'Do-It-Yourself' (DIY) oil changes are less likely to be collected and so present the greatest risk of improper disposal.

- In Germany, the regulation imposes the segregation of WO according to their ability to be regenerated or not and the separate collection. The aim being to supply the regeneration plants with regenerable feedstock.

According to German experts, this measure is not applied by holders and collectors due to different problems (collection cost…).

- Several means have been implemented by the Member States to develop the WO collection and cover the associated cost.

Measures taken	***Countries concerned***	***Main expected effects***		
		To encourage WO collection	***To discourage illegal circuits***	***To cover the collection cost***
Accredited collectors	all the countries	X	X	
Organisation to co-ordinate or centralise the collection activity	4 countries: Dk, F, Fin, I	X	X	X
Subsidies paid to collectors	5 countries: Dk[4], E, F, Fin, I (41 to 101 Euros/t)	X	X	X
Disposal charge paid by the WO holders	Nil: 7 countries B, F, Fin, Gr, I, Lux, Pt	X	X	
	Positive (15 to 189 Euros/t paid by the holders): 6 countries: A, Dk, D, Ire, NL, Sw			X
	Negative (9 to 41 Euros/t received by the holders): 2 countries: E, UK	X	X	

3.2.3 Subsidies and Taxes

As shown in the following table compiling 1999 information from IBC [25] and more recent data directly provided by MS (D, F, It), most of the MS do not subsidy the collection step.

As far as the regeneration is concerned, it is subsidised only in Spain and now in Germany too.

The situation in Italy is evolving. For instance, the partial exemption on the taxation on lubricants when they are produced from re-refined base oil will be suppressed at the end of 2001.

As for the derogation on excise duty, it still applies for WO in 11 of the MS (with a specific case in France – see below).

4 implemented very recently according to [68] p3

Type of subsidy or tax	***Situation in the MS***
Subsidy to collection	– Subsidy: Dk[5], E, F, Fin, I between 41 to 101 Euros/t of WO according to the country – No subsidy: all the other countries
Subsidy to regeneration	– Subsidy: E, D Es: 90 Euros/t of WO D: from 2001, companies regenerating WO become eligible for subsidies worth Euros 2.6 Millions (DM5m) per year – No subsidy: all the other countries
Tax on lubricants put on the market	– Tax: A, D, Dk, F, Fin, I between 16 to 623 Euros/t of WO according to the country Specific case of It: the tax differs on the origin of the base oil: 45% less for lubricant produced from re-refined base oil (327 Euros/t) compared to lubricant produced from virgin base oil (623 Euros/t)[6] – No tax: all the other countries
Exemption of tax on lubricants for lubricants produced from re-refined base oil	– Total tax exemption: A, Dk between 113 to 378 Euros/t of WO according to the country – Partial tax exemption: I 296 Euros/t of WO – No tax exemption: D, F, Fin
Derogation on excise duty for WO[7]	– Total exemption: A, B, D, E, Fin, Ire, I, Lux, Pt, UK between 6 to 58 Euros/t of WO according to the country – Partial exemption: Dk, Sw between 15 to 179 Euros/t of WO according to the country – No exemption: NL – Specific case of F: WO are indeed exempted from the TIPP (Taxe Intérieure pour les Produits Pétroliers) that has otherwise to be paid for consumed fuels. But the TGAP (Taxe Générale sur les Activités Polluantes) has to be paid for each fuel burnt in a cement kiln and other plants, whatever the fuel is, traditional or WO or other waste. – Specific case of D: the use of energy is only taxed for plants producing heat; cement kilns and steel industry producing a product (cement or steel), no tax applies on their fuel consumption; a judgement is on progress by the European Union for this practice, unique in Europe

5 implemented very recently according to [68] p3

6 This measures will end up at the end of 2001; there will be no exemption anymore (see appendices 4 and 5 for more details).

7 Derogation on the duty that has otherwise to be collected on WO which are used as fuel, either directly after recovery or following a recycling process.

B.
Technico-Economic Analysis of WO Treatment Processes

4 REGENERATION

Five aspects of the regeneration are presented in this section:

- the type of WO which are regenerable (input),
- the quality of the base stock produced (out put) and the outlets,
- the existing technologies,
- the success criteria for a regeneration plant,
- the economics of regeneration.

4.1 TYPE OF WO ELIGIBLE FOR REGENERATION

- The WO most suitable to regeneration are those not too heavily polluted and with a high viscosity index (HVI).

  The GEIR and re-refiners consider regenerable the following WO:

  - engine oils without chlorine (European Waste Category[8] EWC code: 130205),
  - hydraulic oils without chlorine (EWC code: 130110),
  - non-chlorinated mineral diathermic oils (EWC code: 130306).

  Under certain conditions (limitation of chlorine or PCB content), this list could be extended to the following categories:

  - engine oils with chlorine (EWC code: 130204),
  - hydraulic oils with PCB (EWC code: 130101),
  - hydraulic oils with chlorine (EWC code: 130109).

  According to the GEIR, 60 to 65% of WO are eligible for regeneration. Other experts indicate 50% of WO.

- Several experts insist on the fact that the WO composition is becoming more and more complex, due to different factors:

  - The increasing use of dispersants as well as esters and poly-alpha-olefins, e.g. to increase the life of the oil. As a result, the WO become more complex and dirty over time.
  - The progressive displacement of conventional mineral based auto lubricants by 'synthetic' products which have enhanced performance characteristics. Whereas some of these synthetic products can be regenerated along with mineral oils, others (based upon esters for instance) are less suitable to regeneration because they tend to be less stable in the presence of caustic (often used by regeneration processes) and less stable to the hydro-finishing step.

[8] European codes used by the EC to classify WO according to Commission Decision 2000/532/EC as amended

It remains to be seen whether the latest technical advances in regeneration prove to be sufficiently flexible to handle the charging composition of WO over the next 10 years.

- It should also be indicated that a low proportion of base oil (less than 2% of the total consumption) are from an agricultural origin, produced from either sunflower or rape-seed.

  These bio-lubricants are used for certain applications where their characteristics represent a real advantage. In particular:

  - because of their good biodegradability, they may be preferred when lubrication losses into the environmental media soil and water occur during use (woodcutting with motor saws, boats…).
  - because of their high viscosity index and low volatility for instance, they are used as cutting oils….

  It is not clear today to which extent bio-lubricants mixed with mineral lubricants may cause problem during the regeneration process. In any case, it will be important to clarify this question in the near future, in order to avoid different regulations or initiatives (e.g. on WO recovery, on the non-alimentary use of agricultural products) being contradictory.

4.2 Quality of the Base Stock Produced and Outlets

- Re-refined base oils are speciality products used in automotive lubricants and industrial lubricants (hydraulic oils).

- The quality of the base oils produced by regeneration is still a matter for discussion between industrial actors, even though that quality has largely improved with processes such as hydro-treatment and solvent extraction.

- Modern regeneration technologies (i.e. not for instance the acid/clay process) allow to produce premium quality base oils: at least Group I according to the API base oils classification and, when resorting to a severe hydro or solvent finishing, Group II base oils.

  There is a perfect comparability between severely hydro-treated re-refined base oils and virgin base oils (viscosity index, volatility, chlorine content…).

  As for the base oils quality:

  - it is not very dependent on the variation of the origin and type of WO collected (the variations of base oils quality are actually not different from the variations of virgin base oils quality); it is thus possible to obtain reasonably consistent base oil products from a specific regeneration plant,
  - it is very dependent on the different processes and production plants.

- As far as the perceived quality in the automotive sector is concerned, the experts' opinions differ:
  - according to the GEIR and re-refiners as well as some auto manufacturers, there is an increasing trend towards the acceptance of re-refined base oil by engine manufacturers,
  - according to others, engine manufacturers are still largely reluctant. One reason is that they fear the negative psychological effect of recycled products on their customers and the repercussion on their corporate image.

  In the UK for instance, the smallest market resistance is in the gear and hydraulic oils segments.

  In the case of the new re-refinery under construction in Eisenhuttenstadt, Germany (see section 3.1.2 above), vehicle lubricants will play a relatively small role. Industrial lubricants are considerably more interesting for this plant which will produce low sulphur, Group II base oil[9]. Also the focus on industrial lubricants is supported by the fact that the sales effort is considerably smaller than for motor oil.

- The structure of the lubricant manufacturing market plays also an important role: whereas the small independent blenders and manufacturers may be easier to convince, large producers with heavily branded products may be more reluctant.

- Two other factors regarding the evolution of the demand is important to indicate:
  - notwithstanding growth in vehicle numbers, demand for automotive lubricants is steadily diminishing (with corresponding increase in performance/quality requirement for the lubricant) as the service life required by auto manufacturers becomes steadily greater. This shrinking of the size of the market, associated to the progressive displacement of conventional mineral based auto lubricants by 'synthetic' products mentioned above, have a disproportionate impact upon demand for virgin conventional mineral base oil which is already in oversupply within Europe.
  - it can be expected that the hydrocarbon-powered, internal combustion engine will be replaced by hydrogen-powered, fuel cell requiring neither gear nor piston lubrication. The time frame for this is uncertain but the technologies now being trailed by DaimlerChrysler, Ford and others might ultimately be successful and their introduction could be speeded by legislative pressures favouring H_2 fuel cell over the hydrocarbon IC engine (as part of the effort to limit the carbon economy with its impact on CO_2 generation).

  These elements are not favourable to the increase of the re-refined base oils demand under free market conditions.

[9] Group II Base Oils can be used in Group I and II lubricant formulations but Group I cannot be used in Group II formulations unless blended with Group III, which is considerably more expensive.

4.3 EXISTING REGENERATION TECHNOLOGIES

Even if most of the existing capacities are still operating the old acid / clay process, numerous major processes exist in Europe and world-wide.

They may differ by the technology used for one or several of the following operations:

- de-watering and de-fuelling (removal of water, light ends and fuel traces (naphtha[10]…)),
- de-asphalting (removal of asphaltic residues: heavy metals, polymers, additives, other degradation compounds),
- fractionation (in two or three cuts),
- finishing.

The following table describes most of them.

As for the finishing, the hydro-treatment is today the most efficient one. It aims at reducing or removing remaining metals and metalloids, organic acids, compounds containing chlorine, sulphur and nitrogen. Operating under a high pressure and at high temperatures, it also reduces the PAH (polycydic aromatic hydrocarbon) content to an acceptable level (health implications said to be comparable to those of virgin base oil[11]).

Considering the quality demand by users and the increasing complexity of engine oils composition, a severe hydro-treatment may be less and less an optional extra in the future.

[10] Light ends could be gasoline or solvents. They are usually referred to as naphtha.
[11] However, virgin base oils have been classified by the EU for carcinogenicity risks but not re-refined base oils yet

Description of the Main Regeneration Technologies

Technology	Process [12]				Com-mon plant size	Expected yield (dry basis)[13]	Advantages	Drawbacks	Comment
	De-watering[14]	De-asphalting[15]	Fractiona-tion[16]	Finishing[17]					
EXISTING TECHNOLOGIES									
Acid/clay	(1) Atmospheric vacuum stripping[18]	(2) Contact with sulphuric acid Contact with absorption clay	(3) Distillation unit then neutralisa-tion and filtration	-	Small (2 to 10 kt/yr)	63%	– Relative low capital cost – Relative simplicity of operations	– Low product quality[19] [20] – Localised adverse environmental impact of by-products (acid sludge & clay)	– The 1st regeneration process – The most widely use (~90% of total capacity)
Distillation / clay	(1) Atmospheric vacuum stripping	(2) Content with absorption clay	-	-		50%	– Less oily clay (than the acid/clay process) to be disposed of	– Poor product quality – Low yield	– Projects do not come out
Distillation / chemical treatment or solvent extraction	(1) Vacuum distillation (2 stages)	(2) Vacuum distillation (3rd stage)		(3) Chemical treatment or solvent extraction	Medium size (~25 kt/yr)	65 – 70%	– Virtually all PAH are removed – Financially attractive		– Vaxon process – 1 plant in Spain

12 The chronological order of the operations are indicated with (1) or (2)…
13 WO contains an average of 20% additives, 10% water, 8% engine blowback (gasoline and diesel fuel) and other contaminants
14 De-watering + de-fuelling = removal of water, light ends and fuel traces (naphtha …)
15 De-asphalting = removal of asphaltic residues (heavy metals, polymers, additives, other degradation compounds)
16 2 or 3 cuts recovery
17 Including the polycyclic aromatic hydrocarbons (PAH) removal in the case of a severe hydro-finishing (high temperature & high pressure)
18 The vacuum distillation indicated for the different processes takes place in a pre-flash unit
19 According to the Concawe report [43], 4 to 17 times higher PAH content than virgin base oils (the health implications still need to be assessed)
20 They are usually darker in colour and tend to have a noticeable odour

Technology	Process				Common plant size	Expected yield (dry basis)	Advantages	Drawbacks	Comment
	De-watering	De-asphalting	Fractiona-tion	Finishing					
EXISTING TECHNOLOGIES (CONTINUED)									
Propane de-asphalting (PDA)	(1) Atmospheric vacuum stripping	(2) Liquid propane	(3) Vacuum distillation	(4) Clay or hydro-treatment		74%	– High yield – Good product quality (if hydro-treated)	– More or less expensive according to the number of stages for the PDA – Significant amount of by-products to be disposed of	– Viscolube
Interline	(2) Atmospheric vacuum stripping	(1) Liquid propane	(3) Vacuum distillation			79%	– Reduced capital & operating costs – High yield		– Was existing in the UK
Thin film evaporator (TFE) & hydro-treatment	(1) Atmospheric vacuum stripping (+ chemical treatment in some cases)	(2) TFE (very high temperature and pressure)	(4) Vacuum distillation	(3) Hydro-treatment		72%	– High product quality		– KTI process – Revivol process

Technology	Process				Com-mon plant size	Expected yield (dry basis)	Advantages	Drawbacks	Comment
	De-watering	De-asphalting	Fractiona-tion	Finishing					
EXISTING TECHNOLOGIES (CONTINUED)									
Thermal de-asphalting (TDA)	(1) Atmospheric vacuum stripping + chemical treatment	(2) Settling + TDA		(3) Clay or hydro-treatment	Large size (100 -180 kt/yr)	74 – 77%			– Agip Petroli / Viscolube in Spain
TFE + lubricant refinery recycling	(1) Atmospheric vacuum stripping	(2) TFE (very high temperature and pressure)		(3) Aromatic extraction + hydro-treatment		65 – 70%			– DEA in Germany
	Pre-treatment in a regeneration plant			Recycling in a refinery					

Technology	Process				Common plant size	Expected yield (dry basis)	Advantages	Drawbacks	Comment
	De-watering	De-asphalting	Fractiona-tion	Finishing					
NEW OPTIONS UNDER DEVELOPMENT									
UOP hydrogen de-asphalting / treating	(3) Atmospheric vacuum stripping	(1) Hydrogen flashing at high temperature	(4) Vacuum distillation	(2) Hydro-treatment					– At the laboratory stage in 1996
ENTRA	(3) Atmospheric vacuum stripping	(1) Tubular reactor				High			
Supercritical extraction	(1) Atmospheric vacuum stripping	(2) Supercritical de-asphalting	(3) Supercritical fractionation				– Reduced capital & operating costs when compared to the standard PDA technologies		– Pilot plant stage in 1996 (Snamprogetti and Krupp)

Source: mainly Concawe [19]

Remark 1: other combinations, not described in this table, could exist (e.g. TFE + clay contact, TFE + solvent extraction…).

Remark 2: as for the new options under development, the information available in the existing literature date from 1996 (the Concawe report [19]). Some of these projects may have been finished or given up in the meantime.

4.4 Criteria of Success

As any industrial activity, the viability of a regeneration plant is dependent on three elements:

- the supply: an industrialist will invest in a plant only if there is a long time guaranty of his feedstock supply.

  It is all the more true in the case of the regeneration since this activity is capital consuming: capital and fixed operating costs represent between 55 and 80% of the overall cost according to the technology, the size and the country (purchase of the WO excluded) (see next section 4.5).

- the market: an industrialist will invest in a plant only if their is a strong demand and if outlets are guaranteed in time.
- the profitability:
  - the revenues have to be high enough to cover the operating costs and to achieve an Internal Rate of Return (IRR) on the capital invested to build the plant,
  - the profitability has to be sound enough to absorb price variations on feedstock and main products.

  The selling price of the re-refined base oil is linked to the selling price of the virgin base oil it competes with (10 to 25% lower – see next section) which is:

  - dependent on the shape of the base oil supply/demand curve that is determined by the major crude oil companies. They lead and re-refineries have no alternative but to follow.
  - strongly impacted by the crude oil price fluctuations and the US dollar rate.

  Due to high crude oil prices, the base oil market today is completely different to that which existed in the late 1990's: group I virgin base oil prices are now 100% higher than they were (but are only just above the average for the last 15 years).

  A plant has to be able to overcome these fairly volatile fluctuations affecting its revenues.

4.5 Economics of Regeneration

4.5.1 Methodology Used

- The economic analysis carried out aims at addressing three issues:
  - the minimum gate fee of the WO delivered to the plant necessary to cover the operating costs as well as to achieve an Internal Rate of Return (IRR) on the capital invested to build a plant. In these calculations, a 10% IRR has been considered as it is a common IRR level considered in the industry,
  - the scale effects,
  - the influence of the technologies and the quality of the re-refined base oil on the overall cost and thus on the WO gate fee.

For that purpose, the calculation has been made for:

- seven different regeneration processes[21]:
  - acid / clay process,
  - TFE + clay finishing,
  - TFE + solvent finishing,
  - TFE + hydro-finishing,
  - TDA + clay finishing,
  - TDA + hydro-finishing,
  - PDA + hydro-finishing;
- 3 different capacities (for most of these technologies):
  - small size (35 kt per year),
  - medium size (around 50 kt per year),
  - larger size (80-100 kt per year, even 160 kt in two cases).

■ The following cost and revenues items have been considered:

- capital cost, with a 10-year depreciation for the core processes and engineering costs and a 20-year depreciation for the non core processes and site acquisition costs,
- fixed operational cost: staff, equipment maintenance, sg&a[22],
- variable operational cost: staff, utilities and chemicals[23], residues treatment,
- revenues: sales of products (re-refined base oil and gasoil) and residues (mainly bitumens).

Remark concerning the type of plant

Some authors have tried to analyse the influence of the type of plant on the regeneration costs by studying grass-roots plants on the one hand and plants built on an existing site on the other hand.

All the non core processes and site acquisition costs (corresponding mostly to the infrastructure -offices, sanitary facilities, laboratory, fenced site, weight scale, workshop…-, the reception of WO and the acceptation control) as well as a part of the staff costs have been subtracted to assess the impact on the overall cost of the pre-existence of the site.

However, this calculation is likely to under-evaluate the reality of the costs because existing infrastructure will have to be maintained, up-dated and up-graded. And from a methodological point of view, we consider this methodology not fully appropriate to the purpose of the present study, because a policy can not be built on cases which can not exist in all the European countries and thus which can not be generalised to the European Union.

For these reasons, some calculations of the costs of regeneration plants built on an existing site are presented only in appendix (see appendix 6).

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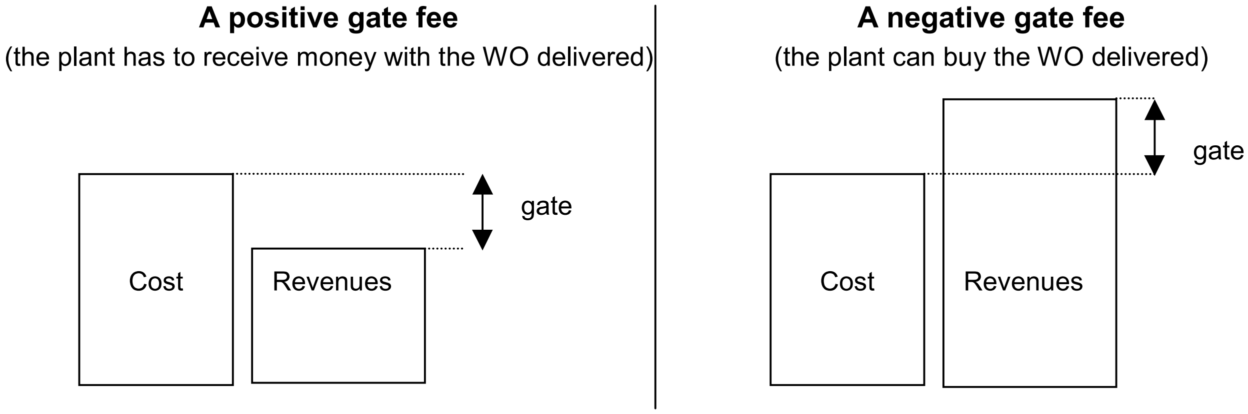
[21] Although only three processes had to be analysed according to the terms of the contract, we took advantage of the GEIR co-operation (see below) to extend the scope of the analysis

[22] Sales, General & Administration

[23] The purchase of WO is not included into the cost as the purpose of the exercise is to assess their gate fee

■ The WO gate fees have been calculated as the difference between the overall cost and the revenues.



■ We were supposed to base our analysis upon data existing in the available literature. But due to the lack of either up-dated or comprehensive data, it has been necessary to dedicate a significant part of our resources to the collection of new data from regeneration plants.

Different data have then been analysed and cross-checked:

- data gathered by TN SOFRES Consulting in the scope of this project, with the co-operation of a GEIR working group constituted for that purpose,
- data available in the literature, mainly the two most comprehensible ones:
  - the UK WO market 2001 report [40],
  - the Concawe report [19].

As for the TN SOFRES Consulting data, they are site specific:

- most of them correspond to existing plants (and the others to installations under project),
- the calculations have been carried out as if they were new plants, i.e. the depreciation of the capital costs have been included (even if in reality, they are already fully depreciated as it is the case in most of the existing plants).

Remark

All the plants considered are producing re-refined base oils which will be used to produce a lubricant in a separate plant. The specific case of a regeneration plant integrating the lubricant production step (as in Greece) is not covered here. It may present some interesting characteristics, in particular the capacity to adapt the regeneration process (and thus the cost) according to the quality of the lubricant required by the market.

Comparison of the Quality of the Different Data Sources

	TN SOFRES Consulting	UK WO market 2001 report [40]	Concawe report [19]
Date of data	2001	2001	1994
Costs considered	all capital and operational costs linked to both the core and non core processes	all capital and operational costs linked to both the core and non core processes	all capital costs but only utilities and staff related to the technological area
Processes considered	6	2	4
acid / clay			*
TFE + clay	*	*	
TFE + hydro	*	*	*
TFE + solvent	*		
TDA + clay	*		*
TDA + hydro	*		
PDA + hydro	*		*
Comments	comparable data		not comparable (we have adjusted the 1994 data to the 2001 situation[24] but it is not enough because still all the costs are not included)

Due to the fact that the Concawe data are not directly comparable to the two other sources and obsolete, the results presented below are mainly drawn from the TN SOFRES Consulting data, completed when necessary by the UK report data [40].

The data were provided to TN SOFRES Consulting by companies operating one of the studied processes, on the basis of their own plant and their own local circumstances:

- on the one hand, these data are probably closer to the actual costs than data which could have been provided by constructors and engineering experts, who usually tend to under-estimate the operating costs (whereas the capital costs are generally relatively objective).
- on the other hand, they reflect the local / national context where the plant is (or is planed to be) located: age of the plant, activity of the plant, fiscal regimes, customers attitudes, subsidies…. It is also likely that they are influenced by the strategic considerations of the actors who gave the data. All these reasons will explain (see below) some of the differences that can be identified between the processes for which data were provided by Italian GEIR members (TDA+clay, TDA+hydro, PDA+hydro) and those coming from German GEIR members (TFE+clay, TFE+solvent, TFE+hydro).

4.5.2 Main Results

The following table synthesises the results obtained for the 7 technologies.
All the detailed calculations are presented in appendix 6 (including the Concawe data).

[24] The Concawe data expressed in 1994 US dollars have been adjusted for inflation, taking into account an annual inflation rate of 2% and a change rate of \$1=1.22 Euros in 2001, and using the following formula: Y 1994\$ = [Y x $(1+0.02)^{(2001-1994)}$ x 1.22] Euros 2001

Cost & WO Gate Fee for a Grass-Root Regeneration Plant

Technology		**Acid / clay**	**TFE + clay**					**TFE + hydro**			
Plant		grass-root	grass-root	grass-root	grass-root	grass-root	grass-root	grass-root	grass-root	grass-root	grass-root
Capacity	kt/yr	100	35	50	80	160	35	50	80	85	35
Capital costs	Meuros	34	20	25	33	50	8	43	50	47	27
Cost		152	242	221	198	148	237	333	275	204	289
on which Internal return on finance (1)	Euros	*40*	*64*	*56*	*47*	*35*	*27*	*94*	*70*	*62*	*59*
Revenues	/ t of WO	177	210	210	210	195	214	254	254	219	321
WO gate fee		**-25**	**32**	**11**	**-12**	**-47**	**23**	**78**	**21**	**-15**	**-32**
Source		Concawe [19]	GEIR 2001 [76] G 1	GEIR 2001 [76] G 1	GEIR 2001 [76] G 1	GEIR 2001 [76] G 2	UK report [40]	GEIR 2001 [76] G 1	GEIR 2001 [76] G 1	GEIR 2001 [76] G 3	UK report [40]

Technology		**TFE + solvent**				**TDA + clay**	**TDA + hydro**	**PDA + hydro**
Plant		grass-root	grass-root	grass-root	grass-root	grass-root	grass-root	grass-root
Capacity	kt/yr	35	50	80	160	100	100	57
Capital costs	Meuros	31	37	44	60	45	69	42
Cost		350	308	258	148	280	304	320
on which Internal return on finance (1)	Euros	*100*	*84*	*62*	*42*	*53*	*81*	*83*
Revenues	/ t of WO	249	249	249	202	211	252	224
WO gate fee		**102**	**60**	**9**	**-54**	**68**	**52**	**96**
Source		GEIR 2001 [76] G 1	GEIR 2001 [76] G 1	GEIR 2001 [76] G 1	GEIR 2001 [76] G 2	GEIR 2001 [76] I	GEIR 2001 [76] I	GEIR 2001 [76] I

(1) on the basis of a 10% risk adjusted rate of return on finance

Selling Price of Re-refined Base Oil Considered

	Acid / clay	**TFE + clay**		**TFE + hydro**	**TFE + solvent**		**TFE+solv or hydr**	**TDA + clay**	**TDA + hydro**	**PDA + hydro**
Euros / t of re-refined base oil	250	300	300	325	320	320	296	300	325	320
	Concawe [19]	GEIR 2001 - G 1	GEIR 2001 - G 2	GEIR 2001 - G 1	GEIR 2001 - G 1	GEIR 2001 - G 2	GEIR 2001 - G 3	GEIR 2001 - I	GEIR 2001 - I	GEIR 2001 - I

The main conclusions which can be drawn from these figures are the following ones.

- First preliminary comment

  As already mentioned in chapter 1.2.1, any consultant who uses existing data not produced by him has to face a major difficulty: the lack of consistency of the data and, due to not enough transparency of the existing data and limited project resources (it was not the aim of the study to compare in detail all available data), sometimes the impossibility to explain the highlighted discrepancies. As a result, some of the conclusions that can be drawn are not as rigorous as others.

  For instance, for the TFE + hydro-finishing process, the 35 kt 'UK' plant is less expensive than the 50 kt 'GEIR' plant, whereas one would have expected to find opposite scale effects.

- Second preliminary comment

  As shown below, the economics of regeneration strongly depends on local circumstances such as fiscal regimes, possibilities for economies of scale, the availability of outlets for the output, the age of the plant.

  In that context, and because the data provided by the GEIR members are site specific, the figures presented in this chapter (and in appendix 6) have to be considered as orders of magnitude only. They will allow to highlight tendencies but will not give answers to all the questions raised by regeneration.

- Overall economics of WO regeneration are determined by three factors:
  - cost of the process, including yields, by-product values, energy and other consumption, pollution controls,
  - value of re-refined base oil and other products (mainly gasoil, also naphtha in the case of some processes),
  - gate fees of the WO delivered to the plant.

<u>Factors influencing the process cost (WO purchase excluded)</u>

- Regeneration is capital consuming: capital costs and fixed operating costs represent between 55 and 80% of the overall cost according to the technology, the size of the plant and the characteristics of the country (impacting for instance the salaries levels, the transportation cost).

- Regarding the technology, the extra cost of modern technologies compared to the old technology Acid / clay may reach 75%. But the cost discrepancies between modern technologies themselves are far less important (around 10% for a given capacity).

  Regarding the finishing step, a severe hydro-finishing treatment may represent an important capital cost of 10 to 15 Million Euros.

The impact on the overall cost per tonne of WO depends on the level of the total cost[25] (influenced by the technology and the size of the plant): it may vary between 10 and 50% of the total cost[26].

- As far as the size of the plant is concerned, scale advantages exist. Considering the various sources of information, the cost of a small plant (around 35 kt/year) may be 20 to 40% (according to the technology) higher than the cost of a large plant (more than 80 kt/year)[27].

  However, it has to be noted that the larger the plant is, the higher the cost of transporting WO to the plant becomes, beginning to erode the advantages of scale.

  In the UK report [40], the authors indicate that 'as a general guide in the UK, we would expect the advantages of scale to begin to decline for plants larger than 100 000 tonnes input'.

- As for the location of the plant, the pre-existence of some infrastructure and other equipment will of course reduce the capital cost. As indicated above, it is difficult to quantify that impact because of the maintenance and up-grading costs which would be necessary in any case.

  Although it does not belong to the core of this study, it is interesting to mention the specific case of the integration of a regeneration plant in a refinery that already produces lube oil basestocks. Beyond some economic advantages linked to the process synergies as well as the reduction of crude oil and energy consumption, some difficulties may explain the lack of interest from the oil companies, in particular the fact that, to meet the needs of their heavy lubricant customers, the refinery will have to compensate in order to produce the heavy lube oil fractions also required (by increasing the crude consumption to the fuels unit). According to Mrs Wheeler's report [72], the integration of a thermal cracking unit would be economically preferable for refineries compared to the integration of a regeneration unit.

25 Capital costs + operating costs (WO purchase excluded)
26 The UK report [40] announces an additional cost of 50%
27 For information, the following formula has been used by an expert (see Mrs Wheeler's report [72], p 14):

$$C2 = C1 * (F2/F1)^{0.6}$$

C1 capital cost of plant 1
C2 capital cost of plant 2
F1 oil feed capacity of plant 1
F2 oil feed capacity of plant 2

Factors influencing the regeneration revenues

- Most of the revenues come from the selling of the re-refined base oil (between 75 and 80%). The additional revenues are brought by the selling of the gasoil and some residues (mainly bitumens).

  The selling price of the re-refined base oil is dependent on five main parameters:

  - the price of the virgin base oil with which the re-refined base oil competes, which is strongly influenced by the crude oil price fluctuations and the US dollar rate.

    For instance, group I virgin base oil prices are now 100% higher than they were in the late 1990s (but are only just above the average for the last 15 years), which explains that the re-refined base oil selling price is high too. But this was not always the case in the past and might not be always the case in the future either.

  - the quality of the re-refined base oil (which varies from one technology to another due to different finishing efficiency).

    Today, a severe hydro-finishing (under a high pressure and a high temperature) is the treatment which produces the higher re-refined base oil quality (up to group II – see section 4.2).

  - the perception of the users and the expectation of the market.

    A (perceived) quality difference of oils derived from WO can force the price to a lower level. Experts agree on the fact that the re-refined base oil is usually 10 to 25%[28] cheaper than the virgin base oil (for the same quality).

  - the partial or total tax exemption on the tax which may exist on sold lubricants, for lubricants produced from re-refined base oil.

    Among the countries / regions where a tax on sold lubricants exists, Italy and Catalonia have both introduced a tax exemption for lubricants produced from re-refined base oil: a total exemption in Catalonia and a partial one (about 50%) in Italy. For that reason, in Italy for instance, the re-refined base oil is currently sold at a higher price than the virgin base oil. But because it is very likely that it will not last after 2002 when this tax exemption is interrupted, the selling price considered in our calculation for the Italian case studies corresponds to a situation without this tax exemption.

  - the distribution costs.

    They depend on the size and configuration of the country as well as the size of the plant (the largest the plant is, the longest distances the supplies have to cover).

  Considering all these parameters, common selling prices of re-refined WO vary in 2001 between about 295 to 325 Euros/tonne (except in the case of the acid / clay process where the price does not go over 250 Euros/t).

  Remarks: it should be noted that some higher figures have been mentioned by regenerators (up to 400 Euros/t). These discrepancies can only partly be explained (technology influence). This certainly reflects different actors strategies.

[28] And even 30% according to Mrs Wheeler [72].

Level of WO gate fee

- Whereas the acid / clay process can easily reach a negative WO gate fee (i.e. the plant can afford to purchase the WO delivered), the two situations exist in the case of modern technologies in the 2001 favourable context (high crude oil price and thus high base oil selling price):
  - most of the cases assessed have a positive gate fee, varying between 10 and 100 Euros/t depending on the technology, the size of the plant and the characteristics of the national market.

    It is only after some years, once the capital costs are at least partly paid off, that the regeneration activity could be profitable.
  - a nil or even negative gate fee (between – 10 to – 50 Euros/t) can be reached in the case of some large plants, although it is not true for all large plants considered. This is particularly the case in Germany.

    This situation may be explained by a lower cost for the processes considered in Germany compared to Italy.

    Regarding Italy, the levels of gate fee (positive) obtained are probably representative of the next year situation when the partial tax exemption on lubricant for lubricants produced from re-refined base oil is suppressed. As a matter of fact, this partial tax exemption, which represents a gap of 296 Euros/t between both types of base oil (in favour to re-refined base oil), is supposed to allow selling re-refined base oil at prices higher than those considered here. It is likely that the positive effect of this partial tax exemption has not been taken into account in the re-refined base oil selling price.

  The implantation of the plant on an existing site, allowing it to benefit from existing infrastructure, is of course likely to decrease the level of the necessary gate fee, and in several cases to allow the gate fee to become negative.

- For a given plant, the base oil selling price is the most important factor affecting its WO gate fees. As a consequence, they are very sensitive to the virgin base oil price and thus to the crude oil price (and dollar rate).

  For instance, for the 85 kt TFE + hydro plant considered, the gate fee assessed in 2001 at – 15 Euros per tonne would become positive to + 9 Euros per tonne if the selling price of the re-refined base oil would decrease by 20%.

  On the contrary, an 20% increase of the re-refined base oil selling price would have the opposite effect on the gate fee of the 80 kt TFE + hydro plant considered, assessed today at + 21 Euros per tonne: it would become negative to – 20 Euros per tonne.

  And with a 35 to 45% increase of the re-refined base oil selling price, all the plants assessed in this project would have a negative gate fees (it is possible that this situation occurs in the future but such a long term assessment base is not appropriate in the scope of the current project).

- In most of the situations assessed where the gate fees are positive, they are lower than the internal return on finance expected (on the basis of a 10% IRR).

  This implies that an actor which would find an interest other than a financial one to invest in a regeneration plant could accept a reduced WO gate fees (for instance a crude oil company for marketing reasons, interesting in improving its corporate image). This is a matter for a larger strategic decision.

- It would have been interesting to draw conclusions regarding the relation between the expected re-refined base oil quality and the WO gate fees.

  But due to the fact that the economics of regeneration really depends on local circumstances, it is not possible, from the data gathered in the scope of this project, to isolate the impact of the expected output quality on the process cost on the one hand and on the revenues on the other hand.

  An in-depth analysis combined with an engineering study would be necessary to bring relevant conclusions on this issue and help to answer to the following questions: is the strategy aiming at improving the quality of the output profitable? Does the market demand justify extra process costs to produce more sophisticated products?

- This paragraph focuses temporarily on the differences between new plants and existing plants.

  Two methodological choices have been made in the calculations which are relevant in the case of new plants:

  - the depreciation of the capital costs (10 years for the core process equipment and related expenses and 20% for the non core process equipment and related expenses),
  - a 10% internal rate of return (IRR).

  In the case of existing plants, it is possible to reach lower gate fees compared to those indicated above for new plants because:

  - all or at least a significant part of the capital costs may be already depreciated,
  - the most appropriate indicator to assess the profitability of the plant becomes the margin and not the internal rate of return any more.

  This may explain the profitability of the small plants which exist in Europe (for instance in Germany, in Italy, in Spain). An in-depth analysis would allow to better understand the conditions explaining that some plants are profitable whereas similar ones are not.

The break even point

- According to re-refiners and several authors[29], the break even point of a regeneration plant would be between 60 and 80 kt per year.

- Actually, the break even point is dependent on the cost and revenues levels, including the WO supply cost (gate fees), which are to a great extent influenced by local circumstances and the crude oil market price level as shown above. It is also different for each technology. For instance, in 2001, according to the data provided to TN SOFRES Consulting:
  - TFE + clay finishing: the break even point is between 50 and 80 kt with a 10% return on investment and WO freely delivered to the plant (nil gate fee).
  - TFE + solvent finishing, TFE + hydro-finishing: the break even point is near 90 kt with a 10% return on investment and WO freely delivered to the plant (nil gate fee).
  - TFE + hydro-finishing: with a 7% return on investment and free WO delivered, a 80 kt plant could reach the break even point.
  - TDA + hydro-finishing: with a 3% return on investment and free WO, the break even point would be around 100 kt.

- In any case, unless having captive outlet markets (with more or less fixed re-refined base oil selling prices), larger plants are more liable to resist to huge crude oil price fluctuations and to maintain a sufficient profitability in the long term. That is why most of the new regeneration plant projects in Europe concern large plant sizes.

4.6 Regeneration and employment

The number of jobs created by a plant is of course dependent on its size. It may reach 55 persons for a 100 kt plant.

29 Coopers & Lybrandt [30], UK report [40]; a minimum efficient scale of 75 kt per year is mentioned in the UK report

5 THERMAL CRACKING

5.1 TYPE OF WO ELIGIBLE FOR THERMAL CRACKING

Thermal cracking can accept various types of hydrocarbon feedstock: WO, waste marine fuels, deep frying oils and, possibly with design considerations, waste plastics (e.g. DIY WO returned in their original container).

5.2 TYPE OF OUTPUTS PRODUCED AND MARKETS

The strategy of thermal cracking is to produce high quality products ranging from de-metallised heavy fuel oil to re-refined light industrial lube oil, including gasoil products.

As described below, thermal cracking offers a big adaptability to the changing market values of products.

According to the promoters of thermal cracking, the gasoil products for instance presents the following advantages:

- a relative high value compared to other fuels (heavy distillate fuel oils, residual replacement fuels) derived from WO by other re-processing technologies,
- a cleaner burning,
- as a commodity product, large markets and marketable anywhere in the world.

5.3 AVAILABLE PROCESSES

- Thermal cracking is a common refinery process that is well known and proven.

  No plant already exists in Europe for WO[30]: the first plant will be operational by the end of 2001 in Belgium.

- Thermal cracking, visbreaking, catalytic cracking, fluid catalytic cracking, hydrocracking and coking are all variations on the basis of the basis principle of breaking or cracking the large hydrocarbon molecules (C_xH_y with 30 carbons) into smaller ones (C_xH_y with 10 to 18 carbons) by the application of sufficient heat in a pressurised vessel. In this fashion, larger molecules of more viscous and less valuable hydrocarbons are converted to less viscous and more valuable liquid fuels.

  The yield can reach 70%.

[30] A 20 kt facility (Guascor group) operates in Spain a simple thermal cracking process and mixes all the light and heavy fractions obtained to feed a thermal engine producing electricity. But this process is very specific and differs from those described in this chapter.

Several processes exist today, such as:

- the Springs Oil Conversion,
- the Great Northern Processing Inc. (GNP) used oil thermal cracking process.

- The Springs Oil Conversion is developed by Silver Springs Oil Recovery Inc, Canada. Two processes are available:

  - SOC1: the de-watering is followed by the thermal cracking performed in fired heater coils with soaking drums or heated kettles.

    This process is suitable to small plants, in the 6 kt to 15 kt/yr range. But it is limited in the feed.

  - SOC2: the de-watering is followed by the thermal cracking performed in an indirectly fired rotary kiln.

    It is suitable to large capacities and can process also oils more refractory to thermal cracking (such as synthetic oils) and higher carbon residues (bunker fuels…).

- The GNP technology is developed in the United States, offered under license by Propak Systems Ltd., Canada, and marketed by Par Excellence Developments, Canada.

  This thermal cracking of WO, utilising 'refinery calibre' systems and equipment, is a relatively recent development: in 1995-96, this process was successfully re-applied in a 30 kt commercial operating plant by a US company to produce high quality gasoil distillate from a feedstock of WO.

  It is this technology which will be installed in Belgium by the end of 2001. The 40 kt/yr plant will be operated by WATCO.

  The process consists in a screening and de-watering section, followed by a thermal cracking section, then a separation or distillation depending on the product slate desired and finally a purification and stabilisation stage.

  This technology is characterised by a large 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.

  As a matter of fact, the process operational conditions (temperature, pressure, residence time…) can be varied to produce a primary product (be it heavy fuel oil, gasoil or base oil) to be maximised and secondary product streams (consumed in the process for calorific value or sold) to be minimised.

Example of Outputs under Appropriate Operating Conditions

Configuration of the plant	Primary product	Secondary products
Case 1	De-metallised heavy fuel oil (77%) or Marine gasoil (MGO)	Naphtha (8%), off-gases (5%), heavy residues (10%)
Case 2	Gasoil (also called diesel fuels, heating oil, furnace oil) (65%)	Naphtha (15%), off-gases (10%), heavy residues (10%), light lube oil (small fraction)
Case 3	Re-refined light lube oil (45%)	Gasoil (30%), naphtha (10%), off-gases (5%), heavy residues (10%)

If a configuration for gasoil production is desired, this is the most severe cracking mode and thus heat input is maximum and throughput is at design capacity. If de-metallised heavy fuel oil or light lube oil is preferred as the primary product from the plant, the process operating conditions can be changed to achieve this.

Thermally cracked gasoil is unstable. It will discolour rapidly and precipitate gums and tars. A stabilisation and purification operation supplementing the thermal cracking can allow to obtain a gasoil which:

- is not odorous (no foul smelling),
- meets regulatory and consumer colour criteria,
- minimises the formation of gums and tars during storage,
- is not highly acidic.

Several methods are available, such as:

- the ROBYS[th] process, developed by CANMET Energy Technology Centre CETC (government of Canada) and licensed to Par Excellence Developments, Canada,
- several chemical stabilisation methods (clay absorption, solvent extraction),
- the hydro-treatment. But for a stand alone WO thermal cracking plant, it may be not feasible due to the very high capital cost and requirement for hydrogen gas.

Numerous prospective world wide customers of thermal cracking (e.g. UK investors) have their eyes on the Belgium plant and it is likely that no other company will buy the technology until they observe WATCO's success.

- It is likely that in order to meet EU requirements for sulphur content in liquid fuels (automotive and/or heating oil) that the resulting cracked products will require either treatment for sulphur reduction or will have to be blended away in lower sulphur product (thereby making use indirectly of someone else's desulphurisation capability).

- The recent development of that technology and that wait-and-see policy explains why thermal cracking has not developed more largely yet.

5.4 ECONOMICS OF THERMAL CRACKING

- Thermal cracking is capital consuming: capital costs and fixed operating costs represent about 80% of the overall cost (WO purchase excluded).

  A thermal cracking plant cost in the order of a third to half the amount of a regeneration plant of similar size (although that comparison is not necessary relevant since the outputs produced are different).

- Experts agree that thermal cracking with its lower capital cost allows plants to be profitable at the 30 kt/yr plant size. No subsidies are necessary.

  The evaluation performed in the scope of this project on the basis of the Belgium plant being built confirms that point (see appendix 7 for more details).

Cost & WO Gate Fee for a Grass-Root Thermal Cracking Plant

		Thermal Cracking		
Technologie				
Plant		grass-root	grass-root	grass-root
Capacity	kt/yr	40	50	80
Capital costs	Meuros	11	13	20
Cost	Euros / t of WO	135	123	112
on which Internal return on finance [(1)]	Euros / t of WO	*50*	*46*	*44*
Revenues	Euros / t of WO	144	144	144
WO gate fee	Euros / t of WO	**-10**	**-21**	**-32**
Source		GEIR 2001 - B	GEIR 2001 - B	GEIR 2001 - B

(1) on the basis of a 15% risk adjusted rate of return on finance

6 OTHER DISPOSAL ROUTES

6.1 RE-USE

Two methods exist to reclaim clean industrial lubricants before returning them to the users:

- laundering: this is a close-loop system especially for hydraulic and cutting WO. Solid removal (filtration), de-watering and fresh additives addition allow to return the oil to its original form again fit for use.
- reclamation: this is a recycling process especially for hydraulic WO. These oils are simply centrifuged and / or filtered and then used, for instance, as mould release oil or base oil for the production of chain saw oil.

6.2 GASIFICATION

This Texaco's technology has been world-wide use for a long time in more than 100 plants.

It consists in converting the carbon containing materials to synthesis gas (H_2 and CO).

It presents the advantage of accepting mixed wastes, e.g. WO and plastic which is particularly interesting in the case of DIY WO returned in their original container.

But because large scale plants are necessary to reach the break-even point, only existing plants could be used to treat WO. For that reason, this solution can not be generalised at the European level.

6.3 BURNING AFTER SEVERE RE-PROCESSING

This category of processing aims at separating the combustible WO portion from the less desirable bottoms fraction which contains the metals, the non-combustible ash, grit and dirt…

Some chemical treatments exist (acid/clay, solvent extraction, propane extraction…, with no finishing step) as do thermal treatments (Texaco Trailblazer process, Emprotec Vaxon process…).

The de-metallised heavy fuel oil produced (also called heavy distillate) can be burnt as marine diesel oil (MDO), fuel for heating plants…

6.4 Burning After Mild Re-processing

A simple cleaning process, to remove water and sediments (typically, it does not deal with the heavy metals, halogens and sulphur), is required before further use of WO as Replacement Fuel Oil (RFO) in the cases of:

- road stone plants: re-processed WO are burned to dry limestone and hard stone for the manufacture of road surfacing materials. This process is in common use in Belgium and the UK.
- fuel blending: re-processed WO are mixed with other heavy streams into fuel oil, which may be sold as bunker fuel for road stone plants and power stations.
- power station: re-processed WO is utilised in pulverised coal power stations, mainly as furnace start up fuel, but it is also used sometimes as an addition to the main fuel where heat input is restricted.

6.5 Burning in Cement Kilns

- Cement kilns are very energy intensive: fuel and electricity can represent up to 70% of variable costs.

Traditionally, cement kilns use a mix of different sources of energy. For instance, in 1999 in France, the distribution between them was as follows:

<table>
<tr><th>% (according to the calorific value)</th><th>France</th><th>Germany</th></tr>
<tr><td>Solid fuels</td><td>49%</td><td rowspan="4">69%</td></tr>
<tr><td>• Coal</td><td>9%</td></tr>
<tr><td>• Petroleum coke</td><td>40%</td></tr>
<tr><td>Tar and miscellaneous</td><td>20%</td></tr>
<tr><td>Heavy fuel oil</td><td>3%</td><td rowspan="2">14%</td></tr>
<tr><td>Gas</td><td>1%</td></tr>
<tr><td>Secondary liquid fuels (SLF)</td><td>27%</td><td>17%</td></tr>
<tr><td>• WO</td><td>9.4%</td><td rowspan="2">9%</td></tr>
<tr><td>• Other hazardous waste (paints, solvents, cleaning agents…)</td><td>10.6%</td></tr>
<tr><td>• Animal flours</td><td>4.5%</td><td></td></tr>
<tr><td>• Tires</td><td>1.2%</td><td rowspan="2">8%</td></tr>
<tr><td>• Other non hazardous industrial waste</td><td>1.3%</td></tr>
</table>

Source: French Association of the Cement Industry, 2001 / German LCA report, 2000 [17]

Because of its relative price advantage over heavy fuel oil and gas oil, the use of SLF (composed of RFO - Replacement Fuel Oil - such as WO, paints, solvents… and of industrial waste such as animal fours, tires…) has increased over years, e.g. from 17% in 1996 to 27% in 1999 (3% per year) in France.

- About 400 kt of WO are used as a SLF in cement manufacture in Europe.

  From a strategic point of view, WO represent one of the superior inputs for cement kilns to the extent that their high calorific value allows cement kilns to mix them with lower calorific value waste.

  In a lot of cases, cement kilns have integrated collectors to secure their supplies.

- All national regulations do not allow to burn WO in cement kiln: WO are accepted as cement kiln fuel in France, Germany, Italy and the UK, but seem to be banned for that use in Denmark, Finland and the Netherlands for instance.

- The gate fee that the cement kilns can pay for the WO is dependent on local circumstances as well on the international economic conditions:
  - the existence or not of a re-processing step before the burning (as a matter of fact, the burning of WO in cement kilns can take place directly after collection or be preceded by a mild re-processing step),
  - the crude oil prices, which directly affect the price of the traditional fuels the WO compete with (the highest the crude oil price is, the highest the cement kilns can pay for WO),
  - the existence of WO duty derogation still in use in 11 Member States (A, B, D, E, F[31], Fin, Ire, It, Lux, Pt, UK): it consists in a derogation on the duty that has otherwise to be collected on WO which are used as fuel, either directly after recovery or following a recycling process. This fiscal measure encourages the use of WO as fuel.

  When considering Germany, Italy, Spain and the UK in 2001, the WO purchasing price paid for by cement kilns varies between 40 and 120 Euros per tonne.

- Due to tighter emission limits, the Waste Incineration Directive (WID), which comes into force on the 1st January 2003 for new installations and on the 1st January 2005 for existing installations, will prevent most of the current RFO users (all facilities except cement kilns and incinerators: road stones plants, industrial furnaces, maybe power stations…) from burning it.

  In these circumstances, it is likely that in the countries where these practices are largely spread (such as the UK), the majority of the RFO will be directed to cement and lime kilns. These users will thus expect to be paid for accepting WO (the three major UK operators expect at least 30 Euros per tonne[32], according to the UK report [40]).

[31] In the case of France, WO are indeed exempted from the TIPP but not from the TGAP (see section 3.2.3 on page 35).

[32] £20 / tonne

6.6 OTHER DIRECT BURNING

Burning WO without any pre-treatment is one disposal option with several different methods of energy recovery:

- burning WO in cement kilns (see chapter above),
- burning WO in municipal waste incinerators (WO is discarded amongst household waste) or chemical waste incinerators (bulk loads of WO are accepted). Some municipal waste incinerators recover energy for power generation or district heating. Most of chemical waste incinerators recover energy to be fed back into the operational energy required for the incinerator itself (replacement of gas or gas oil).

Burning WO in small space heaters in garages, workshops and greenhouses is illegal in most of the cases (it is necessary to have a permit to dispose of hazardous waste; almost none of this type of installations have it and they do not fulfil the emission limit values).

7 CONCLUSIONS OF THE TECHNICO-ECONOMIC ANALYSIS

7.1 BOTTLENECKS OF THE REGENERATION DEVELOPMENT

- Several types of possible bottlenecks, which can exist on a country level or at a European level, can be distinguished.

The technology	No major bottleneck
The profitability	Bottleneck, at least during the first years
The supplies	Bottleneck
The outlets	Bottleneck

They are detailed below.

- There is no major technical bottleneck for regeneration development:
  - the technologies exist,
  - the quality of base stocks produced is comparable to virgin base oils (Group I and even Group II when a severe hydro or solvent treatment is used for the finishing step).

However, it remains to be seen whether the latest technical advances in regeneration prove to be sufficiently flexible to handle the changing composition of WO over the next 10 years and the possible increase of bio-lubricants consumption.

This uncertainty generates risks for investors in regeneration facilities.

- The economic bottleneck is obvious.

In most of the cases, a regeneration plant (with a 10% return on investment) is not economically self sufficient from the beginning, not only when the costs of collecting WO and delivery to the plant are included but even when they are not included. It would need to receive between 10 and 100 Euros for each tonne delivered to the plant, depending on the technology, the capacity and the market conditions.

It is only after some years, once the capital cost are at least partly paid off, that the regeneration activity can be profitable.

On the contrary, some large plants (but not all according to our analysis), located in countries where the re-refined base oil can be sold for a good price, can benefit from both scale advantages and high revenues, allowing them to purchase the WO, but at a relatively low price, between 15 to sometimes 50 Euros / t.

In all the cases, the revenues of a regeneration plant are extremely sensible to the crude oil price fluctuations.

- The WO supplies often represent another bottleneck.

  Under free economic conditions, a regeneration plant is often unable to compete with untreated or re-processed combustion of WO (except in the case of some large plants with favourable local conditions).

  Even when the gate fee is negative, first the price that the plant can pay is not high enough to cover the overall collection and delivery costs (between 25 and 100 Euros/t depending on the country when compiling the 2001 GEIR data and the Coopers & Lybrandt data [30]).

  Secondly, the regeneration plants suffer from the competition with industrial sectors buying the WO for an energetic use, such as cement kilns, brick kilns, power plants...

  - As a matter of fact, due to the structure of their cost and the price of the fuels that the WO substitute, these companies are able to buy the collected WO often at a higher price than the regeneration plants (e.g. between 40 to 120 Euros per tonne when considering Italy, Germany and Spain). As a consequence, the market can often not guarantee the regularity of the supply of a regeneration plant. The situation may be improved a little bit for the regeneration activity when the new Directive on Incineration is implemented (in 2003 for new plants and 2005 for old plants), forbidding the burning of WO in many plants which are currently using WO as fuels and thus decreasing the financial interest of plants used to burn WO directly.
  - The supplies of regenerators are also weakened by the WO excise duty derogation which are still in use in 11 Member States (A, B, D, E, F[33], Fin, Ire, It, Lux, Pt, UK): it consists in a derogation on the duty that has otherwise to be collected on WO which are re-used as fuel, either directly after recovery or following a recycling process. This fiscal measure, prolonged until 2006, encourages the use of WO as fuel.

    For instance, the UK excises are so high (43 Euros/t) that it brings the classic product (heating fuel) up to prices higher than the Eu average. The total exemption for WO burnt as fuel makes WO very attractive for energetic use (that is why the UK is importing a large quantity of WO from other Eu countries) and creates rarity of raw material for regenerators producing base oils.
  - The vertical concentrations from collectors to processors which exist in some countries can create shortage of raw materials for regenerators because integrated companies would prefer to sell to cement kilns or other WO energetic users which offer higher prices (in particular in the case of crude oil price increase).

- As for the outlet, a lot of potential users of re-refined base oils, in the automotive or industrial sector, are still reluctant to use recycled products.

  Besides, the size of the automotive lubricants is shrinking in a context of over-capacity of lubricant production and the demand progressively displaces from conventional mineral-based auto lubricants to ‘synthetic’ products with high performances. These tendencies are unfavourable to the increase of the re-refined base oils demand under free market conditions.

[33] In the case of France, WO are indeed exempted from the TIPP but not from the TGAP (see section 3.2.3 on page 35).

In any case, in this context of an increase of the quality required for lubricants, large regeneration plants will have to produce high quality re-refined base oil, even if niches will still absorb small quantities of lower quality.

7.2 Possible Measures to Stimulate Regeneration

To promote regeneration, it will be necessary to assist the regenerators with incentives (non financial in all cases and sometimes financial too).

Specific measures and arrangements have also to be taken by the regenerator himself.
All these measures aim at diminishing the risk profile of investment in regeneration projects by guaranteeing the existence and durability of the supply and outlets and, when the gate fee is positive, by covering it.

No spontaneous investment will occur unless clear signals regarding these issues are given to investors.

A set of measures and incentives is presented below, classified according to:

- the issue they are addressing: the supplies, the outlets and the profitability,
- the effect which is expected: to secure the feedstock, to secure the outlets, to cover a positive gate fee…

7.2.1 Possible Measures related to the Supplies

- Possible measures to secure feedstock supplies to regeneration plant on which depends the profitability of the invested capital (to use the available regeneration capacity as much as possible)
  - Medium or long term WO supply contracts and voluntary agreements between collectors and the regeneration plant.
  - Participation (shares) taken by collectors in the regeneration activity.
  - Application of the excise duty on the WO that are used as fuel without prior regeneration and treatment.
  - Suppression of the derogation on excise duty for WO used as fuel.
- Possible measures to decrease the WO gate fee for regenerators

  Collection and delivery costs covered, at least partly, by a disposal charge paid by generators / holders, a product charge on sold lubricants, a subsidy from governmental bodies…

  Remark: This measure is necessary also to improve the WO collection rate. Regeneration could then benefit from it.
- Possible measures to supply regeneration plants with regenerable WO to increase the quality of the outputs

  Segregated storage and collection.

Remark: Germany has handled the problem raised by the WO composition becoming more complex by obliging holders and collectors to a segregated storage and collection. Beyond the difficulty to enforce that obligation, the economic side effect has to be mentioned: this might oblige to duplicate the collection networks and vehicles

7.2.2 Possible Measures related to the Outlets

- Possible measures to secure the outlets and if possible to lighten the effect of the crude oil fluctuations
  - Marketing strategy of the regenerator to define the appropriate positioning of its products on the market (e.g. the distinction between products sold below the market price and those at the market price).
  - Medium or long term voluntary agreements between the regeneration plant and lube producers or large lube users.
  - Financial incentives for blenders and lubricant manufacturers to purchase specified re-refined base oils.

  *Rem*ark: the side effect of subsidies to deal with the poor market perceptions of re-refined base oil is that it reinforces the signal that the good is inferior (whereas re-refined base oil can reach the same quality as virgin base oil).

- Possible measures to impose or at least encourage the use of lubricants containing or manufactured with re-refined base oils

  Public procurement.

7.2.3 Possible Measures related to the Profitability

- Possible measures to obtain economies of scale and thus to decrease the WO gate fee

  Stimulation of co-operation between the EU 15 countries.

- Possible measures to increase the re-refined base oil selling price (and the revenues) and thus to decrease the WO gate fee

  Exemption of tax on sold lubricants (if any) for lubricants produced from re-refined base oil.

- Possible measures to cover the residual positive WO gate fee of the regeneration plant (if any)

  Subsidies (from a product charge on sold lubricants, a disposal charge paid by generators / holders, governmental bodies…).

- *Rem*ark: The financial measures aiming at guaranteeing the profitability of the regeneration plants could, in some cases, be temporarily (e.g. until capital costs are at least partly paid off).

C.
Critical Assessment of LCA Studies Comparing Regeneration and Incineration

8 BACKGROUND INFORMATIONS ON LIFE CYCLE ANALYSIS (LCA)

At first glance, the results from the 6 studies considered may appear contradictory and confusing. Due to the complexity of LCAs it may be difficult to understand the reasons behind the differences. It is thus useful to introduce LCA in a comprehensive way.

8.1 LCA AS A TOOL FOR THE EVALUATION OF ENVIRONMENTAL PERFORMANCES OF RECOVERY OPTIONS

- While the analysis of environmental impacts of landfill or incineration without energy recovery may be sufficient to evaluate these waste management options in terms of the protection of the environment, this is not true for recovery options. Additional values are created by the energy generated or the secondary raw materials recovered. Environmental impacts are prevented which would be caused if the energy or materials would have to be generated from primary resources. This environmental gain from material or energy recovery has to be calculated from a complementary energy generation or material production system.

  Therefore, analysis and assessment have to be done by a life cycle approach, analysing and calculating the environmental impacts of these complex systems on the basis of a model. Consequently, we always have to keep in mind that LCA is merely a model and not reality. Results of LCA are restricted to the specific model used. A critical view is necessary on the model used especially in regard whether this model reflects reality sufficiently.

- Life cycle analysis (LCA) is a tool used both to evaluate the environmental burdens associated with a product, process or activity and to consider opportunities to make environmental improvements.

  The LCA methodology is fairly well developed and can reasonably well support comparisons of the environmental benefits of various WO management options. LCA is regarded by many as a rigorous scientific approach for quantifying environmental impacts of a given 'system' (the activities to which the technique is applied).

  ISO 14040 defines: '*LCA studies the environmental aspects and potential impacts throughout a product's life (i.e. cradle-to-grave) from raw material acquisition through production use and disposal. The general categories or environmental impacts needing consideration include resource use, human health and ecological consequences*'.

The methodology of LCA is still under development, but a great part of standardisation has been achieved. Standards in the ISO 14040 series describe principles and framework and the four stages of an LCA:

- Goal and scope definition (ISO 14040 and 14041),
- Life cycle inventory analysis (ISO 14041),
- Impact assessment (ISO 14042)
- LC interpretation / improvement assessment (ISO 14043).

According to ISO 14040, *'LCA can assist in:*

- *Identifying opportunities to improve the environmental aspects of products at various points in their life cycle;*
- *Decision-making in industry, governmental and non-governmental organisations (e.g. strategic planning, priority-setting, product or process design or redesign);*
- *Selection of relevant indicators of environmental performance, including measurement techniques,*
- *Marketing (e.g. environmental claim, eco-labelling scheme or environmental product declaration).'*

8.2 Methodological Framework of LCA

- Goal definition and scoping

At this stage, the LCA is planned such that the purpose and intended application of the LCA can be met. The scope of an LCA study shall clearly specify the functions of the system being studied. The 'functional unit' is chosen, which is a measure of the performance of the functional outputs of the product system. The primary purpose of a functional unit is to provide a reference to which the inputs and outputs are related. This reference is necessary to ensure comparability of LCA results. For example in a comparison of incineration versus regeneration, the functional unit could be "collect and dispose of 1000 kg of WO". The systems and the scenarios to be studied are identified and defined and system boundaries are established. The system boundaries determine which unit processes shall be included within the LCA.

- Life cycle inventory analysis

The inventory quantifies the material and energy consumptions and emissions to air, land and water, for every stage of the life cycle of a product, from the extraction of raw materials through manufacture to disposal. For each unit process, the inputs (in terms of materials and energy) and outputs (in terms of emissions to air, water and solid waste) are calculated and then aggregated over the life cycle. The results are related to one functional unit. The result is a list of physical inputs and outputs resulting from all of the processes considered.

- Impact assessment

  This stage facilitates the interpretation and aggregation of inventory data into forms more manageable and meaningful to the decision-maker. There is no scientific basis for reducing LCA results to a single overall score or number. The methodological and scientific framework for impact assessment is still being developed. The SETAC (Society of Environmental Toxicology and Chemistry) problem-oriented approach is the most widely accepted method within the LCA community. It involves:

  - (a) classification, which groups the data into impact categories, e.g. global warming, acidification,
  - (b) characterisation, which assesses the relative contribution of burdens in each impact category.

- Interpretation and improvement assessment

  This stage is optional and evaluates the relative importance of the impacts categories by assigning weights to them. Other approaches, notably the economic valuation methodology, may omit either or both of the steps of classification and characterisation. Conventional LCAs do not prescribe which form of weighting should be used. Instead, it offers a list of options, including single factor dominance, equal weighting, expert judgement, social preference, ranking according to nuisance and economic valuation.

8.3 KEY FEATURES OF LCA

The following list (ISO 14040, § 4.1) summarises some of the key features of the LCA methodology:

- LCA studies should systematically and adequately address the environmental aspects of product systems, from raw material acquisition to final disposal.
- The depth of detail and time frame of an LCA study may vary to a large extent, depending on the definition of goal and scope.
- The scope, assumptions, description of data quality and output of LCA studies should be transparent. LCA studies should discuss and document the data sources, and be clearly and appropriately communicated.
- Provisions should be made, depending on the intended application of the LCA study, to respect confidentiality and proprietary matters.
- LCA methodology should be amenable to the inclusion of new scientific findings and improvements in the state-of-the-art of the technology.
- Specific requirements are applied to LCA studies which are used to make a comparative assertion that is disclosed to the public.
- There is no scientific basis for reducing LCA results to a single overall score or number, since trade-offs and complexities exist for the systems analysed at different stages of their life cycle.
- There is no single method for conducting LCA studies. Organisations have flexibility to implement LCA practically as established in the International Standards, based upon the specific application and the requirements of the user.

8.4 Specific Requirements to Make a Comparative Assertion from LCA Results

'In comparative studies, the equivalence of the systems being compared shall be evaluated before interpreting the results. Systems shall be compared using the same functional unit and equivalent methodological considerations, such as performance, system boundaries, data quality, allocation procedures, decision rules on evaluating inputs and outputs and impact assessment. Any difference between systems regarding these parameters shall be identified and reported'. (ISO 14040, § 5.1.2.4)

In the case of comparative assertions disclosed to the public, this evaluation shall be conducted in accordance with the critical review process of ISO 14040 section 4.3.3. Another requirement for comparative assertions disclosed to the public is that an impact assessment shall be performed. The findings of the impact assessment should reflect the results of any sensitivity analysis that is performed for estimating the effects on the outcome of a study of the chosen methods and data.

Critical review is a technique to verify whether an LCA study has met the requirements of the ISO standards for methodology, data, reporting and assessment methods (ISO 14040 to 14043). Generally, a critical review is made by a review panel of external, independent and LCA experts.

A critical review may facilitate understanding and enhance the credibility of LCA studies by involving external independent LCA experts. However, the fact that a critical review has been conducted should in no way imply an endorsement of any comparative assertion that is based on an LCA study.

9 LCA IN WASTE MANAGEMENT POLICY

9.1 FROM PRODUCT-ORIENTATED LCA TO PROCESS-ORIENTATED LCA

- LCA methodology has been developed mainly for the purpose of comparing existing, well known products in a specific situation and to do it in a fair, balanced and symmetrical way. The framework for such product-orientated comparisons is described in detail in LCA manuals and the ISO standards, but less efforts have been made yet to develop LCA for strategic purposes and political decision-making. Typical studies of this kind focus on the choice between different types of products having the same usage value.

- While product orientated LCAs start at the beginning of a product's life cycle (*cradle to grave*), a typical LCA in waste management is quite different and starts at the end of a product's life cycle (*gate to grave* system boundary). The whole product's life cycle before is out of its scope and the subject of the LCA is the waste phase. Its post-life cycle might be short if landfilled or incinerated without energy recovery. On the contrary, in case of regeneration (material recycling) or energy recovery, it will give the material or energy recovered a rebirth. In that case the system boundaries will cover the 'second life' of the material until it has reached a quality where it substitutes a material produced from raw materials or the 'second life' of the energy which substitutes a fuel produced from raw materials.

- A typical process-orientated LCA in waste management comprises a *gate to grave* system boundary, the gate being the point at which for instance lubricants become waste.

  This is the case of the Lower Saxony Ministry of Environment study (1997), the UBA (2000) study and the ADEME study (2000), while the Norwegian EPA study (1995) must be considered as a product orientated LCA within a *cradle-to-grave* system boundary.

  The functional unit is defined as "1000 kg of WO" in the process-orientated LCAs, and "1000 kg of lubricants" in the product-orientated approach.

- Such a process-orientated LCA is a suitable tool for a waste management company or a product take-back scheme but of limited value for political decision-making.

  As a matter of fact, most LCA studies are performed under specific contemporary conditions and estimations (e.g. transport distances, waste management structures, standard processes, standard products). They are short-term orientated and case-specific while LCA as a policy tool has to be long-term orientated and as general as the regulations discussed. Hence foreseeable changes which are implied by environmental regulations as well as technical progress are generally not taken into account.

9.2 POLICY-ORIENTATED LCA

LCA is already in use in the decision-making process for waste management, mainly in the field of municipal solid waste and packaging waste. Some national administrations already use or intend to use the findings of LCA as a basis for waste legislation. Various lobbying organisations use LCA to support the reasons for the proposals which they have made in their own interest.

Process-orientated LCAs can be a tool for decision-making in the waste management policy if they are done as prospective LCAs. They have to:

- cover new process in development,
- identify theoretical potentials for environmental gains,
- choose appropriate system boundaries.

Measures adopted in fields other than waste management, such as product requirements, can have a strong influence on the environmental impact of a product during its whole life cycle. For instance, policy decisions with respect to lubricant quality standards could influence the total environmental impact of lubricants (as discussed hereafter). An integrated policy has to take into account these cross-effects and LCA studies have to find methods in order to analyse those effects.

9.3 FACTORS AFFECTING THE LCA RESULTS OF WASTE MANAGEMENT OPTIONS

- The product quality standards

  Policy decisions related to the quality of the product becoming waste may have direct influence on the environmental impacts of waste management options.

  For instance, in the case of lube oil (or lubricants), the decrease of the micro-pollutant content (e.g. PAH, heavy metals) of lube oil may cause:

  - a reduction of the environmental impacts due to the regeneration or recycling process,
  - an increase of the environmental impacts due to the lube oil production (as it would become necessary to add some operations intended to reduce the micro-pollutant content of crude oil).

  Thus within a LCA perspective, the total environmental impact of the 'regeneration systems' will decrease dramatically as the direct burdens due to the regeneration process itself will decrease and the avoided burdens due to the production of virgin oil will increase.

  Conclusion: an evaluation of WO management options is not suited as a basis for waste management policy if based on today's lube oil quality standards only. It is just useful to analyse the starting point. An integrated product policy (IPP) has to take into account these cross-effects.

- The time horizon

  LCAs can be based on data of specific single plants, on data describing different levels of technology and development or on mean values in a specific branch or region. In each case, the results are different.

  Typically, LCA results used in waste management are derived from today's situation and technology. Those LCAs will give a sound evaluation of the environmental effects only for the short term (up to maximum 3 years).

  To evaluate the environmental effects in a mid-term the most advanced technology under development has to be considered.

Conclusion: an evaluation of WO management options is not suited as a basis for waste management policy if based on today's situation and mean technology only. It is just useful to analyse the starting point.

- The bonus calculation

If energy is produced from WO or if virgin base oil is substituted by re-refined base oil, an environmental bonus is given to the recovery option in LCA. The bonus reflects the environmental impacts of energy generation or material production from primary sources which are avoided. A beneficial recovery system will have a calculated overall negative (avoided) impact on the environment for the most important parameters.

Conclusion: an evaluation of WO management options must quantify the environmental impacts of energy generation or material production from primary sources which are avoided. LCA of WO management options must be based on well-designed system boundaries.

- Case-specific vs system comparison

In some LCAs the analysis is case-specific (restricted to single plants and their direct surroundings) while the conclusions are claimed to be generally valid and suitable as a basis for policy recommendations. This might be permissible if there is only one plant of this kind or if the plants have all the same quality and environmental performances. Such an analysis may be misleading if the plants are very different. A single plant analysis may be misleading because of local or specific conditions also.

Conclusion: sound results on management options for WO have to be based on a LCA system analysis with wider boundaries. Basically single case studies are not suited for waste management policy making. The system specifications have to be representative. The average situation today and achievable future scenarios should form the basis of the analysis.

- The Influence of specific national conditions

Three topics are particularly impacted by specific national conditions:

- Distances for collection and transport of recovered materials.
- The mix of energy consumed.

  In the EU member states, the use of energy resources differ (e.g. the share of coal, gas, oil, hydroelectric power and nuclear power). But more important than these differences is the question what the marginal energy resource is.
- The prioritisation of the environmental impacts.

  This concerns local environmental impacts, whose rating might indeed be different from one country to another due to local conditions or to the ecological sensitivity of the natural environment.

  As far as WO recovery options are concerned, as it will be shown hereafter, the environmental impacts which are assessed are mainly related to global impacts as greenhouse gas emissions, resources depletion and trans-boundary emissions. As a matter of fact, at today's state of the art, data on emissions related to local environmental impact categories can only be based on estimated data with a large range of uncertainty. Thus, local conditions will not play a big role in this issue for WO management options LCA.

9.4 Specific Environmental Problems not Covered by LCA

- Regional and global impacts

The result of a LCA is the total environmental impact of the system analysed. Normally there is no distinction where these impacts occur. In general it is possible that a strong increase in emissions at one place compensates lower emissions at another place. These accountings do not cause any problems as long as the emissions do not have any specific regional impacts - as it is the case with e.g. greenhouse gas emissions. Their impact is global and cumulative, and the environmental impact is completely independent on the location of the emissions. Other emissions as acidifying emissions or emissions taking part in the photo-oxidants formation contribute to trans-boundary pollution or to pollution in large areas. Emissions into water and toxic emissions into the air, as dust for example, will cause local or regional problems.

Regarding emissions with a predominantly regional or local toxic impact, an LCA could generate paradoxical results in contradiction to environmental targets. Indeed, in spite of very high emissions which could cause local damage in the surroundings of a plant the overall results could be so positive that this option would be the favourable one. An analysis of the specific contribution of certain processes or steps in the life cycle, which normally should be done in LCA, will deliver a lot of information whether there is such a problem. As long as an LCA does not cover the regional distribution of environmental impacts, it is necessary to consider these effects additionally.

Conclusion: Specific local environmental impacts are not covered by LCA. Additional measures and regulations have to assure that unwanted specific local impacts are not caused as a consequence of recovery operations. Normally plants applying environmental regulations should prevent such consequences.

- Toxic emissions

LCA as a method derived from energy balances is dependent on accurate and sound data. The easiest way to get sound data is to have them accounted and measured continuously. This is normally done with energy and material flows, other data like CO_2 emissions are easily and accurately calculated.

However, emissions of toxic substances and other emissions in small quantities and low concentrations are often not monitored continuously, they are difficult to measure and the data range may be quite large. As a consequence, the data base is incomplete and contains large uncertainties. A methodological problem is the accounting of the emissions towards a certain impact due to the high number of substances.

Conclusion: specific emissions, e.g. toxic substances, are not sufficiently covered by LCAs. Additional measures and regulations have to assure that unwanted impacts are not caused as a consequence of recovery operations.

- Environmental standards of recovery plants

Recovery operations in LCA are accounted as differences of environmental impacts (see chapter below for more details).

For instance, if fuel in cement kilns is substituted by WO, the bonus for the WO recovery option is calculated as the difference between:

- the emissions generating by the burning of the WO in the cement kiln and
- the environmental impacts of the avoided fuel extraction and processing prior to its use in the cement kiln.

Therefore, LCAs do not give information on the absolute impacts caused by the recovery plant itself, which are mainly determined by the plant environmental standards.

Concerning the environmental impacts of the recovery operations, two questions arise:

- Does WO recovery influence the environmental standard?
- Is there a danger that LCAs neglect the increase of environmental impacts?

  For instance, in the majority of WO recovery LCAs, emissions of toxic substances (like heavy metals or organic pollutants) are not fully covered. Therefore, the associated impacts tend to be neglected.

Conclusion: In an LCA, the level of environmental protection and the emissions and raw material consumption standards are not fully taken into account. Additional regulations have to assure a high level of environmental protection.

10 REVIEW OF THE LCA STUDIES RELATED TO WO RECOVERY OPTIONS

10.1 BRIEF PRESENTATION OF THE STUDIES UNDER CONSIDERATION

An overview of the studies considered is presented in this chapter.

The CONCAWE study includes some environmental information (mainly CO_2 emissions and energy consumption) but it is not an LCA. For that reason, it will not be detailed in this section. However, some elements are provided in appendix 8 regarding the WO disposal routes available or under development in 1993[34] as well as general environmental considerations about accumulation of pollutants which are discussed in the CONCAWE report.

The FIAT study compares two regeneration technologies specific to Italy at the time of the study (1997? 1998?). It does not compare regeneration to incineration. For that reason, it will not be detailed in this section either and some elements are given in appendix 9.

The next chapters include a summary for each of the other 4 studies. These summaries are based on the original assertions from the authors. They do not contain any critical comment from us at that stage. Our critical opinion on these studies will be given in a latter chapter.

These four studies are LCA studies designed to compare regeneration with other recovery options. In order to facilitate the comparison between these LCA studies, the summaries given in the next chapters have been established according to the same structure:

- Scope and goal of the study,
- LCA methodology,
- Functional unit,
- System boundaries for the comparison of the recovery options,
- Technological representativeness and sources of data,
- Data quality,
- Environmental impact categories,
- Main Results,
- Sensitivity analysis,
- Main conclusions of the authors.

[34] No other study as comprehensive as this one on that subject is available

Brief Description of the Studies under Consideration

Ref.	Title of the study	Date[35]	Commissioner	Practitioner	Critical Review	Scope	Documents analysed in this study
NOR 95 [16]	Burning or Re-refined used lube oil?	1995	The Norwegian Environmental Protection Agency (Norway)	Oestfold Research foundation (Nw)	No	Comparative impact assessment (LCA) of burning and regeneration	Summary report (EN), 32 pages
CON 96 [19]	Collection and disposal of used lubricating oil	1996	CONCAWE (The Oil Companies' European organization for environment, health and safety)	Internal CONCAWE (B)	Not an LCA	Cost-effectiveness study. Data about CO_2 emissions from burning and regeneration treatment	Full report (EN), 108 pages
GER 97 [18]	WO - Fuel or lubricant? Examination for precedence in accordance with the waste recycling act	1997	Lower Saxony Minister of the Environment + Mineralöl-Raffinerie Dollbergen GmbH (MRD) (Germany)	Ökopol GmbH, Hamburg (D)	No	Comparative impact assessment (LCA) of burning and regeneration	Summary report (EN), 31 pages.
FIAT 97 [20]	Environmental and economic impact of re-refined products: a life cycle analysis	1997	Centro Ricerche FIAT (Italy)	Internal FIAT (I)	No	Comparative assessment (LCA) of two regeneration processes (clay treatment vs hydrofinishing treatment)	Summary report (EN), 13 pages
UBA 00 [17]	Ökologishe Bilanzierung von AltölVerwertungswegen - Ökologisher Vergleich von vier wichtigen Altölwertungsverfahren	2000	Umweltvundesamt (Federal Environmental Agency -UBA), Germany	IFEU - Institut für Energie- und Umweltforschung GmbH, Heidelberg (D)	Pr. Grahl (Heidekamp), Pr. Hedden (Karlsruhe), Dr. Möller (Hamburg) (D)	Comparative impact assessment (LCA) of burning, regeneration and chemical recycling	Full report (GER) including appendix, 170 pages
ADM 00 [21]	Recyclage et Valorisation énergétique des huiles usagées - Atouts et faiblesses	2000	ADEME (Agence de l'Environnement), France	Ecobilan SA (Ecobalance Group – PriceWaterhouseCoo-pers), Paris (F)	BIO Intelligence Service (F) + TNO (NL) + INSA-Lyon (F) + Ecole des Mines (F)	Impact assessment (LCA) of burning. Impact assessment of regeneration and recycling. Comparative analysis.	Summary report (FR), 68 pages + Full report (150 pages) + Appendix (150 pages)

35 the date of the report (not of the data)

10.2 'Burning or Re-refining Used Lube Oil? - Life Cycle Assessments of the Environmental Impacts' [16], 1995 (Norway)

- Scope and goal of the study

A screening LCA was carried out in order to compare the environmental impacts and the resource consumption of the following two product systems:

- the burning system: lubricant production and use and WO burning,
- the regeneration system: lubricant production and use and WO regeneration.

- LCA methodology

The project was carried out as a screening LCA, in accordance with LCA methods described in the manual 'Nordic Guidelines on LCA' developed by the Nordic Council of Ministers.

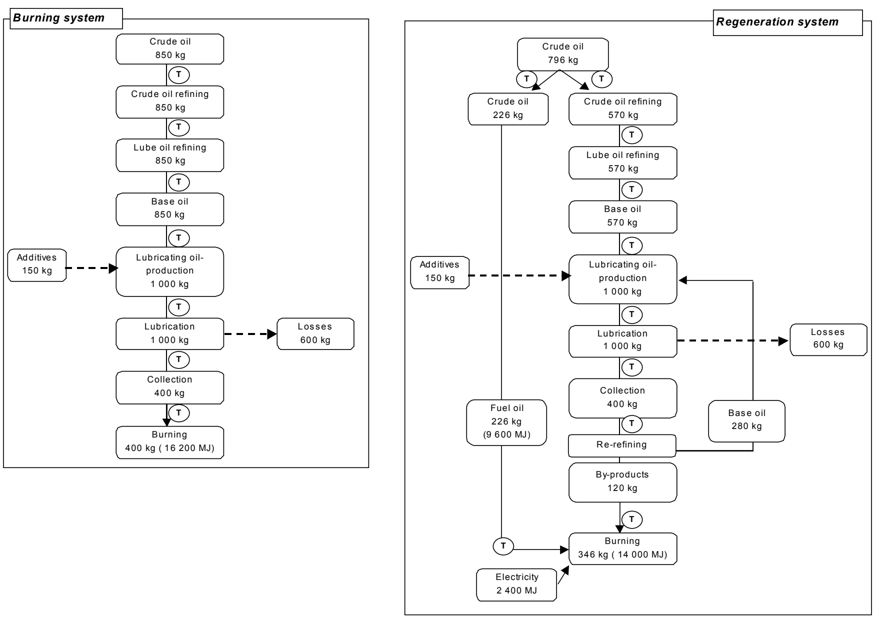
The data in this project were analysed using the LCA Inventory Tool computer program, developed by Chalmers Industriteknik in Gothenburg, Sweden.

- Functional unit

1000 kg of lubricant.

For the selection of the functional unit, the current method of burning WO has provided the starting point. The collected WO are currently burned in approved WO burning plants, which generate a certain amount of energy. If regeneration of the WO to base oil takes place, it is assumed that the burning plants will have to replace the losses of WO partly with fuel oil and partly with electricity (the selection of these alternative energy resources were based upon inquiries about the burning process).

- System boundaries and comparability of the systems



The LCA was carried out with respect to these two systems and the comparison was made on the basis of a common functional unit.

According to the authors, the arrangement of adding energy to the regeneration system in the form of fuel oil and electricity in order to achieve equal functionality (lubrication + energy utilisation), made it possible to compare the two product systems.

The functionality, quality, life span, and number of lubrication intervals were assumed to be the same for the virgin lubricant and the re-refined lubricant.

In both systems, 3 process units are excluded from the life cycle inventory: the losses of WO, the additives production (see hereafter), the burning process.

- Technological representativeness and sources of data

The analysis was limited to a screening LCA, i.e. an analysis based upon the best available data and information with no extensive new analyses.

Crude oil is produced then processed in a crude oil refinery, followed by processing in a lube oil refinery. Discharges data from the crude oil refining was derived from a previous analysis performed for Statoil (Nov. 1993). In the lube oil refining process it was assumed that base oil make up one of many valuable products (no yield).

No lube oil refining is performed in Norway. Esso refines oil in many countries. Most of Esso's products in Norway are refined in France. Specific data were obtained from Esso Norge (data certainly from 1994).

Due to the lack of data about the additives production (an average of 15% of the product), the screening analysis does not include the contributions from the additives. Since these are present in both product systems, this only causes minor deviation.

The burning system: data are derived from Nordic WO burning plants. It was assumed that the WO burning plants do not have scrubbers installed to reduce the emissions of CO_2 from the process. No more detail is given (yield of the process, gas cleaning treatment…).

The regeneration system: it was assumed that the lack of energy generated compared to the burning system was compensated by heavy fuel oil and electricity. An investigation of the current WO burning plants has conducted to the values given in the Figure.

- Data quality

Not discussed in the report.

Environmental impact categories

The computation methods are detailed in appendix.

The environmental impact categories selected are:

- global climate change,
- acidification,
- VOC emissions,
- CO emissions,
- fossil energy resources,
- eutrophication,
- waste disposal.

Main results

Environmental impacts	Burning	Regeneratio n	% difference
Fossil energy resources (MJ / kg of oil)	47.08	42.46	10%
Global Warming Potential (kg eq CO2 / kg of oil)	3.87	3.19	18%
Acidification Potential (g eq. H+/ kg of oil)	0.29	0.06	79%
VOC emissions (g / kg of oil)	13.50	9.05	33%
Eutrophication Potential (g COD-/ kg of oil)	39.12	35.02	10%
CO emissions (g CO / kg of oil)	10.21	9.74	5%
Waste (g / kg of oil)	411	411	0%

Poly-aromatic hydrocarbons (PAH) used to be a problem in re-refined base oils from a health and environmental point of view. These are formed during incomplete combustion of organic matter. PAH are relatively difficult to break down, but when they are separated epoxides are formed, which attack DNA and may cause the development of cancer. However, recent tests indicate that it is possible to remove PAH in the regeneration process of modern plants, thus avoiding the accumulation of PAH.

Quality of re-refined lubricant: DEA Mineral Oil in Germany has performed research on re-refined base oil and concluded that with respect to their required quality and specifications, the re-refined base oil quality was better than the virgin base oil.

Sensitivity analysis

None.

■ Main conclusions of the authors

The valuation methods indicate that the following environmental impacts are the most important ones:

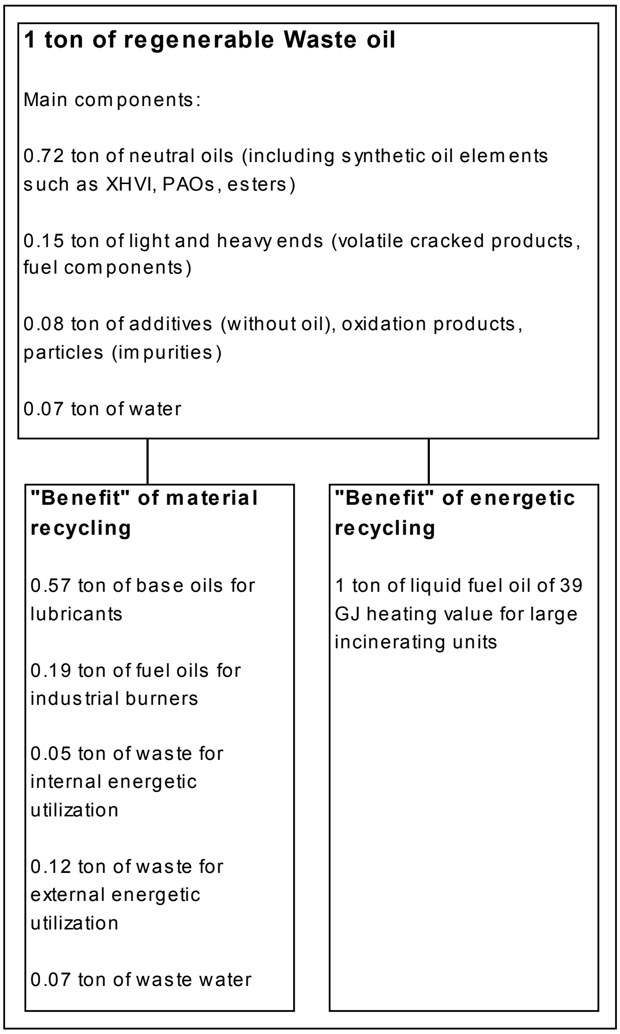
- consumption of fossil energy resources,
- contribution to climate change,
- emissions of volatile organic compounds (VOC).

The conclusions of the authors are: 'Based upon the specified conditions and material flows, the analysis indicates that the regeneration system contributes less to the environmental impacts than the burning system does, with respect to all evaluated environmental parameters. ... The LCA demonstrates that environmental improvements will be obtained by regenerating WO into base oil, instead of burning WO in order to generate energy.'

10.3 'WO - Fuel or Lubricant?', Examination for Precedence in Accordance with the Waste Recycling Act [18], 1997 (Germany)

- Scope and goal of the study

In spring 1995, Ökopol GmbH was tasked by the Lower Saxony Ministry of the environment and Mineralöl-Raffinerie Dollbergen GmbH (MRD) to investigate in how far the recycling of WO should be given precedence over burning as required by the Waste Recycling Act.



The modes of utilisation considered for WO are:

- the regeneration by distillation to base oils (the regeneration system),
- the direct use as a secondary fuel in large incinerating plants (the burning system).

- Methodology

The project was carried out as an ecobalance study, which is based on the methodological framework of LCA.

- Functional unit

  1000 kg of regenerable WO (category 1).

- System boundaries and comparability of the systems

  In order to achieve comparability of both systems (recycling vs burning), it is assumed that those products which are not produced through waste recovery have to be produced from primary raw materials.

  One metric ton of collected WO can substitute either for an appropriate quantity of industrial fuel (39 GJ) or for the pre-products for the production of lubricants (0,57 ton). If one of these options is chosen the respective other product (so-called "complementary product") cannot any longer be produced from the WO but has to be made from primary raw material.

  With respect to the regeneration system, the WO substitute 0,57 t of base oil made from virgin crude oil. This value define the complementary product of the burning system as 0,57 t of base oil made from virgin crude oil.

  With respect to the burning system, the WO produce 39 GJ of heating value for large incinerating plants. As to its composition and combustion parameters WO burnt directly (i.e. without any reprocessing) can be compared with medium-viscosity heavy residual fuels from primary refining which are likely used in big incinerators in Germany. This value define the complementary product of the regeneration system as 39 GJ of heavy residual heating oils which are produced from primary crude oil refining.

  The system boundaries of the two options (regeneration versus burning) are designed to form complete comparable scenarios which yield an equivalent benefit, as they encompass all the potential benefit of material recycling and energetic recovery from 1000 kg of WO:

  - The regeneration system
    - the recovery of 1000 kg of WO (category 1),
    - the production of 570 kg of base oil from WO regeneration,
    - the production of fuels (39 GJ of heating value) from primary raw materials [complementary product].
  - The burning system
    - the recovery of 1000 kg of WO (category 1),
    - the production of 570 kg of base oil from primary raw materials (virgin base oil refining) [complementary product],
    - 39 GJ of heating value from WO.

  The system boundaries do not include the process units which are assumed to be common in the both systems:

  - WO collection,
  - lubricant formulation,
  - industrial burning.

- Technological representativeness

  The product range and the yield ratio are well detailed and based on the recycling systems installed at Mineralöl-Raffinerie Dollbergen GmbH (technology: thermal distillation - no more details).

  To ensure a high technical quality of the study, the method of ecobalancing and the basic data used were discussed with WO recycling firms as well as with the petroleum industry represented by the Mineralöl-Wirtschaftsverband (MWV), the German cement industry represented by the Forschungsinstitut der Zementindustrie (FIS) as well as the Federal Ministry of the Environment (BMU) and the Federal Environmental Agency (UBA).

  A quantitative description of those fuels actually substituted by WO is not available and could not be considered constant due to price fluctuations in the fuel market. The study covers separately two types of primary fuels which can be substituted to WO: fuel oil (scenario 1a) and coal (scenario 1b). This is an example from real life since coal dust constitutes about 69% of the primary fuels in cement factories (14% of heating oils/natural gas, 9% of solvents and various WO, 8% of used tires).

  The geographical distribution of existing units utilising WO is not considered within the scope of the system comparison (as the logistics of collection do not differ in both scenarios investigated).

- Sources of data
  - the assessment of the WO regeneration process was based on data (1995) found by Ökopol during an extensive input-output analysis at Mineralöl-Raffinerie Dollbergen.
  - For the field of virgin base oil refining, a set of data was used which was co-ordinated with virgin base oil refiners and which reflects the situation in German refineries sufficiently well.
  - The data on mineral oil production and transport as well as on crude oil refining were taken from appropriate literature.
  - The data on other fuel production and transport were taken from an appropriate data source (GEMIS).
  - No data from energy recovery plants were needed as the combustion process itself was implicitly excluded from the system boundaries.

- Data quality: not discussed.

- Environmental impact categories
  - total primary energy consumption (MJ / ton of WO)
  - global warming potential (kg eq. CO_2/ ton of WO)
  - acidifying potential (kg eq. SO_2 / ton of WO)
  - fuels consumption (kg / ton of WO)
  - water consumption (kg / ton of WO)
  - waste production (kg / ton of WO)

  Besides the classical environmental indicators covered in LCA reports, this study covers an interesting discussion about short- and long-term accumulation of pollutants due to regeneration (PAH, VOC, metals).

- Main Results

In the scenario 1a, the 39 GJ of heating value are produced from virgin crude oil refining; in the scenario 1b, they are produced from coal.

WO Regeneration versus Direct burning (1/2)

primary energy consumption (MJ / t of waste oil input)

Scenario 1 : Waste Oil Regeneration

waste oil collection	868
waste oil regeneration	2386
crude oil production (transportation)	594
crude oil refinery	520
total scenario 1a	**4368**

waste oil collection	868
waste oil regeneration	2386
coal (mining, transportation)	4300
coal mill	462
total scenario 1b	**8016**

Scenario 2 : Direct Burning

waste oil collection	868
crude oil (production, transport)	826
crude oil refining	826
virgin base oil refining	3968
total scenario 2	**6488**

Global Warming Potential (kg eq. CO2 / t of waste oil input)

Scenario 1 : Waste Oil Regeneration

waste oil collection	30
waste oil regeneration	167
crude oil production (transportation)	55
crude oil refinery	41
total scenario 1a	**293**

waste oil collection	30
waste oil regeneration	167
coal (mining, transportation)	356
coal mill	35
total scenario 1b	**588**

Scenario 2 : Direct Burning

waste oil collection	30
crude oil (production, transport)	76
crude oil refining	57
virgin base oil refining	296
total scenario 2	**459**

Acidifying Potential (kg eq. SO2 / t of waste oil input)

Scenario 1 : Waste Oil Regeneration

waste oil collection	0.26
waste oil regeneration	0.39
crude oil production (transportation)	0.50
crude oil refinery	0.13
total scenario 1a	**1.28**

waste oil collection	0.26
waste oil regeneration	0.39
coal (mining, transportation)	6.26
coal mill	0.06
total scenario 1b	**6.97**

Scenario 2 : Direct Burning

waste oil collection	0.26
crude oil (production, transport)	0.69
crude oil refining	0.17
virgin base oil refining	0.69
total scenario 2	**1.81**

WO Regeneration versus Direct burning (2/2)

Raw material consumption for fuel (kg / t of waste oil input)

Scenario 1 : Waste Oil Regeneration

waste oil collection	
waste oil regeneration	14
crude oil production (transportation)	943
crude oil refinery	12
total scenario 1a	**969**

waste oil collection	
waste oil regeneration	14
coal (mining, transportation)	1602
coal mill	11
total scenario 1b	**1627**

Scenario 2 : Direct Burning

waste oil collection	
crude oil (production, transport)	1310
crude oil refining	17
virgin base oil refining	38
total scenario 2	**1365**

Process Water consumption (kg / t of waste oil input) [* : unknown]

Scenario 1 : Waste Oil Regeneration

waste oil collection	0
waste oil regeneration	166
crude oil production (transportation)*	
crude oil refinery*	
total scenario 1a	**166**

waste oil collection	0
waste oil regeneration	166
coal (mining, transportation)	0
coal mill	0
total scenario 1b	**166**

Scenario 2 : Direct Burning

waste oil collection	0
crude oil (production, transport)*	
crude oil refining*	
virgin base oil refining	73
total scenario 2	**73**

Waste for disposal (kg / t of waste oil input) [* : unknown]

Scenario 1 : Waste Oil Regeneration

waste oil collection	0
waste oil regeneration	0.70
crude oil production (transportation)	0.01
crude oil refinery	0.24
total scenario 1a	**0.95**

waste oil collection	0
waste oil regeneration	0.70
coal (mining, transportation)*	
coal mill*	
total scenario 1b	**0.70**

Scenario 2 : Direct Burning

waste oil collection	0
crude oil (production, transport)	0.02
crude oil refining	0.33
virgin base oil refining	0.08
total scenario 2	**0.43**

Waste for utilization (kg / t of waste oil input) [* : unknown]

Scenario 1 : Waste Oil Regeneration

waste oil collection	0
waste oil regeneration	160.50
crude oil production (transportation)	1.09
crude oil refinery	3.25
total scenario 1a	**164.84**

waste oil collection	0
waste oil regeneration	160.50
coal (mining, transportation)*	
coal mill*	
total scenario 1b	**160.50**

Scenario 2 : Direct Burning

waste oil collection	0
crude oil (production, transport)	1.51
crude oil refining	4.51
virgin base oil refining	0
total scenario 2	**6.02**

With respect to accumulation of pollutants (PAH, metals, dioxins), there are no clear advantages for one of the two routes for WO.

- Sensitivity analysis

The effects of some essential variations have been studied, but are not described here as they do not modify the hereafter conclusions.

- Main conclusions of the authors

For all the environmental indicators assessed in this study (except for two indicators: overall waste production and water consumption), WO regeneration is significantly more environmentally friendly than direct burning in the case where the heating value of WO replaces residual fuels from crude oil refining. But in the case where the substituted fuel is coal, the results would be reversed for almost all environmental indicators.

The clearly recognisable differences of the balance results for Scenario 1a and Scenario 1b demonstrate the high importance of the selection of complementary products within the scope of scenario determination. The authors concluded that "the unambiguity of the results of the examination cannot be guaranteed" (as the results of the comparison between the regeneration and the burning options are primarily dependent on the selection of complementary products within the scope of scenario determination: WO instead of either coal or crude oil products).

10.4 'Recyclage et Valorisation Energétique des Huiles Usagées - Atouts et Faiblesses' [21], 2000, ADEME (F)

■ Scope and goal

The French Environment Agency has been commissioned by the French Ministry of Environment in 1995 to compile environmental data about the collection and the disposal of WO in France.

The aim of the study was to determine the environmental benefits and drawbacks of a five of WO disposal routes currently in use or under development, by using the LCA methodology.

The study conducted in 1997 and 1998 has been followed by a technical board (with ADEME and interested parties).

Five WO disposal options have been compared:

- Two of them are representative of the current situation in France:
  - Regeneration with vacuum distillation + clay treatment,
  - Incineration in a cement kiln.
- Three options are either developed in other countries or under development in France on a small scale:
  - Regeneration by direct contact with hydrogen,
  - Incineration in road limestone coating plants,
  - Refinery recycling.

■ LCA methodology

The data in this project was analysed using the LCA Inventory Tool computer program, developed by Ecobilan (Team™ using the database Deam™).

With respect to ISO 14040, a critical review has been conducted prior to disclose comparative assertions to the public; this critical review has been performed in 1999 by four external, independent experts co-ordinated by BIO Intelligence Service.

■ Functional unit

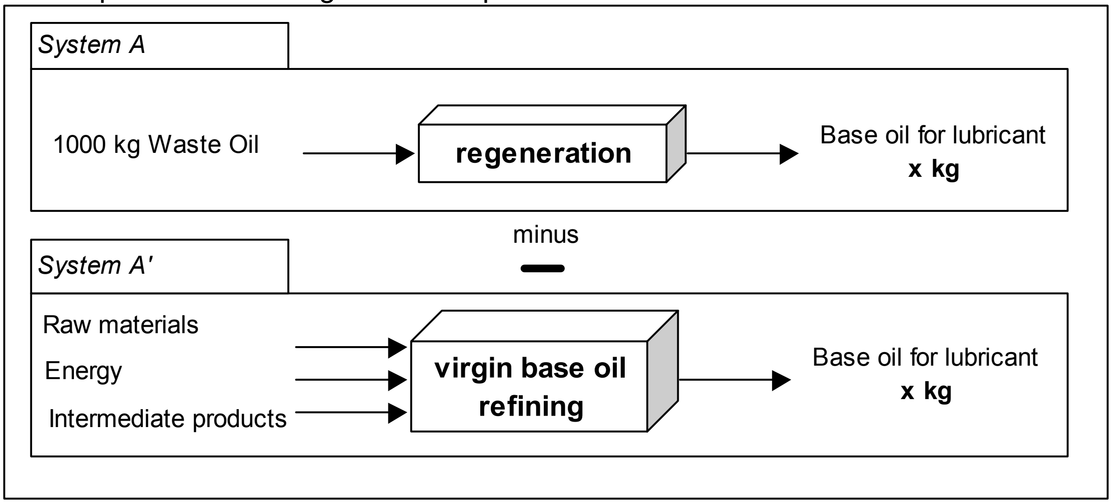
'Disposal of 1000 kg of WO available from a collector plant'.

■ System boundaries and comparability of the systems

The collection of WO is not included in this study as this process remains the same for the five options under comparison. The methodological basis for the comparison between disposal options are as follows:

- the products obtained within a WO material recovery option (for instance re-refined base oils) lead to the saving of the equivalent products obtained from raw materials (saved oils from crude oil refinery and lube oil refinery);
- in a burning option, the energy output from WO incineration lead to the saving of primary fuels;
- the above savings are taken into account by subtracting the avoided impacts from their alternative route.

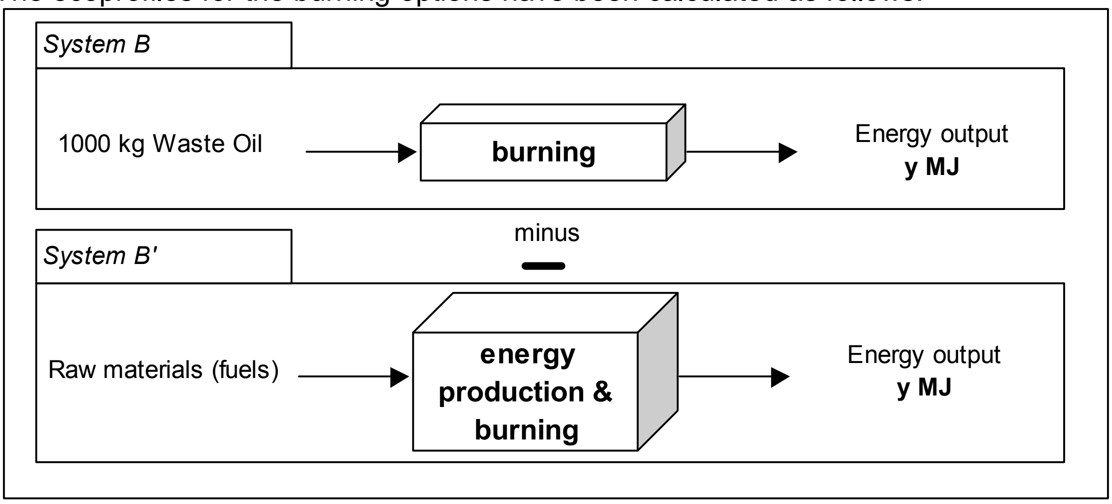
The ecoprofiles for the regeneration options have been calculated as follows:



With respect to the system A', the box "virgin base oil refining" is described by considering all the unit processes from crude oil extraction to the production of base oil for lubricant.

The system A describes two functions (objectives): 1°) the disposal of 1000 kg WO, and 2°) the production of x kg of base oil. The system A' describes one function: the production of x kg of base oil. Thus, the overall system (A-A') has been designed to reduce the system to only one function: the disposal of 1000 kg WO.

The ecoprofiles for the burning options have been calculated as follows:



With respect to the system B', the box "energy production & burning" is described by considering all the unit processes from raw materials extraction to the use of y MJ in a burning plant (the raw materials considered are described in the next table as "primary fuels saved").

The system B describes two functions: 1°) the disposal of 1000 kg WO, and 2°) the combustion of y MJ (from WO) in a burning plant. The system B' describes one function: the combustion of y MJ from primary fuels. Thus, the overall system (B-B') has been designed to reduce the system to only one function: the disposal of 1000 kg WO.

The two ecoprofiles (regeneration and burning) are thus comparable because they describe the same and unique function (the disposal of 1000 kg WO).

Remark: due to the methodological framework used in this study, each environmental indicator may be either positive (environmental disadvantage when the recovery option generates a greater impact than the avoided process) or negative (environmental benefit when the recovery option generates a lesser impact than the avoided process).

- Technological representativeness and sources of data

WO content is representative of the content of WO collected in France in 1996.

Option	Technolo-gy	Represe ntative-ness	Source of data	Date of data	Capacity (t/y)	Products and by-products (kg for 1000 kg of input WO)
Regeneratio n (Rfa)	Vacuum distillation + clay treatment	currently used in France	Eco-Huile company (Lillebonne, Fr) Long-time company	1996 -1997	90 000	Base oil: 500 Gazole: 90 Heavy Fuel oil: 90 Bitumen fluxant: 110
Regeneratio n (Rch)	Hydrogen pre-treatt + vacuum distillation (UOP process)	Under develop-ment in USA	Pilot scale from Puralube Inc. (USA)	1997	80 000 (provided)	Base oil: 780 Heavy fuel oils: 90 Bitumen fluxant: 56
Recycling (Rra)	Refinery recycling	Under develop-ment in France	Estimated data from laboratory tests (French Union of Oil Industrials) in a Total's refinery (Gonfreville, Fr)	1994	50 000 (provided)	Vacuum gas oil: 850 Light chlorinated fuel oil: 55
Burning (Vci)	Cement kilns	Currently used in France	Average data from 3 plants owing to Lafarge Ciments (dry process)	1996	nd	Primary fuels saved (average data from 15 French cement kilns in 1996): Crude oil coke: 60% Tar oil: 29% Coal: 11% (other scenarios have been studied)
Burning (Vce)	Asphalt plants	Currently used in UK	Data from Orco fuels Ltd (UK plants) for pre-treatment - ARC Southern (Whatley, UK) for burning. Completed by US EPA and Italian data.	1996	65 000	Primary fuels saved: UK: Gas-oil: 100% France: Heavy fuel oil: 75% Natural gas: 25%

NB: tar oil has been described as bitumen (cf Vci Option).

All the process trees are well described in the report.

With respect to the base oil refining process (the avoided process in the regeneration system), data were derived from the Dunkerque's refinery (1996) which is managed by several companies: Elf, BP and Mobil. Data from this refinery have been judged sufficiently representative by an industrial expert. With respect to the other avoided processes, data are representative of the average of west European plants (1992-93).

- Data quality

detailed in the report**.**

- Environmental impact categories

The summary report gives a comparative assessment of the options under consideration with respect to the following environmental impacts (which are stated to be of main importance):

- total primary energy consumption and fossil fuel consumption,
- water consumption,
- global climate change,
- acidification,
- health effects of emissions (human toxicity),

It is stated that waterborne emission may be negligible in this study (within the five options there is no important water treatment). In the full report, the following indicators are also detailed:

- mercaptans emissions to air,
- carbon monoxide (CO) emissions to air,
- particles emissions to air,
- suspended matter discharged into water,
- dissolved matter discharged into water,
- eutrophication (water),
- total waste production.

Main Results

The complete life cycle inventories are detailed in the report.

Impact Assessment of WO Recovery Options (Reference Scenario) as Presented by the Authors in the Summary Report of the Study

Rfa: Regeneration with vacuum distillation + clay treatment
Rfa optim.: Rfa with high performance
Rch: Regeneration with hydrogen pre-treatment + vacuum distillation
Rra: Refinery recycling
Vci: Burning in cement kilns
Vce: Burning in asphalt plants

	Regeneration options				Burning options		
values for 1000 kg WO	**Rfa**	**Rfa improved**	**Rch**	**Rra**	**Vci**	**Vce**	comments
Primary energy (GJ)	-40	-40	-40	-40	-55	-40	- saving for every option - low difference between options by comparison with the total energy saving
Fossil fuel consumption (kg) (method 2)	-1000	-1000	-1000	-1000	-1400	-1000	- saving for every option ; - advantage for the cement kiln
Fossil fuel consumption (MJ)	1100	-2200	-1600	-1500	-9000	-3200	- saving for every option except Rfa ; - advantage for the cement kiln
Water consumption (t)	-30	-30	-50	0	-25	0	- saving for every option ; - high values due to the refinery choosen to modelise oil production ; -Vce : bad value due to the source of data for light fuel production
Climate change (GWP, kg eq CO2)	100	-150	-200	-50	-1200	-200	- robust ranking, according to the energetic yield of the different options ; - the difference between Vci and the other options is however depending on the allocation rule for the refinery ; - the regeneration can be improved with hydrogen finishing (Rfa improved)
Acidifying potential (AE, g eq SO2)	-100	100	-300	0	-300	50	- good result for the Rch option, due to the capture of sulfur by hydrogen ; - bad result for the Vce option because it is assumed that the used oils replace a fuel with a low content in sulfur.
Hydrocarbons to air (g)	-3000	-3000	-3000	-1000	-7000	-7000	- saving for every option, correlated to the energetic balance
Particles to air (g)	-100	-150	-200	-200	-400	-200	- saving for every option, correlated to the energetic balance
Toxicity (USES, kg eq 1-4 dichlorobenzene) to humans and ecosystemes							- poor reliability of the indicator (values are not display) ; - the heavy metals in used oils are the major contributors ; -risk assessment would be useful for this impact category.
Eutrophication potential (g eq PO4)	10	10	10	0	-10	0	- very low values for every option ; - this indicator is not useful to differenciate the options (low values and data uncertainty).
Solid waste (kg)	0	0	0	0	-100	0	- very low values (except for Vci) ; - this indicator is not useful to differenciate the options.

Remark concerning the 'fossil fuel consumption' indicator

Two methods exist to calculate that indicator:

- a simple addition of the mass of fossil fuels entering the processes (1 MJ of coal is similar to 1 MJ of crude oil for instance).

  This method is the one used in the ADEME study.

  This method is referred as 'method 2' in the previous table.

- the weighting of every fossil fuels according to its relative rarity (natural gas: 0.62, oil: 1, coal: 0.0409, lignite: 0.1836). By this way, the total input of fossil fuels depends on the energy sources at the energy recovery plant.

  This method is the one used in the UBA (2000) study.

  This method is referred as 'method 1' in the table in chapter 10.5 hereafter (UBA 2000 study).

For this indicator, the relative positioning of regeneration versus incineration strongly depends on the method used.

'Method 2' is more beneficial in the incineration scenario. This is consistent with the ADEME study, and may also be derived from the UBA study's data.

In the UBA study where 'method 1' is used, the relative positioning of both management options depends on the energy sources at the incineration plant. For instance, for the cement kiln, it is lower in the case of regeneration in the UBA study (as coal and lignite are the predominant primary fuels in cement kilns, the energy recovery from WO would replace fossil fuels with a low contribution to this impact), but it remains lower in the case of incineration in the ADEME study (as oil is the essential primary fuel in cement kilns, the WO replace fossil fuels with a high impact).

More Details about the Impact Assessment of WO Recovery Options (Reference Scenario) (Extracted From the Complete Report)[36]

Rfa:	regeneration with vacuum distillation + clay treatment
Rfa optim.:	Rfa with high performance
Rch:	regeneration with Hydrogen pre-treatment + vacuum distillation
Rra:	Refinery recycling
Vci:	Burning in cement kilns
Vce:	Burning in asphalt plants

values for 1000 kg WO	**Rfa**	**Rfa optim.**	**Rch**	**Rra**	**Vci**	**Vce**
Fossil fuel consumption (kg / 1000 kg of waste oil)	- 1 000	- 1 000	- 1 000	- 1 000	- **1 400**	- 1 000
Total energy from fossil fuel (MJ /1000 kg of waste oil)	- 1 100	- 2 200	- 1 600	- 1 500	- **9 000**	- 3 200
Total primary energy consumption (MJ / 1000 kg of waste oil)	- 38 000	- 40 000	- 40 000	- 39 000	- **67 000**	- 43 000
Depletion of non renewable ressources (U / 1000 kg of waste	- 55	- 56	- 60	- 55	- **73**	- 56
Water consumption (t)	- 30	na	- **50**	0	- 25	0
Global warming potential 100 y (kg eq CO2 / 1000 kg waste o	108	- 145	- 270	- 57	- **1 180**	- 223
Acidifying potential (g eq. H+ / 1000 kg waste oil)	- 87	113	- **305**	- 14	- **288**	62
Human toxicity potential (g eq 1-4 dichlorobenzene / 1000 kg c	40 000	na	- **3 000**	3 000	8 000	70 000
Eutrophication potential (g eq. PO4 / 1000 kg waste oil)	6	7	5	- 0.2	- **4**	- 0.3
Emissions to air						
particles (g / 1000 kg of waste oil)	- 105	- 138	- 190	- 168	- **378**	- 198
hydrocarbons (unspecified) (g / 1000 kg of waste oil)	- 3 200	na	- 3 800	- 1 400	- **6 700**	- **6 600**
heavy metals (g / 1000 kg of waste oils)	0.6	na	-	-	**0.1**	**0.1**
Emissions to water						
suspended matter (g / 1000 kg of waste oil)	-32.7	-32	-75.3	-59	-114.2	-5.6
Waste production						
hazardous waste (kg / 1000 kg of waste oil)	-0.4	-0.4	-0.5	0	-0.6	0
total waste (kg / 1000 kg of waste oil)	-2.1	-2.0	0.9	-1.2	**-101**	-0.8

[36] The differences between some figures of the table extracted from the summary report (see above) and that table extracted from the complete report correspond to the approximations made by the authors and thus reflect the relevance level of the figures considered by the authors.

■ Sensitivity analysis

- Primary fuel saved in the burning option

Impact Assessment of the Burning Option in a Cement Kiln Depending on the Primary Fuels Saved

	Primary fuels saved in cement kilns			
	reference (3:1:6)	**100% coal**	**100% coke oil**	**100% tar oil**
Fossil fuel consumption (kg / 1000 kg of waste oil)	- 1 400	- 1 600	- 1 400	- 1 100
Total energy from fossil fuel (MJ /1000 kg of waste oil)	- 9 000	- 4 500	- 11 000	- 6 800
Total primary energy consumption (MJ / 1000 kg of waste oil)	- 67 000	- 133 000	- 61 000	- 54 000
Depletion of non renewable ressources (U / 1000 kg of waste	- 73	- 6	- 88	- 68
Global warming potential 100 y (kg eq CO2 / 1000 kg waste o	- 1 180	- 810	- 1 475	- 710
Acidifying potential (g eq. H+ / 1000 kg waste oil)	- 288	- 20	- 365	- 230
Human toxicity potential (g eq 1-4 dichlorobenzene / 1000 kg c	8 000			
Eutrophication potential (g eq. PO4 / 1000 kg waste oil)	- 4.3	0.01	- 5.2	- 4.1
Emissions to air				
particles (g / 1000 kg of waste oil)	- 378	- 175	- 450	- 307
hydrocarbons (unspecified) (g / 1000 kg of waste oil)	- 6 700			
heavy metals (g / 1000 kg of waste oils)	0.1			
Emissions to water				
suspended matter (g / 1000 kg of waste oil)	-114.2	-0.2	-138.4	-106.9
Waste production				
hazardous waste (kg / 1000 kg of waste oil)	-0.6	-0.001	-0.8	-0.6
total waste (kg / 1000 kg of waste oil)	-101	-887	-5	-4

Impact Assessment of the Burning Option in an Asphalt Plant Depending on the Primary Fuels Saved

Reference: gasoline - UK context

French context: 75% of heavy fuel oil + 25% of natural gas

	Primary fuels saved in asphalt plants	
	reference (gasoil)	**french context**
Fossil fuel consumption (kg / 1000 kg of waste oil)	- 1 000	- 1 010
Total energy from fossil fuel (MJ /1000 kg of waste oil)	- 3 200	- 3 500
Total primary energy consumption (MJ / 1000 kg of waste oil)	- 43 000	- 43 000
Depletion of non renewable ressources (U / 1000 kg of waste	- 56	- 71
Global warming potential 100 y (kg eq CO2 / 1000 kg waste o	- 223	- 210
Acidifying potential (g eq. H+ / 1000 kg waste oil)	**62**	**- 357**
Human toxicity potential (g eq 1-4 dichlorobenzene / 1000 kg c	70 000	
Eutrophication potential (g eq. PO4 / 1000 kg waste oil)	- 0.3	- 0.2
Emissions to air		
particles (g / 1000 kg of waste oil)	- 198	- 157
hydrocarbons (unspecified) (g / 1000 kg of waste oil)	- 6 600	
heavy metals (g / 1000 kg of waste oils)	0.1	
Emissions to water		
suspended matter (g / 1000 kg of waste oil)	-5.6	- 21.5
Waste production		
hazardous waste (kg / 1000 kg of waste oil)	0	0
total waste (kg / 1000 kg of waste oil)	-0.8	-2.4

- Allocation procedure

  Crude oil is extracted then processed in a crude oil refinery. A crude oil refinery yields several products: coke, base oil, heavy fuel, gas-oil, vacuum residue, distillation residue, asphalt (tar oil), plant fuel, jet fuel…. Therefore, the materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures.

  In this study (as well as in most of the LCA studies), input and output data have been allocated between co-products in proportion to the mass value of the products (‘massic’ or weight-based allocation). This ‘massic’ procedure may be criticised as it induces an overvaluation of the impacts due to either coke or asphalt (tar oil) because these co-products may be indeed considered as refinery's waste.

  In order to illustrate the impact on the results that the choice regarding the allocation procedure can have, we have carried out a simulation with other allocation rules: the economic allocation, which is another allocation procedure often used by LCA experts, e.g. to perform a sensitivity analysis. The inputs (consumptions) and outputs (releases) have been partitioned between co-products in proportion to the economic value of the products.

Simulation: Economic Imputation of Refinery Co-Products

	Rfa	Rch	Rra	Vci
Fossil fuel consumption (kg / 1000 kg of waste oil)	- 839	- 984	- 824	- 554
Total energy from fossil fuel (MJ /1000 kg of waste oil)	1 400	- 1 700	- 1 200	- 4 000
Total primary energy consumption (MJ / 1000 kg of waste oil)	- 33 000	- 38 000	- 33 000	- 32 000
Depletion of non renewable ressources (U / 1000 kg of waste	- 48	- 87	- 47	- 23
Global warming potential 100 y (kg eq CO2 / 1000 kg waste o	119	- 283	- 45	- 840
Acidifying potential (g eq. H+ / 1000 kg waste oil)	- 80	- 310	- 7	- 123
Eutrophication potential (g eq. PO4 / 1000 kg waste oil)	4.4	7.9	- 7.0	- 1.7

Waste production

hazardous waste (kg / 1000 kg of waste oil)	-0.5	-0.7	-0.1	-0.3
total waste (kg / 1000 kg of waste oil)	-2.1	0.7	-1.1	-99

Environmental impacts linked to the oil coke production saved in cement kilns have become negligible (because, when considered as a refinery’s waste, the coke has a very low economic value and thus the portion of inputs and outputs allocated to coke is low too); on the other hand, the environmental impacts linked to base oil have not vary significantly (the devaluation of the atmospheric distillation process is compensated by the overvaluation of the base oil).

Thus the burning option in a cement kiln remains environmentally favourable but the environmental benefits have been significantly lowered (by comparison with results shown previously).

This allocation procedure (based on the economic value of the co-products yielded in a crude oil refinery) reduces the differences in benefits between regeneration and burning in cement kilns.

■ Main conclusions of the authors

- The results show that all the WO recovery options under consideration are favourable in terms of environmental impacts (by comparison with a 'do nothing' system).
- With respect to the five options, emissions to water and waste production are not a major aspect of the environmental impacts associated to WO recovery.
- The most important environmental impacts due to the WO recovery options are stated to be both atmospheric emissions and fossil fuel consumption.
- Some general considerations regarding health effects associated to air emissions have been discussed but a detailed risk analysis would be needed.

Comparative impact assessment:

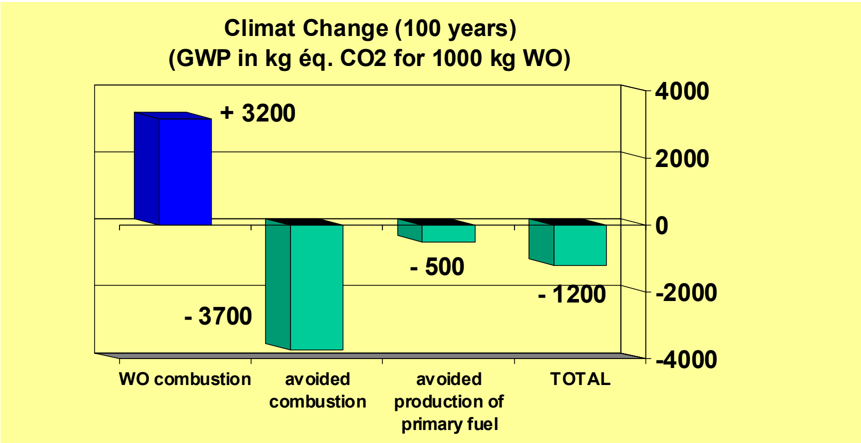
- For almost all the environmental impacts under study, the difference between two recovery options is more essentially determined by the avoided processes rather than the treatments themselves: the recovery process is less important by itself than the avoided process.

  It shall also be noted that the impacts of transport are negligible compared to the impacts of the industrial processes.

  As an illustration, the figures hereafter show the major sources of climate change in the regeneration and the burning in cement kiln system. The two figures give a similar pattern: within a life cycle perspective, the total contribution of the management system under consideration is the result of the difference between two different quantities: the impact of the recovery treatment minus the impact of the main avoided system.

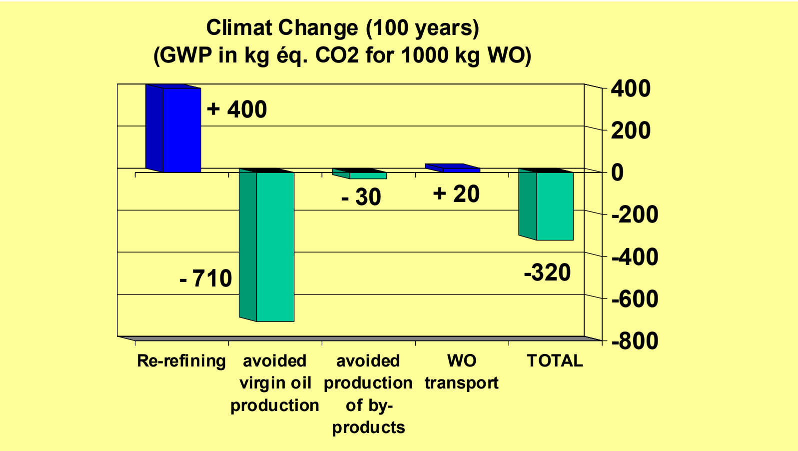
Impact of the Regeneration System on Climate Change

Prospective scenario (Rch): the most favourable of the technologies under LCA studies



Impact of the Incineration System on Climate Change

Scenario Vci



Note that the additional impact caused by the recovery treatment itself (regeneration or incineration) is 8 times lower in the regeneration system (+400 kg eq CO_2 / 1000 kg WO) than in the incineration system (+3200 kg eq CO_2 / 1000 kg WO).

- With respect to the energy indicator (primary energy consumption), the authors indicate that the most favourable option is the burning in cement kilns. And several indicators are linked to the energy indicator, especially the global warming potential.
- For most of the impact categories, the burning in asphalt plants is closer to regeneration. For 2 categories, the acidifying potential and the potential toxicity of air emissions, the impact of the burning in asphalt plant is positive. However, as for the acidifying potential, it is greatly dependent upon the saved primary fuel: the above conclusion is acceptable within the UK context (fuels saved are 100% gas-oil) but it is reversed in the France context (fuels saved are: 75% heavy fuel oil and 25% natural gas). Therefore, this option would be more favourable in France than in UK.
- The regeneration option currently in used in France (Rfa) can be improved (energy recovery of by-products, reducing the energy consumption for the treatment, selecting primary fuels with a low content in sulphur, chlorine and metal).
- It is shown that a regeneration option with high performance may become quasi equivalent to a burning option in a cement kiln, except for the global warming potential which remains at the advantage of the burning option in a cement kiln, but not in an asphalt plant (similar benefit with high performance regeneration).
- From the results of the sensitivity analysis, the authors concludes that the former tendencies are sound and significant.

Benefits of the burning option in a cement kiln by comparison with regeneration options:

- fossil fuel consumption (the burning option over-saves 400 kg of fossil fuel for 1000 kg WO).
- depletion of non renewable resources.
- global warming potential (the burning option over-saves 550 to 950 kg of eq. CO_2 for 1000 kg of WO).

Other environmental impacts are more contrasted:

- Depending on the regeneration technology: acidifying potential, eutrophication potential, hazardous waste.
- Depending on the primary fuels saved in cement kilns: total waste, acidifying potential.

10.5 'ÖKOLOGISCHE BILANZIERUNG VON ALTÖL-VERWERTUNGSWEGEN' [17], 2000, UBA (GERMANY)

■ Scope and goal

The aim of the study was to determine the environmental benefits and drawbacks of 4 of WO disposal routes currently in use in Germany, by applying the LCA methodology.

This study, commissioned by the German ministry of the Environment UBA, has been performed by IFEU (Institut für Energie- und Umweltforschung Heidelberg GmbH) and the consultancy agency ARCADIS Trishier & Partner GmbH (AT&P). The study has been followed by a technical board (with UBA and the interested parties).

Four WO disposal options have been compared:

- One of them is representative of the direct burning options (energy recovery): Burning in a cement kiln.
- One option is representative of the regeneration methods (material recycling): Regeneration with vacuum distillation + chemical treatment to base oil.
- One option is representative of the 'thermal cracking' methods (feedstock recycling): Transformation (with thermal and chemical treatment) into lighter fuel oils.
- One option is representative of the gasification process (feedstock recycling): Gasification of WO (end-product: methanol).

■ LCA methodology

The background database was derived from the LCA Inventory Tool computer program, Umberto 3.0.

With respect to ISO 14040, a critical review has been conducted prior to disclose comparative assertions to the public; this critical review has been performed in December 1999 by three external, independent German experts.

■ Functional unit

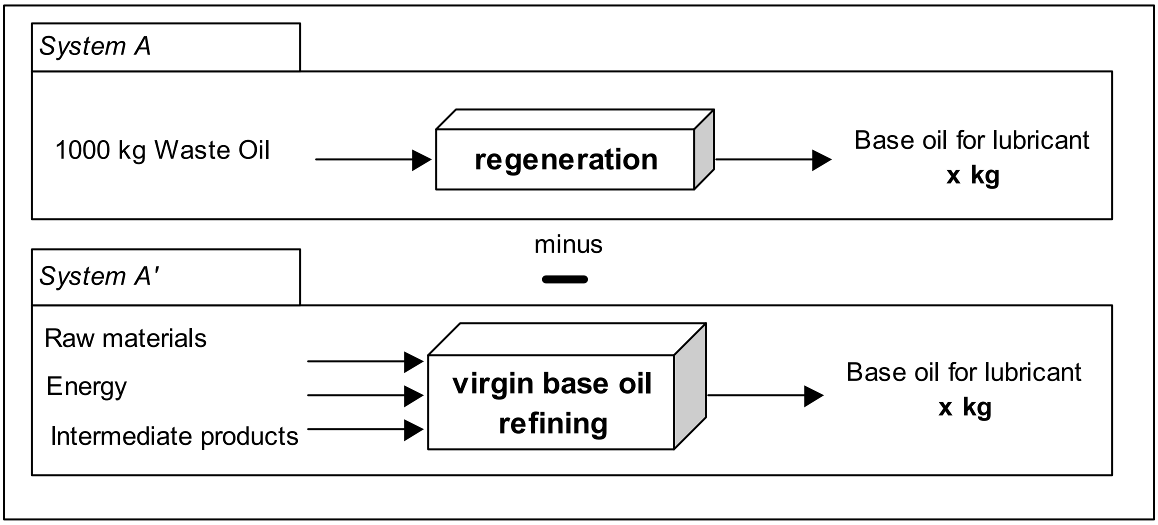
" Disposal of 1000 kg of WO available from a collector plant".

■ System boundaries and comparability of the systems

The collection of WO is not included in this study as this process remains the same for the 4 options under comparison. The methodological basis for the comparison between recovery options is the following:

- the products output from a WO disposal option (for instance re-refined base oils) lead to the saving of the equivalent products obtained by the traditional route (saved oils from crude oil refinery and base oil refinery);
- in a burning option, the energy output from WO burning leads to the saving of the primary fuels usually used for energy recovery (saved primary fuels);
- the above savings are taken into account by subtracting the avoided impacts from their usual route.

The ecoprofiles for the regeneration option have been calculated as follows:

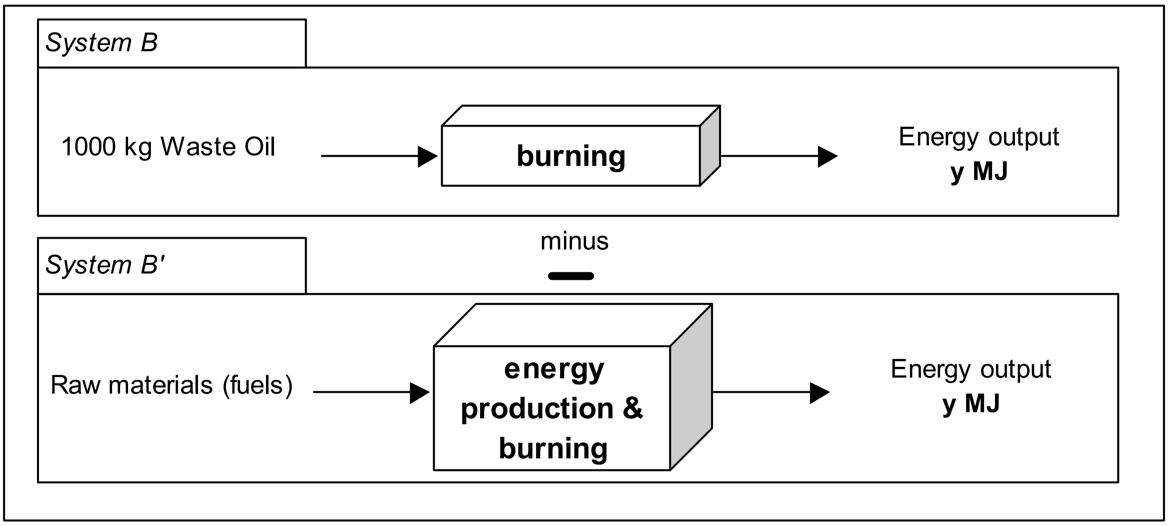


With respect to the system A', the box 'virgin base oil refining' is described by considering all the unit processes from crude oil extraction to the production of base oil for lubricant.

The system A describes two functions: 1°) the disposal of 1000 kg WO, and 2°) the production of x kg of base oil for lubricant. The system A' describes one function: the production of x kg of base oil for lubricant. Thus, the overall system (A-A') has been designed to reduce the system to only one function: the disposal of 1000 kg WO.

The ecoprofiles for the feedstock recycling options have been calculated by using the same methodology than for the regeneration option: the output of the both system A and respectively A' are 'x kg of methanol' and 'x kg of primary fuels', as described in the next table.

The ecoprofiles for the burning option have been calculated as follows:



With respect to the system B', the box 'energy production & burning' is described by considering all the unit processes from raw material extraction to the use of y MJ in a burning plant (the raw materials considered are described in the next table as 'primary fuels saved').

The system B describes two functions: 1°) the disposal of 1000 kg WO, and 2°) the combustion of y MJ (from WO) in a burning plant. The system B' describes one function:

the combustion of y MJ from primary fuels. Thus, the overall system (B-B') has been designed to reduce the system to only one function: the disposal of 1000 kg WO.

The ecoprofiles of every option (regeneration, burning or feedstock recycling) are thus comparable because they describe the same and unique function (the disposal of 1000 kg WO).

Remark: due to the methodological framework used in this study, each environmental indicator may be either positive (detrimental environmental impact when the disposal option generates a greater impact than the avoided process) or negative (environmental benefit when the disposal option generates a lower impact than the avoided process).

- Technological representativeness and sources of data

WO content is representative of the content of WO collected in Germany in 1996.

Technological Representativeness of the Various WO Disposal Options

Option	Technology	Representativity	Source of data	Date of data	Capacity (t/y)	Products and by-products (kg for 1000 kg of input WO)
Regeneration (MRD)	Vacuum distillation + chemical treatment	Currently used in Germany	Dollbergen refinery	1996	130 000	Base oil: 540 kg Fuel oil: 6105 MJ Bitumen fluxant: 48 kg Other fuels: 3720 MJ
Thermal cracking (BKM)	Thermal + chemical treatment (with H_2SO_4)	Currently used in Germany	Baufeld refinery (Chemnitz)	1996	120 000	Fuel oils: 849 kg (32 700 MJ ; (<0.5% S) Secondary fuels: 63 kg Primary fuels saved: 59% EL fuel (0.15% S) 41% S fuel (1% S)
Gasification (SVZ)	Refinery recycling	Currently used in Germany	Schwarze Pumpe + bibliographic data for the avoided process	1996	160 000	methanol: 1080 kg Primary input saved: 75% natural gas 10% heavy oil 15% lignite
Burning (CEM)	Cement kilns	Currently used in Germany (8 sites)	Average data from German plants	1996	170 000 (max: 340 000)	WO: 39 MJ / kg (clinker: 11.3 t / t WO) Primary fuels saved: Crude oil coke: 8% Lignite: 40% Coal: 52% (with 46% imported from South Africa)

All the process trees are well described in the report.

With respect to the avoided processes, data are well described in the report; they are representative of the German situation.

- Data quality

Data gaps and sources of uncertainties are discussed in the report.

- Environmental impact categories
  - primary energy consumption
  - fossil fuel energy consumption,
  - water consumption,
  - climate change (greenhouse effect),
  - acidification potential,
  - eutrophication potential,
  - photochemical pollution (photo-oxidant formation potential),
  - health effects of emissions (human toxicity with respect to cancer) and ecotoxicity,
  - land occupation (surface).

- Main Results

In the report, the complete life cycle inventories are detailed.

Impact Assessment of WO Disposal Options (Reference Scenario)

MRD: Regeneration with vacuum distillation + clay treatment (end product: base oil)
BKM.: WO thermal cracking (end product: fuel)
SVZ: Gasification process (end product: methanol)
CEM: Burning in cement kilns

	Regeneration	**Feedstock recycling**		**Burning**	
values for 1000 kg WO	**MRD**	**BKM**	**SVZ**	**cement**	comments
Primary energy (GJ)	**-40**	**-40**	**-40**	**-40**	- saving for every option ; - no difference between options.
Fossil fuel consumption (kg eq. crude oil) - method 1	**-1000**	**-1000**	**-500**	**-100**	- saving for every option ; - advantage for the regeneration (MRD) and the fuel reprocessing (BKM).
Water consumption (t)	**-2**	**0**	**-15**	**-1**	- saving for every option ; -advantage for the gasification process due to the refinery choosen to modelise oil production.
Climate change (GWP, kg eq CO2)	**-200**	**-200**	**50**	**-1200**	- significant difference, according to the energy yield of the different options - advantage for cement kiln
Acidifying potential (AE, g eq SO2)	**-3700**	**-1500**	**-3100**	**-3100**	- saving for every option ; - better result for regeneration, cement kiln and gasification
Photochemical pollution (PCOP, g eq C2H4)	**-250**	**-250**	**-30**	**-100**	- saving for every option, correlated to the energetic balance ; - advantage for the regeneration and the reprocessing options ; - the ranking between options remains unchanged by considering the total emissions of hydrocarbons to air.
Particles to air (g)	**-20**	**-20**	**-2**	**-2**	- saving for every option, correlated to the energetic balance ; clear advantage for regeneration and reprocessing options
Human toxicity (g eq arsenic)	**-0.5**	**-0.9**	**-0.2**	**-0.1**	- the heavy metals in used oils are the major contributors ; advantage for regeneration
Eutrophication potential (g eq PO4)	**-1**	**-1**	**-4**	**0**	- very low values for every option ; - this indicator is not useful to differenciate the options (low values and data uncertainty).
Solid waste (kg)	**20**	**20**	**-30**	**-2**	- bad values for the regeneration and reprocessing options due to the disposal of excavated materials such as clay (inert waste).

Detailed Assessment of WO Disposal Options (Reference Scenario)

Note: in the table, "foreground" refers to the LCA of the main system (A or B in the above figures), and "background" refers to the avoided system (A' or B').

values for 1000 kg WO	MRD - Regeneration			BKM - Thermocracking			SVZ - Gasification			Incineration in cement kilns		
	foreground	background	total	foreground	background	total	foreground	background	total	foreground	background	total
Fossil fuel consumption (kg eq crude oil)	47	981	**- 934**	4	933	**- 930**	109	607	- 498	0.06	152	- 152
Primary energy (MJ)	2 681	42 489	**- 39 808**	343	40 372	**- 40 029**	7 110	49 240	**- 42 130**	22	38 520	**- 38 498**
Water consumption (kg)	3 300	5 260	- 1 960	431	746	- 315	1 350	16 487	**- 15 137**	45	1 230	- 1 185
Climate change (GWP, kg eq CO2)	1 116	1 324	- 208	2 845	3 020	- 175	1 431	1 366	65	2 630	3 909	**- 1 278**
Acidifying potential (AE, kg eq SO2)	2.8	6.5	**- 3.7**	9.8	11.3	- 1.5	0.21	3.3	- 3.1	0.13	3.3	- 3.1
Photochemical poll. (PCOP, kg eq C2H4)	0.04	0.30	**- 0.26**	0.08	0.33	**- 0.25**	0.05	0.09	- 0.03	0.0001	0.12	- 0.12
Particles (g)	3.6	24.4	**- 20.8**	0.4	23.2	**- 22.8**	-	1.8	- 1.8	-	2.5	- 2.5
Human toxicity (kg eq As)	0.00003	0.0006	- 0.0005	0.0002	0.0011	**- 0.0009**	0.000002	0.0002	- 0.0002	0.0000006	0.0001	- 0.0001
Eutrophication potential (kg eq PO4)	0.0011	0.0026	- 0.0015	0.0012	0.0024	- 0.0012	0.0079	0.012	**- 0.0044**	0.00000	0.0002	- 0.0002

values for 1000 kg WO	**MRD**			**BKM**			**SVZ**			**Cement kilns**		
	foreground	background	total	foreground	background	total	foreground	background	total	foreground	background	total
waste (to eliminate) (kg)	24	5	18	18	2	17	1	29	**- 28**	0.05	2	- 2
waste (to recover) (kg)	33	0	33	24	0	24	36	40	**- 4**	0.04	3	**- 3**

Sensitivity analysis

- Sensitivity analysis about the MRD option (regeneration)

  The regeneration option currently in used in Germany (MRD) can be improved (the treatment may be completed by a hydrofinishing treatment). Such an improved process would be associated with a reduction of the energy consumption and the related impacts (greenhouse effect, acidification).

  The regenerated base oil is indeed of better quality than the standard base oil. Therefore, it could be assumed that the regenerated lube oil may replace a base oil made with 90% of mineral oil and 10% of poly-a-olephin. Consequently, the background or avoided process would consume 4% more fuel energy and release 13% more greenhouse effect gas (+200 kg eq CO2 for 1000 kg WO). This assumption would therefore improve the regeneration's environmental profile.

- Sensitivity analysis about the BKM option (thermal cracking)

  In the reference scenario, it has been assumed that the fuel derived from WO would replace the following fuel mix: 59% EL fuel (light oil with 0.15% sulphur) and 41% S fuel (heavy oil with 1% sulphur). Sensitivity analysis:

  a) 100% EL fuel: this scenario makes worse the acidification and the human toxicity (this is due to a lower impact of the background process: 5 kg eq SO2 vs 11.3 kg in the reference scenario; and -50% for the toxicity indicator).

  b) 100% S fuel: this scenario improves drastically the acidification and the human toxicity (this is due to a greater impact of the background process: 20 kg eq SO2 vs 11.3 kg in the reference scenario; and +100% for the toxicity indicator).

  Remark: the acidification potential due to the production of heavy oil (S fuel) is about 4 times more important than the acidification potential due to the production of light oil (EL fuel). With respect to human toxicity, the ratio is comprised between 3 and 4.

- Sensitivity analysis about the SVZ option (gasification)

  In the reference scenario, it has been assumed that the methanol derived from WO would replace a process using the following raw materials: 75% natural gas, 10% heavy oil; 15% lignite. Results of the sensitivity analysis:

  a) 100% natural gas: this scenario makes worse the SVZ option. For instance, either the greenhouse effect or the acidification potential associated with the background process (avoided process) are lowered by about 30%; thus, these impacts are increased by about 30% within the SVZ option. With respect to the criteria "consumption of fossil fuels", the background process is lowered by about 10%, thus, this impact category is lowered by about 10% within the SVZ option.

  b) 100% heavy oil: this context improves drastically the fossil fuel consumption and the acidification ; there is no change for the greenhouse effect potential. The acidification potential associated with the background process (avoided process) is 3 times higher than the background process in the reference scenario (9.5 vs 3.3 kg eq SO2); this impact is lowered by about 300% within the entire SVZ option (-9.3 vs -3.1 kg eq SO2). On the other hand, the fossil fuel consumption of the background process is increased by about 30% (780 vs 600 kg eq crude oil).

c) 100% lignite: this scenario improves drastically the greenhouse effect (the SVZ option would become even better than the burning option but makes worse the fossil fuel consumption (the SVZ option would become the worse option for this indicator). The greenhouse effect potential associated with the background process (avoided process) is 2.5 times higher than the background process in the reference scenario (3500 vs 1300 kg eq CO_2). The acidification potential associated with the background process (avoided process) is 30% higher than the background process in the reference scenario (4 vs 3.3 kg eq SO_2). The fossil fuels consumption associated with the background process (avoided process) is 2 times lower than the background process in the reference scenario (300 vs 600 kg eq crude oil).

Remark: methanol is generally produced from natural gas ('steam reforming') in Western Europe except in Germany where methanol is generally produced from heavy oil ("partial oxidation"); in Eastern Europe, lignite is generally used.

- Sensitivity analysis about the burning option

  In the reference scenario, it has been assumed that WO would replace the following mix: 8% crude oil coke, 40% lignite and 52% coal.

  The impact assessment of the burning option in a cement kiln is dependent on the primary fuels saved. The results of the sensitivity analysis with 100% fuel oils are: the GWP of the background process is reduced from 3900 kg eq CO_2 to 3200 kg eq CO_2 for 1000 kg WO. For the overall incineration in cement kiln option, the GWP becomes less beneficial: - 600 kg eq CO_2 instead of - 1200 kg eq CO_2 in the reference scenario. For the fossil fuel consumption, the cement kiln option becomes equivalent to the regeneration options (-1000 kg eq crude oil).

- Sensitivity analysis about the allocation procedure

  Crude oil is extracted then processed in a crude oil refinery. A crude oil refinery yields several products: coke, base oil, heavy fuel, gas-oil, vacuum residue, distillation residue, asphalt (tar oil), plant fuel, jet fuel…. Therefore, the materials and energy flows as well as associated environmental releases shall be allocated to the different products according to clearly stated procedures.

  In this study (as well as in most of the LCA studies), inputs (consumptions) and outputs (releases) have been allocated between co-products in proportion to the mass value of the products ('massic' or weight-based allocation). This 'massic' procedure may be criticised as it induces an overvaluation of the impacts due to either coke or asphalt (tar oil) because these co-products may be indeed considered as refinery's waste.

  As for the ADEME study, and in order to illustrate the impact on the results that the choice regarding the allocation procedure can have, we have carried out a simulation with other allocation rules: the economic allocation, which is another allocation procedure often used by LCA experts, e.g. to perform a sensitivity analysis. The inputs (consumptions) and outputs (releases) have been partitioned between co-products in proportion to the economic value of the products.

  This allocation procedure doesn't change significantly the environmental profiles of the four options under study.

■ Main conclusions of the authors

- The results show that all the WO recovery options under consideration are favourable in terms of environmental impacts (by comparison with a 'do nothing' system), except for the greenhouse effect in the gasification option.
- It is not possible to state that one recovery option is better than the others for all environmental impacts; every recovery option is associated with at least one environmental benefit by comparison with the other recovery options; for instance, MRD is the best recovery option with respect to the acidification potential, BKM with respect to the human toxicity, SVZ with respect to the eutrophication and the summer smog, and the incineration in cement kiln with respect to the greenhouse effect.
- The impact assessment is based on two alternative routes: the treatment itself (foreground process) and the avoided processes (background process). For almost all the environmental impacts under study, the difference between two recovery options is more essentially determined by the background processes rather than the foreground processes. With respect to the comparison between the four options, the recovery process is less important by itself than the avoided process. This conclusion is the same in the ADEME study (see the figures illustrating that point in chapter 10.4).
- The environmental impacts due to collection and transport of WO and primary materials are not significant compared to the impacts of the industrial processes.
- Some general considerations regarding the accumulation of pollutants in the end-products have been discussed but a detailed analysis remains needed.

11 LESSONS FROM THE REVIEW OF THE LCA STUDIES RELATED TO WO RECOVERY OPTIONS

11.1 SCOPE OF THE LCA STUDIES COMPARING SEVERAL WO DISPOSAL OPTIONS

The 4 main channels for the disposal of used oils currently collected (from Concawe report, 1996)			***Scope of the LCA studies***			
			ADEME 2000	UBA 2000	GER 97	NOR 95
direct burning options (recovery of energy value as industrial fuel)		cement kilns	**Vci**	**cement**	**not specified**	**not specified**
		space heaters				
		waste incinerators				
reprocessing (conversion to fuels or chemical feedstock)	mild	burning in road limestone coating plants	**Vce**			
		burning when blended with fuel oil				
	severe	vaxon process				
		trailblazer				
		transforming into good quality fuel oil		**BKM**		
re-refining (to lubricant base oil)	current technologies	acid / clay process				**not specified**
		distillation / clay process	**Rfa**	**MRD**	**MRD**	
		distillation / chemical process				
		propane deasphalting (PDA) process				
		thin film evaporator (TFE) process				
		thermal deasphalting (TDA) process				
		pretreatment and lube refinery recycling				
		interline process				
	other technologies under development	UOP (regeneration by hydrogen contact)	**Rch**			
		ENTRA				
		supercritical extraction				
		refinery recycling	**Rra**			
gasification process (conversion to chemical feedstock as methanol)				**SVZ**		

■ The recovery options under investigation

The recovery options covered by LCA studies include:

- regeneration to base oil (closed-loop recycling): Rfa, Rch, MRD, not specified.
- recovery of energy as industrial fuel (energy recovery): BKM, SVZ, Rra.
- conversion to fuels or chemical feedstock (feedstock recycling): Vci, cement, Vce, not specified.

Not all the recovery options are covered within the available LCA studies. The choice of the investigated options has not been based on environmental considerations but rather on practical considerations:

- UBA 00 and GER 97: only the recovery options currently available in Germany at an industrial scale have been investigated (except for the burning option in GER 97 which is based on a theoretical consideration for the primary fuels replaced by WO; no prospective investigation).
- NOR 95: the recovery options have not been detailed, but the study covers the situation in Norway at the time of the study (1995).

- ADEME 00: this study investigated current technologies either in France (Rfa, Vci) or elsewhere in Europe (Vce in UK and Italy), and prospective technologies (Rch, Rra). With respect to the refinery recycling (Rra), the technology was under development in France at the date of the study. The regeneration option by hydrogen contact (Rra) has been investigated because it may be a promising technology (an industrial plant being under construction in the USA at the date of the study) as the process doesn't need any specification for the WO quality (the process is able to neutralise large quantities of PCB and metals).

■ The base oil quality standards

It has not been the task of the published LCA studies to analyse the influence of the base oil quality standards on the overall environmental effects of the WO management options. All the studies are based on today's base oil quality standards. So we don't have any knowledge about what should be the base oil quality standards which could offer the larger environmental benefits for the regeneration options. From the outcome of the available LCA studies it is not feasible to derive targets for new base oil quality standards.

■ The time horizon

With respect to the LCA reports under consideration, the scope of only one (ADM 00) has covered a prospective analysis of regeneration technology under development. However, concerning the avoided processes (e.g. base oil production from raw materials and energy production) every studies covered only the today's situation but not a prospective situation where the environmental performance of these avoided (background) processes would be different. It could be argued that several studies (ADM 00 and UBA 00) have performed extensive sensitivity analysis in order to assess the influence of some parameters which can influence the environmental performance of these avoided processes. However, a prospective situation where WO would replace or be replaced by other waste streams (such as tyres for instance) for burning has not been assessed.

■ Case-specific vs system comparison

The LCA studies under consideration may be considered as case-specific comparisons between disposal options. The data used to describe the process are plant-specific with respect to the regeneration and the feedstock recycling options; as for the burning options, the data are representative of an average national situation in France (ADM 00), Germany (GER 00) and Norway (NOR 95).

■ Compliance with the ISO Standards related to LCA (ISO 14040 to 14043)

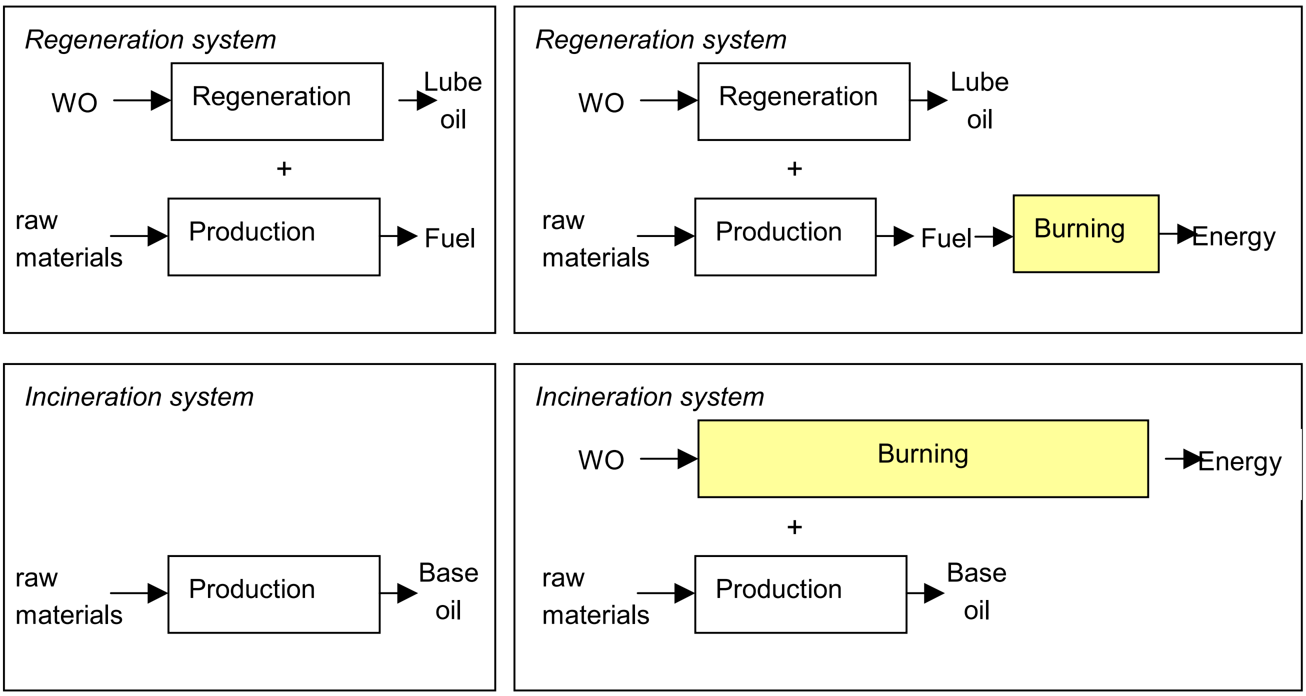
The first International Standard concerning LCA (ISO 14040) has been published in 1997: it describes the principles and framework for conducting and reporting LCA studies, and includes certain minimal requirements. Two studies (ADM 00, GER 00) have been recognised as compatible with the ISO standards concerning LCA studies: in the both studies, a critical review has been carried out. These studies are correctly designed to compare the waste management options under consideration (regeneration, feedstock recycling and energy recovery).

The two other studies (NOR 95, GER 97) have been performed before the publication of the ISO standards concerning LCA.

In our opinion, the system boundaries in the NOR 95 study may be considered as correctly designed to compare the regeneration and the burning options. But the technological representativeness has not been assessed, the data quality is not sufficiently transparent, and no sensitivity analysis has been performed to show the effects of changing the assumptions for the choice of the energy sources which can replace the heating value of WO (80% fuel oil and 20% electricity) in the regeneration system.

As for the GER 97 study, it is not well-designed because the burdens due to the combustion of either WO or substituted primary fuels are not included.

Studied systems ***Systems which should have been studied***



This exclusion may be of importance with respect to the greenhouse effect indicator for instance.

For that reason, the results from the GER 97 study will not be integrated in the next chapters. Nevertheless the recovery options covered by the GER 97 study will be included as they are covered by the well-designed UBA 00 study.

11.2 RESULTS OF THE LCA STUDIES

11.2.1 Regeneration vs Energy Recovery

Hereafter, the results from the reviewed studies are summarised as regeneration compared to incineration with energy recovery. An 'R' indicates lower impacts for regeneration (regeneration is better), and an 'I' indicates lower impacts for incineration (incineration is better). No consideration has been given to neither the magnitude in the difference nor the data quality. The following results are independent from the quantity of collected WO.

Two types of energy recovery have been analysed in the LCA studies: incineration in cement kilns and incineration in asphalt plants.

Source **Scenarios compared**	**UBA (2000)** **R vs I**	**ADEME (2000)** **R vs I**	**ADEME (2000)** **R vs I**	**ADEME (2000)** **R vs I**	**N-EPA (1995)** **R vs I**	**ADEME (2000)** **R vs I**	**ADEME (2000)** **R vs I**	**ADEME (2000)** **R vs I**
Regeneration	Current	Current	Improved	Prospective	Current?	Current	Improved	Prospective
Geography	Germany	France	France	France	Norway?	France	France	France
Representativeness	Site specific	Site specific	Site specific	Pilot scale	Site specific?	Site specific	Site specific	Site specific
Technology	Distillation + chemical treatment	Distillation + clay treatment	Distillation + clay treatment + hydrofinishing	UOP process (HYLUBE patent)	?	Distillation + clay treatment	Distillation + clay treatment + hydrofinishing	UOP process (HYLUBE patent)
Incineration	Cement	Cement	Cement	Cement	Burning plant	Asphalt plant	Asphalt plant	Asphalt plant
Geography	Germany	France	France	France	Norway	UK, Italy, USA	UK, Italy, USA	UK, Italy, USA
Representativeness	National	3 plants	3 plants	3 plants	site specific?	Site specific	Site specific	Site specific
Fuels	Coal: 52% Lignite: 40% Coke oil: 8%	Coal: 11% Tar oil: 29% Coke oil: 60%	Coal: 11% Tar oil: 29% Coke oil: 60%	Coal: 11% Tar oil: 29% Coke oil: 60%	Heavy oil: 80% Electricity: 20%	Gas oil 100%	Gas oil 100%	Gas oil 100%
Total energy	R=I	R=I	R=I	R=I		R=I	R=I	R=I
Fossil fuels	R	I	I	I	R	R=I	R=I	R=I
Water input	R=I	R	R	R		R	R	R
Climate change	I	I	I	I	R	I	I	R=I
Acidifying potential	R	I	I	R=I	R	R	I	R
Photochemical pollution (VOC)	R	I	I	I	R	I	I	I
Dust emission in air	R	I	I	I		I	I	R=I
Human toxicity	R	I		R		R		R
Ecotoxcity (aquatic)		I		R=I		I		R
Ecotoxcity (terrestrial)		I		R=I		I		R
Eutrophication (water)	R=I	R=I	R=I	R=I	R=I	R=I	R=I	R=I
Solid waste	I	I	I	I	R=I	R=I	R=I	R=I

- Major sources of impact in a regeneration and a burning system

  Within a life cycle perspective, the total contribution of the management system under consideration is the result of the difference between two different quantities: the impact of the recovery treatment (regeneration or incineration) minus the impact of the main avoided system (virgin base oil production or traditional fuel or energy production).

  It shall first be noted that, when considering only the recovery treatments, the impacts generated by the regeneration plant are often lower than those generated by the incineration plant.

  But when considering the whole life cycle, for almost all the environmental impacts under study, the difference between two recovery options is more essentially determined by the avoided processes rather than the treatments themselves: the recovery process is less important by itself than the avoided process.

- Comparison with a ‘do nothing’ system

  As a consequence of the previous consideration, all the WO regeneration and incineration options under consideration are favourable in terms of environmental impacts (i.e. they contribute to avoid impacts) by comparison with a ‘do nothing’ system (except the acidifying potential in the case of burning in an asphalt plant[37]).

- Different plants where WO are incinerated for an energetic purpose

  Considering the current technologies, the incineration in asphalt plant is less favourable than incineration in cement kilns (essentially because the primary fuels are gas oil).

  This has a strong influence on the relative positioning of regeneration and incineration. Whereas modern regeneration technologies can have similar or better environmental performances compared to incineration in asphalt kilns, the results are more mitigated when comparing to incineration in cement kilns, as detailed hereafter.

- Impacts of transport

  The environmental impacts due to collection and transport of WO and primary materials are not significant within a life cycle perspective compared to the impacts of the industrial processes. (ADEME, 2000; UBA, 2000).

- Total primary energy consumption

  The 3 WO management options under consideration (regeneration, incineration in cement kilns and incineration in asphalt plants) lead to significant energy savings. The benefits are similar in the regeneration and burning systems (about -40 MJ/kg of WO).

[37] and also in the case when the regeneration process is modified in order to improve the quality of the re-refined base oils (in term of sulphur and heavy metals content); this modification entails a degradation of the environmental performance of the regeneration system with respect to acidification (case of the existing regeneration plant in France)

- Fossil fuels consumption

  The 3 WO management options lead to significant savings in fossil fuels consumption. However, the 3 studies give very different results, favouring one option in 2 cases and another option in one case, when comparing regeneration with burning systems. This can be explained by the fact that the ranking is strongly influenced by the method used to calculate this indicator (cf. chapter 10.4 above and appendix 10) and by the primary fuels which are replaced by WO at the burning plant, as well as the type of burning plant.

  The Norwegian study states an advantage for the regeneration system. The benefit of the burning system is low (10%). When regenerating WO, it was assumed that the loss in energy generated from the burning system was replaced by heavy fuel oil (80%) and electricity (20%). In Norway, the hydroelectricity is predominant. No sensitivity analysis has been carried out during the study, but we can assume that the hierarchy between the management options will be strongly dependent on the electricity ratio (it is likely that the higher the amount of electricity replacing WO as fuels, the more advantageous the regeneration would be).

- Water consumption

  It is lower in the case of regeneration in the ADEME study. This is due to the high water consumption at the virgin oil production's plant which is reported to be very specific to the plant under study (Dunkerque's refinery). In the UBA study, the total input of water is similar between regeneration and incineration in cement kilns. In the NOR95 study, this aspect was not addressed.

- Climate change

  The 3 WO management options lead to significant savings in greenhouse effect emissions.

  The ADEME and the UBA studies show a significant benefit of incineration in cement kilns as compared with regeneration. Based on extensive sensitivity analyses, the two studies state that this tendency is not dependent on the primary fuels at the cement kilns; the primary fuels only have an effect on the magnitude of the impact.

  However, in the case of incineration of WO in an asphalt plant, the savings of greenhouse effect emissions are the same for the regeneration and the incineration options.

  In the Norwegian study, the regeneration system saves more greenhouse effect emissions that the incineration. Despite of a lack of transparency regarding the hypotheses and their influence on the results (no sensitivity analysis performed), one can assume that this advantage can be explained:

  - mostly by the type of substituted primary fuels considered for the burning in a cement kiln system: heavy fuel oil (80%) and electricity (20%). As a matter of fact, given the electricity mix in Norway (large proportion of hydroelectricity which causes no greenhouse effect emissions), this situation credits a lesser climate change bonus to the burning system,
  - to a lower extent, possibly by the virgin base oil refinery yield[38].

[38] During this review, we were not able to identify another parameter (in addition to the mix electricity) in the Norwegian study which could explain the final advantage of the regeneration upon the burning. Considering the fact that when comparing the regeneration of waste oil and the production of virgin base oil, the second

Consequently, with respect to climate change, one preponderant parameter influences the hierarchy between the two disposal options, it is the choice of the primary fuels which replace the heating value of WO (e.g. the choice of the avoided fuels in the burning system).

To conclude with climate change, the environmental precedence between the WO recovery options under consideration is influenced:

- strongly by the environmental performance of the burning system, which depends on the nature of the primary fuels which replace the WO,
- to a lower extent by the environmental performance of the regeneration system, which is affected by the magnitude of the avoided impact of the virgin base oil production, reflecting the performance at the virgin base oil refinery.
- a third element of importance would be, as shown in the ADEME study, the type of the regeneration unit process.

■ Emissions of acidifying gas (SOx, NOx, HCl, HF)

- Regeneration compared to incineration in cement kiln

  They are different among the studies addressed. This may be explained by the fact that the results may depend on the performance of the gas cleaning process at the regeneration plant.

  When no cleaning system is present at the regeneration plant (current situation in France), the burning option is more beneficial. However, when a cleaning system is installed at the regeneration plant (current situation in Germany, prospective technology in the ADEME study), the regeneration option is more environmentally beneficial than the incineration option in the UBA study, but not in the ADEME study.

  In cement kilns, acidic substances such as HCl and SOx are neutralised by the alkali raw materials, which act in fact as a caustic scrubber. Nevertheless, it is not clear to what extent the difference between the studies is dependent on the neutralising yield of the acidic substances (this yield has been assumed to be 99.80% in the ADEME study which is very high, but no value has been given in the UBA report). This discussion shows how tightly linked this environmental indicator is to a specific parameter, such as the neutralising yield.

  The Norwegian study concludes that regeneration is better than incineration in cement kiln when considering the emissions of acidifying gas. But this study, based on a simplified LCA approach (i.e. the analysis is based upon the best available data and information with no extensive new analyses), has not traced back these emissions. Furthermore, the results cannot be correlated to the sulphur content of WO as this parameter is not disclosed in the NOR 95 study. The tendency shown by this study is not sufficiently transparent, thus must not be considered as reliable.

- Regeneration compared to incineration in asphalt kiln

  The regeneration option is more beneficial, a gas cleaning system being present or not at the regeneration plant (current situation in France and prospective technology in the ADEME study).

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one generates much more greenhouse emissions than the first one (see for instance the charts about global warming presented in chapter 10.4), it is reasonable to assume the yield at the virgin base oil refinery to be a sensible parameter.

- Emissions of VOC (volatile organic compounds) and emissions of dust

  Both types of emissions are related in every scenarios discussed.

  Regarding the comparison between the recovery options, the studies draw contradictory results. No investigation has been done to understand to what extent this opposition may be due to either a different electric mix in France and Germany (for avoided process in the burning system) or a different heat source at the cement kilns (burning system) or a different heat source at the virgin base oil refinery (regeneration system).

  However, it can be stated that with respect to these impact categories, the environmental precedence between the WO management options appears to be the same than for the fossil fuels indicator (see above).

- The toxicity potential

  It does not include the long term mobility of heavy metals in the clinker (cement) because of important scientific uncertainties.

  Furthermore, both the ADM 00 and UBA 00 studies are based on a different method to compute this indicator. The most reliable method appears to be in the ADEME report, as it is based on the USES approach (Uniform System for the Evaluation of Substance) which is recommended by the European Commission for policy purposes (see appendix 10). The results are largely dependent on the trapping rate of heavy metals in the clinker (assumed to be 99.98% in the cement kilns in the ADEME report, no details in the UBA study). However many uncertainties remain (about both data and methods) thus we prefer to state no general conclusion with respect to this indicator.

- The eutrophication potential

  It is stated to be very low in both regeneration and incineration scenarios. As a consequence, both the magnitude of the absolute figures and the magnitude of the difference between options are not significant compared to the level of uncertainties linked to an LCA approach. In accordance with the authors of the studies, we consider this indicator to be inadequate to differentiate the management options.

- Solid waste

  Regarding the comparison between the recovery options, the studies draw contradictory results.

  First, the regeneration option produces solid waste in the UBA 2000 study (mainly inert clay waste to be disposed of) whereas it contributes to avoid the impact in the ADEME 2000 study.

Secondly, in the ADEME study, this indicator is considered not being adequate to differentiate the management options because both the magnitude of the absolute figures and the magnitude of the difference between options are not significant compared to the level of uncertainties linked to an LCA approach.

However, it can be stated that the benefit of the burning in cement kilns options depends on the type of primary fuels used at the burning plant. For instance, incineration is better than regeneration if the fuel replaced is coal (solid waste are essentially due to coal mining). With all other primary fuels (coke oil, tar oil, fuel oil, electricity), the results are similar for regeneration and incineration in cement kilns.

11.2.2 Fuel and Feedstock Conversion vs Energy Recovery

Source Scenarios compared	UBA (2000) C vs I	UBA (2000) C vs I	ADEME (2000) C vs I	ADEME (2000) C vs I
feedstock conversion	current	current	prospective	prospective
end product	fuel oils	methanol	vacuum gas oil	vacuum gas oil
geography	Germany	Germany	France	France
technology	thermal + chemical	gasification	refinery recycling	refinery recycling
incineration	cement	cement	cement	asphalt plant
geography	Germany avg	Germany avg	France avg	UK, Italy, US
fuels	coal 52% lignite : 40% coke oil: 8%	coal 52% lignite : 40% coke oil: 8%	coal 11% tar oil : 29% coke oil: 60%	gas oil 100%
Total energy	C=I	C=I	I or C=I	C=I
Fossil fuels	C	C	I	C=I
Water input	C=I	C	I	C=I
Climate change	I	I	I	I
Acidifying potential	I	C=I	I	C
Photochemical pollution (VOC)	C	I	I	I
Dust emission in air	C	C=I	I	C=I
Human toxicity	C	C=I	C=I	C
Ecotoxcity (aquatic)			I	I
Ecotoxcity (terrestrial)			I	C
Eutrophication (water)	C=I	C=I	C=I	C=I
Solid waste	I	C	I	C=I

Various fuel and feedstock conversion technologies (C) have been studied.

Considering the current technologies in Germany, the results are different according to the impact categories: several environmental indicators are favourable to the chemical conversion options (fossil fuels), others are favourable to the incineration in cement kilns (climate change), and others are favourable or not to the chemical conversion option depending on the chemical conversion process (solid waste, toxicity, photochemical pollution).

The results from the ADEME study are less reliable as scoping with a recycling technology still under development in France (data based on a pilot scale).

11.2.3 Regeneration vs Fuel and Feedstock Conversion

Source Scenarios compared	UBA (2000) R vs C	UBA (2000) R vs C	ADEME (2000) R vs C	ADEME (2000) R vs C	ADEME (2000) R vs C
regeneration	current	current	current	improved	prospective
geography	Germany	Germany	France	France	France
technology	distillation + chemical treatment	distillation + chemical treatment	distillation + clay treatment	distillation + clay treatment + hydrofinishing	UOP process (HYLUBE patent)
feedstock conversion	current	current	prospective	prospective	prospective
end product	fuel oils	methanol	vacuum gas oil	vacuum gas oil	vacuum gas oil
geography	Germany	Germany	France	France	France
technology	thermal + chemical	gasification	refinery recycling	refinery recycling	refinery recycling
Total energy	R=C	R=C	R=C	R=C	R=C
Fossil fuels	R=C	R	R=C	R=C	R=C
Water input	R	C	R	R	R
Climate change	R=C	R	C	R	R
Acidifying potential	R	R	R	C	R
Photochemical pollution (VOC)	R=C	R	R	R	R
Dust emission in air	R=C	R	C	R=C	R=C
Human toxicity	C	R	C		R
Ecotoxcity (aquatic)			C		R
Ecotoxcity (terrestrial)			C		R
Eutrophication (water)	R=C	R=C	R=C	R=C	R=C
Solid waste	R=C	C	R=C	R=C	R=C

- Representativeness of the results for the fuel and feedstock conversion processes

The results presented in this table for the fuel and feedstock conversion processes are either site-specific (UBA, 2000 for thermal cracking and gasification) or prospective (ADEME, 2000 for refinery recycling). Without other study to compare with, it is difficult to judge on the representativeness and the reliability of the results.

As a consequence, all the conclusions presented below in this chapter would have to be confirmed in the future.

- Regeneration vs thermal cracking

First it should be noted that the term 'thermal cracking' covers different types of processes (see section 5.3 on page 57). It is likely that the process covered by the UBA 00 study is different from the modern technology being implemented in Belgium (the WATCO project), without being able to judge on the importance of the differences in terms of environmental impacts.

Secondly, in addition to the UBA 00 study covering thermal cracking, we can include here the conclusions drawn in Mrs Wheeler's report [72], which deals with some environmental issues of WO thermal cracking compared to WO regeneration, in the case of the Canadian situation. It does not constitute an LCA as the UBA 00 study. General assertions are presented with respect to energy consumption and the release of contaminants to the environment. No judgement on their accuracy has been performed. A further analysis would be necessary to confirm these statements, which is not the purpose of this project.

The two main conclusions of Mrs Wheeler's report [72] are the following ones:

- regeneration into base oils and thermal cracking are equivalent on energy recovery and greenhouse gases (CO_2 and CO),
- thermal cracking is preferable to regeneration when emissions of pollutants (such as sulphur, heavy metals, halides) are considered.

It then results that:

- regeneration and thermal cracking would be equivalent on energy recovery and greenhouse gases (both studies) as well as photochemical pollution and dust emission (UBA 00 study),
- thermal cracking would be preferable to regeneration when human toxicity is considered,
- as for acidification, the studies lead to different conclusions. Due to a lack of information (in particular in Mrs Wheeler's report), it is not possible to explain the origin of the differences.

- Regeneration vs gasification

  Regeneration would be preferable to gasification for all impacts except solid waste and water input.

- Regeneration vs refinery recycling

  The results based on a prospective refinery recycling technology under development in France show that regeneration would become preferable to that option for some impact categories or equivalent for the others in the case of a modern regeneration technology.

12 CONCLUSIONS OF THE LCA STUDIES CRITICAL ASSESSMENT

12.1 SOUNDNESS OF THE LCA RESULTS

This chapter shows that the results (more the tendencies than the absolute figures) concerning the comparison between regeneration and burning for 4 environmental impacts categories can be considered sound and representative of a wide diversity of situations prevailing in Europe.

12.1.1 Representativeness of the Options Considered

- Regeneration technologies

  Three technologies have been considered:

  - vacuum distillation + clay treatment (the old process operated in France, which has been up-graded in 2001[39]),
  - vacuum distillation + chemical treatment (one of the current processes in Germany),
  - hydrogen pre-treatment + vacuum distillation (UOP process under development in the USA).

  This choice has not been based on environmental considerations but rather on practical considerations (availability of the information).

  It is not possible to judge if other regeneration technologies would present major differences in the environmental impacts with the ones assessed in the available LCA studies.

  But the three technologies assessed can be considered being representative of a diversity of regeneration technologies existing in Europe, including modern processes.

  Thus these choices do not weaken the main conclusions of the LCAs which are summarised hereafter in section 12.3.

- Burning options

  Two of the burning options existing in Europe are covered by the LCAs discussed:

  - burning in cement kiln,
  - burning in asphalt plant.

  No information are available on the other types of incineration: power plants, household boilers, greenhouses…

  But a large proportion of the collected WO in Europe are sent to one of these two types of plants. And the impacts of these two options are different, reflecting a variety of burning plants which exist.

[39] this up-grade has been included in the ADEME study as the second scenario 'improved regeneration'

Thus these choices do not weaken the main conclusions of the LCAs which are summarised hereafter in section 12.3.

As far as the avoided processes are concerned, sensibility analyses have been performed to simulate several types of energy and fuels that the WO replace. But in reality, WO can also replace other waste (tires, solvents…). No simulation has been carried out to analyse that situation, whose environmental impacts are expected to be very different.

- Other management options

Thermal cracking, gasification and refinery recycling are three management options which are not yet largely developed in Europe (see sections 5 and 6 above) but which are representative of possible future development.

12.1.2 Representativeness of the Data Considered

- Let us remind that when considering the whole life cycle, for almost all the environmental impacts under study, the difference between two recovery options is more essentially determined by the avoided processes rather than the treatments themselves: the recovery process is less important by itself than the avoided process.

For that reason, the representativeness of the final results depends more on the representativeness of the data related to the avoided processes than on the one of the treatment processes.

- Regeneration options

As far as the regeneration plants are concerned, the data are more site specific than dependent on the characteristics of the country where the plant is located. They reflect the diversity which exists between plants, wherever they are located.

As for the avoided process (base oil refinery), they are representative of an average situation in Western Europe[40].

As a consequence, the results can be extrapolated at the European level.

- Burning plants

The burning plants are representative of an average situation in the concerned country (France, Germany and Norway for cement kilns and the UK for asphalt plants).

The data for the avoided processes (production of traditional fuels) are representative of the average situation in Western Europe.

[40] Except in the ADEME study where the water consumption of the refinery considered is very high compared to equivalent refineries

- Other management options

  The data used for the fuel and feedstock conversion processes are either site-specific (UBA, 2000 for thermal cracking and gasification) or prospective (ADEME, 2000 for refinery recycling). Without other study to compare with, it is difficult to judge on the representativeness and the reliability of the results.

  Furthermore, the process covered by the UBA 00 study being probably different from the modern technology whose implementation is in progress in Belgium (the WATCO project), other analyses will be necessary in the future to consolidate the results.

12.1.3 Relevant Environmental Impact Categories

Considering the current state of the art for the inventory and assessment stages within the LCA framework, the following environmental impacts are the most reliable for comparing the WO management options in the LCAs carried out:

- Consumption of fossil energy resources,
- Contribution to global climate change,
- Contribution to regional acidifying potential,
- Emission of Volatile Organic Compounds (VOC),
- Waterborne emissions,
- Solid waste.

The results of the LCAs performed show that the waterborne emissions and the solid waste do not constitute adequate indicators to differentiate the WO management options because both the magnitude of the absolute figures and the magnitude of the difference between options are not significant compared to the level of uncertainties linked to an LCA approach.

Regarding the solid waste, it shall be indicated that it is not very clear if and how the environmental impacts of the solid residues generated either by the regeneration plant or the burning plant have been assessed.

12.2 GAPS IN THE LCAS AVAILABLE

12.2.1 Impact Categories Missing

- Impact categories which cannot be derived from life cycle inventory data (generally speaking) or from the LCAs available for WO:
  - not compatible with the LCA methodology[41]:
    - noise,
    - odour,
    - nature conservation (biodiversity, etc.),
    - land use,
    - risk of nuclear accidents.
  - not assessed in the WO LCAs available:
    - nuclear waste,
    - toxic emissions.
- As for toxic emissions (heavy metals, organic pollutants…), the LCA methodology is not currently relevant to quantify and compare reliable indicators with respect to human toxicity and ecotoxicity.

  An attempt to compute such indicators has been made in both the ADEME and UBA studies but using different methods and obtaining highly uncertain results.

  More generally, few studies have been reported on the toxicity and potential health effects of re-refined base oils. And chronic impacts have not been studied.

  Nevertheless, it seems that re-refined base oil are not acutely toxic, not are they skin or eyes irritant.

12.2.2 Gaps Regarding the Systems Studied

- The following considerations, which may have a significant influence on the environmental impacts have not been covered by the available studies:
  - the situations when WO replace other wastes and not traditional fuels at the burning plants,
  - the influence of the base oil quality standard produced and / or regenerated on the environmental impacts of the different management options,
- Even if the ADEME study integrates the analysis of a modern regeneration technology under development, the main results from the reviewed LCA studies are based on today's situation and mean technology.

  In view of defining a waste management policy, this can just constitute a starting point**.** A prospective evaluation, taking into account the possible evolutions of technologies in the mid term, has to be integrated.

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[41] for instance, summing local impacts as noise and odour does not make a lot of sense because they are not global and cumulative impacts but rather dependent on the location of the 'emissions'

12.3 Main LCA Results

The following conclusions drawn from the LCAs analysed can be considered sound.

- From a local impacts perspective, when considering only the recovery treatments, the impacts generated by the regeneration plant are often lower than those generated by the incineration plant.

- The environmental performance of an old regeneration process can be improved with a modern technology (but it is not possible to generalise that conclusion, based on the comparison between an old clay treatment with the UOP process).

- The environmental impacts due to collection and transport of WO and primary materials are not significant within a life cycle perspective compared to the impacts of the industrial processes[42].

- For almost all the environmental impacts under study, the recovery treatment (regeneration or incineration) is less important by itself than the avoided process (virgin base oil production or traditional fuel or energy production).

  Within a life cycle perspective, the total contribution of the management system under consideration is indeed the result of the difference between two different quantities: the impact of the recovery treatment minus the impact of the main avoided system (this latter representing a bonus). The environmental impacts of WO recovery systems are mainly determined by this bonus and less by the direct impacts of recovery processes themselves.

- All the WO recovery options under consideration are favourable in terms of environmental impacts (i.e. they contribute to avoid impacts) by comparison with a 'do nothing' system[43].

- The amount of the bonus brought by the avoided process is determined by the choice of the substituted process[44].

  Especially in the case of WO burning with energy recovery, the type of fuels that the WO replace is crucial: fossil fuel, hydroelectricity, thermal electricity, other wastes….

  This explains that, in the LCAs analysed:

  - for almost all environmental impacts considered, burning in cement kilns (where WO replace fossil fuels) is more favourable than burning in an asphalt kiln (where WO replace gas oil),
  - a modern regeneration may be, according to the impact considered, more favourable than or equivalent to burning in an asphalt kiln,
  - compared to burning in a cement kiln (where WO replace fossil fuels), WO regeneration has environmental advantages and drawbacks depending on the impact considered.

  It appears that regeneration would present advantages for all environmental impacts in all scenarios if the WO would replace non fossil fuels (e.g. hydroelectricity, nuclear electricity[45]).

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[42] This is often the case in LCAs performed for waste management options (e.g. packaging waste).
[43] except for the greenhouse effect in the gasification option
[44] This is also the case for other wastes with a high calorific value as plastic wastes.
[45] and maybe other wastes

- The positioning of regeneration compared to fuel and feedstock conversion will have to be validated in the future:
  - Compared to thermal cracking, WO regeneration would have environmental advantages and drawbacks depending on the impact considered.
  - Regeneration would be preferable to gasification for all impacts except solid waste and water input.
  - A modern regeneration technology would become preferable to refinery recycling for some impact categories or equivalent for the others.

Appendices

Appendix 1

List of the Available Studies Gathered and Analysed

List of the Available Studies Gathered and Analysed

Study Title	Organisation / Author	Main information used in the present study	Ref
Observatoire des huiles usagées	ADEME	Data on quantities collected, energy recovered, regenerated, disposed and capacities, 1998 data	[1]
Directive du conseil 75/439/CEE du 16/6/1975 concernant l'élimination des huiles usagées	European Commission	European directive on WO, legislation	[2]
EUROPALUB statistics	EUROPALUB, Mr DUFOUR	Statistics on production, market, capacities of refining and regeneration of lubricant and WO, 1999 data	[6]
Meeting GEIR Dollbergen (Hanover)	CATOR, Spain, Mr TORRAS	Tax, subsidies, collection, regeneration, list of actors, 1999 data	[7]
The Fourth ICIS-LOR World Base Oils Conference, London		List of regeneration capacities by country and on market	[9]
Report on the implementation of community waste legislation (Directive 75/439/EEC on WO)	European Commission	Quantities collected, energy recovered, re-refined, deposit, 1995-1997 data	[10]
Recycling of WO in Europe (Presentation paper to EU Recycling Forum, Brussels)	GEIR, Renato SCHIEPPATI, President	Regeneration, Market description	[14]
Burning or Re-refining used lube oil? Life cycle assessments of the environmental impacts	The Norwegian environmental protection agency Mie VOLD	LCA and environmental impacts Comparison of incineration and re-refining	[16]
Ökologische Bilanzierung von Altöl-Verwertungswegen Ökologischer Vergleich von vier wichtigen Altölverwertungsverfahren	Umweltvundesamt	LCA and environmental impacts 4 recovery routes analysed (regeneration, incineration in cement kilns, cracking for gas oil, cracking for methanol).	[17]
WO - Fuel or lubricant? Examination for precedence in accordance with the waste recycling act	Lower Saxony Minister of the Environment Monika GRIEFAHN	LCA and environmental impacts Regeneration, emission, waste, pollution analysis 1995 data	[18]
Collection and disposal of used lubricant	CONCAWE (The oil companies' European organisation for environment, health and safety) M. PEDENAUD	LCA and environmental impacts Cost-effectiveness, transport, CO2 emissions, European market, collection, technical comparison	[19]

Study Title	Organisation / Author	Main information used in the present study	Ref
Environmental and economic impact of re-refined products: a life cycle analysis	Centro Ricerche FIAT M. LEVIZZARI	LCA and environmental impacts Consumption of base oil, collection, recovery routes (regeneration), technical analysis	[20]
Recyclage et valorisation énergétique des huiles. Atouts et faiblesses	ADEME	LCA and environmental impacts Regeneration, incineration, 2000 data	[21]
La collecte des huiles usagées en France	SRRHU (Société de Ramassage pour la Régénération des Huiles Usagées), France	Collection, legislation, actors of the WO management system, capacity of regeneration and incineration, quantities, 1999 data	[23]
End uses for used oil: A market perspective	Par Excellence Developments Inc, Don KRESS, President	Environmental technology consulting and marketing company based in Sudbury Canada. Description of process for thermal cracking	[24]
EU15 National regulations for collection and utilisation of used lubricant	IBC International Business Consultants GmbH, Dr Jan HEDBERG	Economic aspect, consumption, waste, collection, regeneration, tax and subsidies, 1999 data	[25]
Lubricants statistics		Consumption by application	[27]
Statistics EUROPALUB	EUROPALUB	Consumption and production of lubricant	[29]
Economics of WO regeneration	Coopers & Lybrand, John DUIJSENS	Economic aspects of the collection, recovery routes, waste, collection, 1995 data	[30]
WO regeneration in Europe	VITO - Raw Materials Centre of Expertise, DEVOLDERE	Regeneration, legislation, 1997 data	[31]
Guidelines for the management of oil wastes	FINNIDA (Finnish International Development Agency), HEIKKI TUUNANEN, Director	Description of the situation in Finland: collection, legislation, …, 1993 data	[32]
Contestaciones al cuestionario para que los Estados miembros Informen sobre la incorporacion al derecho interno y aplicacion de la directiva 75/439/CEE relativa a la gestion de los aceites usados, cuya ultima modificacion la constituye la Directiva 91/689/CEE	Ministerio de Medlo Ambiente, Spain	Waste, Collection, regeneration	[33]

Study Title	Organisation / Author	Main information used in the present study	Ref
Proposed National Hazardous Waste Management Plan, National Waste Database	EPA (Environmental Protection Agency), Ireland	Waste, legislation, 1998 data	[34], [35]
Le gisement national d'huiles usagées	ADEME	Consumption by application, waste, 1998 data	[37]
Waste Strategy 2000 (England and Wales)	DETR (Department of the Environment, Transport and the Regions), United Kingdom	Description of the organisation and recovery routes. 1999 data	[39]
Waste management policy in Germany The effect of new European directives and implementation status of waste law projects in Germany	Federeal Ministry of Environment Dr Helmut SCHNURER	Legislation	[38]
UK WO Market 2001	DETR / Oakdene Hollins Ltd, David FITZSIMONS	Quantities on WO in UK, technology, cost, prices, 1998 data	[40]
Collection of uses oil in the Netherlands September 2000	Dutch used oil collectors Arie NIJDAM	Market	[41]
Used oil recovery system miniraff, technical information	Minitec Engineering Dr Ekkehard HAMMER	Technologies	[42]
Filières de recyclage et de valorisation énergétique des huiles usagées France		Energy recovery	[43]
Comprehensive Product Stewardship System (CPSS) for WO A discussion paper, Australia	Department of the Environment and Heritage Graeme MARSHALL	Waste	[44]
Base oils for GF-3 and beyond The key to enhanced Performance Levels Canada	Par Excellence Development (PED) Peter MACK, Manager OEM Marketing & Base Oil Development	Regeneration, Technologies	[45]
Possible sources of elements in WO Canada	Par Excellence Development (PED) Don KRESS	Technologies	[46]

Study Title	Organisation / Author	Main information used in the present study	Ref
ROBYS Gasoil stabilization and purification Canada	Ontario centre for environmental technology advancement Par Excellence Development (PED), Don KRESS	Technologies Presentation of the process named ROBYS for thermo-cracking of WO	[47]
Fuel Oil Purification & Stabilization Canada	CANMET Energy Technology Centre Par Excellence Development (PED), Don KRESS	Technique Presentation of the process named ROBYS for thermo-cracking of WO	[48]
Shell Soaker Visbreaking Process Canada	Par Excellence Development (PED) Don KRESS	Technologies Presentation of the process named ROBYS for thermo-cracking of WO	[49]
New approches to WO reduction and reuse Canada	Energy Systems Division, Argonne National Laboratory Par Excellence Development (PED), Don KRESS	Technologies	[50]
Minutes of meeting with WATCO on new thermocracking plants	WATCO, Mr TRODOUX	Thermal cracking, technico-economic data	[51]
Suggested used lube oil management system for the European community	IBC International Business Consultants GmbH Dr Jan HEDBERG	Regeneration, collection	[52]
Presentation of IBC regeneration process	IBC International Business Consultants GmbH Dr Jan HEDBERG	Regeneration, technologies	[53]
Environmental loop for lubricants in Europe	IBC International Business Consultants GmbH Dr Jan HEDBERG	Flows of WO between collection, energy recovery, regeneration Comparison of the situation in the main countries of the world	

Study Title	Organisation / Author	Main information used in the present study	Ref
Description of the ROBYS process for thermocracking of WO Drawbacks and advantages	Par Excellence Development (PED) Don KRESS	Thermo-cracking process New technology for stabilisation of output with solvent	[54]
Presentation of the Swedish regeneration plant		Regeneration Fuel oil produced from WO	[55]
Waste management plan 1998-2004 Situation in Denmark	Danish Ministry of Environment	Quantities	[56]
Use of Waste Materials in the Cement Industry	Austrian Ministry of Environment	Quantities of WO burnt in cement kilns	[57]
Consorzio oblligatorio degli oli usati Italy	Consorzio oblligatorio degli oli usati	Collection of WO Description of the collection system with the list of actors (collectors, regeneration companies)	[57]
Processes subject to integrated pollution control Fuel production and combustion sector (including power generation) Combustion processes: Waste and recovered oil burners	Environment Agency, HMSO	Energy recovery and pollution Pollution from incineration of WO in different kinds of plants	[58]
Evolution of quantities of WO collected in Belgium		Collection of WO	[59]
Marine Fuel Specifications Canada	Par Excellence Development (PED) Don KRESS	Technologies Marine fuel	[60]
Introduction to Used Oil Canada	Par Excellence Development (PED) Don KRESS	Regulation Training module providing an overview of the used oil management program and on regulatory scenarios	[61]
Quantities and kind of energy source for cement kilns in France	Syndicat Français de l'industrie Cimentière	Incineration	[62]
Destruction des composés organiques dans un four a voie séche	CITEC	Incineration	[63]

Study Title	Organisation / Author	Main information used in the present study	Ref
Waste burning fuel		Incineration Description of techniques used	[64]
Remarks of ADEME on the French WO situtation May 2001	ADEME, Mrs Lydie OUGIER et Mr Eric LECOINTRE	Collection, regeneration, energy recovery 1999 data about the French situation: WO quantities, treatment costs, WO purchasing price, taxes…	[65]
Letter to the EC – February 2001	the Permanent representative of Greece	Information on the transposition and application of Council Directive 75/439/EC	[67]
Letter to the EC – December 2000	the Permanent representative of Italy	Information on the transposition and application of Council Directive 75/439/EC	[69]
Re-refined oils quality – Nov 1999	Claudia GRANDI, GEIR	Quality of re-refined base oils	[70]
Gestion de residuos especiales: vehiculos Fuera de Uso, Aceites Usados… - Mars 2001	Club Espanol de los Residuos	Situation in Spain (non official document)	[71]
Regenerate WO Into Basestocks or Thermally Crack Them Into Fuels	Lucie B. WHEELER – Silver Springs Oil Recovery Inc.	Refinery, regeneration, thermal cracking	[72]
Synopsis of business plan & Financial model for Petrus Oils Germany WO recycling project int Eisenhuttenstadt, Germany, September 2001	M. WILLIAMSON, Petrus Oils	Regeneration – project for a new plant	[73]
An overview regarding premium quality achievable with available advanced technologies, oct 2001	M. SCHIEPPATI, Viscolube	Regeneration, market, re-refined base oil quality	[74]
WO consumption & collection in the E.U. – year 2000, August 2001	IHMB - GEIR	WO consumption & collection in the E.U. – year 2000	[75]
Working Group organised by TN SOFRES Consulting in July 2001 with GEIR members: Viscolube, Baufeld, Dolbergen, Watco, Fuhse		Collection, regeneration	[76]

Appendix 2

List of Experts Interviewed or Contacted

List of Experts Interviewed or Contacted

Name	Organisation
Member States[46]	
Mrs WOLFSLEHNER Evelyn	BMU, A
Mr GILLET	MoE, B
Mr VAN GRIMBERGEN lies	OVAM, B
Mr WUTTKE Joachim	UBA, D
Mr JARON Andreas	BMU, D
Mr DIHLMANN Peter Mr MICHAEL Ernst	UVM, D
Mr MARTINEZ HURTADO Fermin	SGCA, Es
Mrs OUGIER Lydie Mr LECOINTRE Eric	ADEME, France
Mrs LEVINEN Riitta Mr PFISTER Klaus	VYH, Fin
Mrs HENRY Marie-Claire Mr DINGREMONT Benoit	MoE, Fr
Mr CROWE Matthew	Irish Environmental Protection Agency, Ire
Mr CORONIDI Maurizio	ENEA, It
Mr SCHMIT Robert	AEV, Lux
Mr DE KORT Toon Mr MEIJER Hans	VROM, NL
Mr PASSARO Dulce	Inresiduos, Pt
Mrs APPELBERG Margareta	MoE, Sw
Mr MEGAINEY Chris	DETR, UK

Experts from the Industry

Mr VERCHEVAL Jean	Groupement Européen de l'Industrie de la Régénération GEIR, Belgium
Mr SCHIEPPATI Renato Mr DALLA GIOVANNA Fabio	Viscolube, Italy & GEIR
Mr HARTMANN Christian Mr SZRAMKA Werner	Baufeld, Germany & GEIR
Mr PÖHLER Joachim Mr BRUHNKE Detlev	Dolbergen, Germany & GEIR
Mr FUHSE Martin	HORST FUHSE, Germany & GEIR
Mr HARTMANN Christian Mr SZRAMKA Werner	Baufeld, Germany & GEIR
Mr WILLIAMSON Chris	Petrus Oil, UK & GEIR
Mr TORRAS J.	Catalana de Tractament d'Olis Redisuals CATOR, Spain
Mr HATELEY Edward	European Union of Independent Lubricant Companies UEIL, France
Mr LEDURE Jacques Mr Trodoux Eric	WATCO Oil services, Belgium & ECOLUBE Recycling SA, Belgium & GEIR

[46] We only got answers from F and Ire

Experts from the Industry (contd.)

Mr RAMSDEN Paul	OSS Group Ltd, UK
Dr HEDBERG Jan	International Business Consultants GmbH IBC
Mr KRESS Don	President Par Excellence Developments Inc, Canada
Mr MIRGONE Pio Mr BRAVO	Exxon, It & European Petroleum Industry Association EUROPIA, Belgium
Mr WRIGLESWORTH	BP, UK & EUROPIA
Mr BIVONA	ERG, It & EUROPIA
Mr GRANADOS	Repsol YFP, Es & EUROPIA
Mrs POOT Brigitte	TotalFinaElf, Fr & EUROPIA
Mr ALWAST Holger	PROGNOS, Belgium
Mr MARTIN Eric	CONCAWE, Belgium

Appendix 3

Types of Base Oils and WO

Types of Lubricants and WO

The use of lubricants can be split according to two segments: automotive (more that 65%) and industry (less that 35%).

An important quantity of lubricants consumed is lost during use (auto-consumption): about 50% in average. This percentage varies from a type of use to another: more than 50% of automotive oils generate WO[47] whereas more than 50% of industrial oils are lost during use.

The following segmentation of WO is based on market considerations:

- (black) engine oils: they represent more than 70% of the WO stream[48]. With homogeneous characteristics, they are sought by regeneration plants.
- black industrial oils: they represent about 5% of WO. They are potentially suitable for regeneration but due to the content of additives and other substances, automotive oils are preferred by regeneration plants.
- light industrial oils: they represent about 25% of WO. Relatively clean, their selling price is high. They can either be regenerated on site or be re-used for other purposes. Their market is very specific and independent from the classical supply routes of regeneration.

The study will then focused on engine oils (and the regenerable black industrial oils), at least in the chapters dealing with the technico-economical and environmental analysis. As far as the physical flows (quantities of WO collected, regenerated…) are concerned, the data presented in the other chapters are based on the available literature which may include the three types of WO.

The following table details:

- the typology of lubricants and a split of the lubricant consumption according to this typology,
- the average ratio to be considered for each category of lubricant to assess the WO generated during their use,
- the type of WO, black oils (from engine origin or industrial origin) or light oils, generated in each case.

[47] 53% according to ADEME, Fr
[48] 82% according to ADEME, Fr

Typology of Lubricants and WO

Lubricants Consumption					*WO (WO)*		
Category	***Application***	***Use***	***European Consumption 1999 (kt)***	***% of consumption***	***Ratio (oil consumed / WO generated)***	***WO 1999 (kt)***	***Type of WO***
Engine oils	Engine oils for passenger cars	To diminish friction between moving parts of engine	2 098	42%	59%	1 238	Black oils
	First fill oils for passenger cars						
	Engine oils for commercial vehicles						
	First fill oils for industrial vehicles						
	Multipurpose diesel oils						
	Two-stroke engine oils						
	Other engine oils						
Gear oils & transmissions	Automatic transmission fluids	To inhibit wearing out of gears and bearings and also to inhibit oxidation and corrosion	1 149	23%	24%	276	Black oils
	Automotive gear oils						
	Industrial gear oils						
	Hydraulic transmission oils						
	Schock absorber oils						
Greases	Automotive greases	To diminish friction between moving parts of engine	150	3%	27%	40	Black oils
	Industrial greases						
Metalworking oils	Quenching oils	In metal working for lubricating and cooling of both tools and the metals to be worked	350	7%	0%	0	Lost
	Neat oils for metalworking						
	Soluble oils for metalworking						
	Rust prevention products						
Highly refined oils	Turbine oils		150	3%	48%	72	Light oils
	Electrical oils						
Other oils	Compressor oils	To inhibit wearing out of gears and bearings and also to inhibit oxidation and corrosion	400	8%	61%	244	Black oils
	General machine lubricants						
	Other oils for non-lubricating uses						
Processing oils	Process oils		699	14%	77%	538	Light oils
	Technical white oils						
	Medical white oils						
TOTAL			**4 995**	**100%**	**50% in average** but can vary according to countries, for example 42% for France [37]	**2 409**	

Sources: [6], [27], [29], [37]

Appendix 4

Multi-country Analysis

Multi-Country Analysis

The following indicators have been used, allowing a quantitative and qualitative description of the organisation and the actors in the countries and an easy comparison between countries.

Main philosophy	
Collection	Quantities collected (kt)
	Collection rate (%)
	Nb of licensed collectors
	Collection license granted by …
	Obligation of collectors
	Collection (circuits, destination…) organised by …
	Existence of competition between collectors / hauliers
	Main transportation mode
	Collection cost paid by …
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits
Energetic use	Energetic use rate (%)
	Nb of licensed plants
	Existence of a re-processing step
Regeneration	Regeneration rate (%)
	Technology of regeneration
	Number of plants (in 1998)
	Total capacity (kt) (in 1998)
	Capacity (Minimum - Maximum) (in 1998)
	Utilisation rate (%)
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)
	Exemption for WO incinerated as fuel
	Tax on WO incinerated as fuel (Euros/t of WO)
	Tax on lubricant consumption (Euros/t of oil)
	Exemption for lubricant produced from re-refined base oil
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)
Costs	Collection (Euros/t)
	Transportation (Euros/t)
	Re-processing before energetic use (Euros/t)
	Regeneration (Euros/t)
Subsidy	Collection of WO to be used as fuel (Euros/t)
	Collection of WO to be re-refined (Euros/t)
	Regeneration of WO (Euros/t)
Prices (tax excl.)	Price paid by WO holders for collection
	Purchasing price of collected WO for energetic use (Euros/t of WO)
	Purchasing price of collected WO for regeneration (Euros/t of WO)
	Selling price of re-refined WO (Euros/t of oil)
Comments	

A focus has been put on the organisation of the collection as well as on the financial incentives and fiscal context. This second aspect is particularly described in the financial flows (see appendix 5).

Remark

Due to the lack of recent and comprehensive information, these tables will need to be completed and up-dated in the scope of another study.

These main sources of information used are:

- IBC [25] for data about taxes and subsidies (1999 data),
- 1999 or 2000 data collected in the scope of that study for F, and some for B, It and D as well,
- Coopers & Lybrand [30] for the other MS (1993 data).

NB1

The energetic use rates and the regeneration rates indicated in the following pages are those calculated on the basis of the quantity of waste produced (thus potentially collectable), not on the basis of the quantity of waste effectively collected.

They are inferior to the ratios calculated on the basis of the waste collected. Both types of ratios are presented in chapter 3.1.1.2 on page 26.

NB2

'n.a.' means 'non available'. An empty line means also that the information was missing.

Description of countries		AUSTRIA	Source Austria
Main philosophy		A non subsidised system, with no regeneration capacity and a self financed system (focused on motor oil) for the maintenance of voluntary collection sites of municipalities	[30] p1
Collection	Quantities collected (kt)	34	[75]
	Collection rate (%)	74%	[75]
	Nb of licensed collectors	Vendors of motor oil, stations & garages	[30] p1
	Collection license granted by …	Regional authorities	
	Obligation of collectors	* Anyone generating more than 200 litres WO is obliged to inform the regional authorities within a year. Obligation to give their WO to collection sites owned by municipalities (143 collection sites), to licensed collectors or to hauliers. Customers are granted the right to deposit in the vendor's collection tank free of charge a quantity of used motor oil equal to the amount of new motor oil that they purchase * Licensed collectors: obliged to pick up all user oil from generators which are closer to their place of business than to that of any other haulier	[30] p1
	Collection (circuits, destination…) organised by …	Each individual collector under responsibility of the municipalities	
	Existence of competition between collectors / hauliers		
	Main transportation mode	Road	[30] p1
	Collection cost paid by …	Stations & garages (which transfer, to the buyers of motor oil, the cost of installing and maintaining collection site as well as the collection cost)	[30] p1
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(+) The Waste Law of 1990 has limited the points of sale of motor oil to gasoline station, repair garages and retail stores specialised in order to improve the used oil management system (-) Existence of a disposal charge	[30] p1
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(+) Licensed collectors are all vendors of motor oil	[30] p1
Energetic use	Energetic use rate (%)	74%	calculation
	Nb of licensed plants	* 2 cement kilns (which burn about 50% of WO collected) * 2 incineration plants	[30] p1
	Existence of a re-processing step	No	[30] p2
Regeneration	Regeneration rate (%)	0%	[10]
	Technology of regeneration	-	[30] p1
	Number of plants (in 1998)	0	[30] p1
	Total capacity (kt) (in 1998)	-	[30] p1
	Capacity (Minimum - Maximum) (in 1998)	-	[30] p1
	Utilisation rate (%)	-	[30] p1
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO (-) Total tax exemption for WO used as fuel	[30] p1
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	38	[25] p14
	Exemption for WO incinerated as fuel	Total: 38	[25] p14
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	378	[25] p14
	Exemption for lubricant produced from re-refined base oil	-	[25] p14
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	-	[30] p3
Costs	Collection (Euros/t)	n.a.	[30] p3
	Transportation (Euros/t)	n.a.	[30] p3
	Re-processing before energetic use (Euros/t)	-	[30] p3
	Regeneration (Euros/t)	-	[30] p3
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p1
	Collection of WO to be regenerated (Euros/t)	-	[30] p1
	Regeneration of WO (Euros/t)	-	[30] p1
Prices (tax excluded)	Price paid by WO holders for collection	75-302	[30] p1
	Purchasing price of collected WO for energetic use (Euros/t of WO)	n.a.	[30] p3
	Purchasing price of collected WO for regeneration (Euros/t of WO)	-	
	Selling price of re-refined base oil (Euros/t of oil)	-	
Comments			

NB: it has been possible to up-date several data related to the Belgian situation.

Description of countries		**BELGIUM**	**Source Belgium**
Main philosophy		A non subsidised system, with apparently a recent development of the regeneration	[76]
Collection	Quantities collected (kt)	60	[75]
	Collection rate (%)	79%	[75]
	Nb of licensed collectors	40	[30] p5
	Collection license granted by …	The government of the region (Flandres, Wallonia, Brussels)	[30] p5
	Obligation of collectors	The collectors have to provide the WO holders with information to which re-processors the WO is delivered. Collectors must have a permit for each region where they collect WO	[30] p5
	Collection (circuits, destination…) organised by …	Each individual collector	[30] p5
	Existence of competition between collectors / hauliers	Yes (many small collectors)	[30] p5
	Main transportation mode	Road	[30] p5
	Collection cost paid by …	Holders	[30] p5
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate		
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic use	Energetic use rate (%)	78% about 50% (1)	calculation [76]
	Nb of licensed plants	* Cement kilns * Road making industry * Lime industry	[76]
	Existence of a re-processing step	Yes, 7 plants (6 in Flandres + 1 in Wallonia)	[30] p6
Regeneration	Regeneration rate (%)	1% about 50% (1)	[10] [76]
	Technology of regeneration	-	
	Number of plants (in 2001)	2 (2)	[76]
	Total capacity (kt) (in 2001)	45 kt	[76]
	Capacity (Minimum - Maximum) (in 2001)	5 – 40 kt	[76]
	Utilisation rate (%)	75%	[76]
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) Total tax exemption for WO used as fuel	[25] p14
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	6	[25] p14
	Exemption for WO incinerated as fuel	Total: 6	[25] p14
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	-	[25] p14
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)	50	[76]
	Transportation (Euros/t)	included	[76]
	Re-processing before energetic use (Euros/t)	75-100	[76]
	Regeneration (Euros/t)	85-223	[76]
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p6
	Collection of WO to be re-refined (Euros/t)	0	[30] p6
	Regeneration of WO (Euros/t)	0	[30] p6
Prices (tax excluded)	Price paid by WO holders for collection	Free of charge for non contaminated automotive WO (less than 3000 L) 5 to 12 Euro/ton paid to collectors for contaminated automotive WO	[76]
	Purchasing price of collected WO for energetic use (Euros/t of WO)		
	Purchasing price of collected WO for regeneration (Euros/t of WO)		
	Selling price of re-refined WO (Euros/t of oil)	180 to 300	[76]
Comments		(1) whereas the Belgian MS declared only 1% to the EC in 1997, about 35 kt are regenerated today in Belgium or abroad according to WATCO (2) 2 regeneration plants according to WATCO - Watco Oil Services Hautrage – 40 kt - Mottay & Pisard Vilvoode – 5 kt A 40 kt/yr thermal cracking plant will be installed in Belgium by the end of 2001, operated by WATCO.	[10] [76] [76] [76]

Description of countries		DENMARK	Source Denmark
Main philosophy		A subsidised system which benefit to collection and energy recovery	[30] p10
Collection	Quantities collected (kt)	35	[75]
Collection	Collection rate (%)	75%	[75]
Collection	Nb of licensed collectors	See below	
Collection	Collection license granted by …		
Collection	Obligation of collectors	* The municipalities are obliged to initiate collection systems or delivery facilities for hazardous waste from industries as well as households * Municipalities are obliged to establish at least one collection site for used oil (and other wastes) * The industry is obliged to use the system	[30] p10
Collection	Collection (circuits, destination…) organised by …	WO is recovered by 2 organisations: * Public: The collection system of the municipalities connected with Kommunekemi A/S (a hazardous waste disposal firm) At least 1 collection site for each of the 275 municipalities 18 larger collection sites serve as transfer points to go to the incineration plants * Private: Dansk Oli Genburg (DOG) A/S (a private collector and re-processor) that owns 5 private collectors of WO	[30] p10
Collection	Existence of competition between collectors / hauliers	No	
Collection	Main transportation mode	Rail	[30] p10
Collection	Collection cost paid by …	Holders	[30] p10
Collection	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	Already a very efficient collection	
Collection	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic use	Energetic use rate (%)	75%	calculation
Energetic use	Nb of licensed plants	* Incineration plant: Kommunekemi A/S * Heating plants, …	[30] p10
Energetic use	Existence of a re-processing step	Often	
Regeneration	Regeneration rate	0%	[10]
Regeneration	Technology of regeneration	-	[30] p10
Regeneration	Number of plants (in 1998)	0	
Regeneration	Total capacity (kt) (in 1998)	-	
Regeneration	Capacity (Minimum - Maximum) (in 1998)	-	
Regeneration	Utilisation rate (%)	-	
Regeneration	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-)The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	319	[25] p14
Taxes	Exemption for WO incinerated as fuel	WO used as fuel are submitted to an ecotax of 304 Euros/t, but a grant of 304 is paid to all plants, except Kommunekemi	[25] p14
Taxes	Tax on WO incinerated as fuel (Euros/t of WO)	0 for all plants except Kommunekemi (304 Euros/t)	[25] p14
Taxes	Tax on lubricant consumption (Euros/t of oil)	113	[25] p14
Taxes	Exemption for lubricant produced from re-refined base oil	Total: 113	[30] p10
Taxes	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)	41.8 - 56.4	[30] p10
Costs	Transportation (Euros/t)	Included	[30] p12
Costs	Re-processing before energetic use (Euros/t)	Filtration: 55 - 68,8 Re-processing: 110 - 151,4 (high cost due to relative small plants)	[30] p12
Costs	Regeneration (Euros/t)	-	[30] p10
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	
Subsidy	Collection of WO to be re-refined (Euros/t)	-	
Subsidy	Regeneration of WO (Euros/t)	-	
Prices (tax excluded)	Price paid by WO holders / disposers for collection	By WO generators: * 128 for containers in collection sites of municipalities * 101,8 for oil delivered in loss weight	[30] p10
Prices (tax excluded)	Purchasing price of collected WO for energetic use (Euros/t of WO)	* Kommunekemi: pays 27 if < 5% water or charge 171 if > 5% water (only 136 if delivered in loss weight) * DOG does not pay or charge	[30] p10
Prices (tax excluded)	Purchasing price of collected WO for regeneration (Euros/t of WO)	-	
Prices (tax excluded)	Selling price of re-refined WO (Euros/t of oil)	-	
Comments		* The Danish system for collection and treatment of WO was established in 1972 on the initiative taken by the National Association of Danish Municipalities * The current level of the eco-tax on WO used as fuels, created in 1993, is 304 Euros/ton (it used to be 272,5)	

Description of countries		FINLAND	Source Finland
Main philosophy		A subsidised system, managed by a semi-private hazardous waste disposal firm (EKOKEM) which benefits to collection rate and makes priority to energetic use	[30] p17
Collection	Quantities collected (kt)	39	[75]
	Collection rate (%)	80% (2)	[75]
	Nb of licensed collectors	3	[30] p17
	Collection license granted by …	Government and EKOKEM	[30] p17
	Obligation of collectors	* Local authorities: each municipality is obliged to establish at least one collection facility for WO and other hazardous waste and accept WO only from households and small generators * Licensed collectors: have the monopoly into one or more of the 12 regions and transport WO to the EKOKEM and other incineration / treatment plants	[30] p17
	Collection (circuits, destination…) organised by …	EKOKEM (hazardous waste disposal firm owned by industry, the government and municipalities)	[30] p17
	Existence of competition between collectors / hauliers	No: after competitive bidding, hauliers are given the exclusive right to pick up all the WO from oil generators in the region	[30] p17
	Main transportation mode	Road	
	Collection cost paid by …	Subsidies paid by EKOKEM	[30] p17
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(+) Individual holders: free of charge (+) Companies: free of charge if having more than 1 t of WO (see below for more details)	
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(+) Centralised organisation managed by EKOKEM	
Energetic use	Energetic use rate (%)	51%	calculated
	Nb of licensed plants	3 types: * Hazardous waste incineration plants (including EKOKEM) * Several other firms for energetic use of WO without pre-treatment * Power plants (after a pre-treatment)	[30] p17
	Existence of a re-processing step	Sometimes	
Regeneration	Regeneration rate	4%	[10]
	Technology of regeneration		
	Number of plants (in 1998)	0 (1)	[30] p21
	Total capacity (kt) (in 1998)	-	[30] p21
	Capacity (Minimum - Maximum) (in 1998)	-	[30] p21
	Utilisation rate (%)	-	[30] p21
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) No regeneration plant in the country (-) Collected WO is sold at very low price for energetic use (-) No tax exemption for re-refined oils	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	58	[25] p14
	Exemption for WO incinerated as fuel	Total: 58	[30] p17
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[30] p17
	Tax on lubricant consumption (Euros/t of oil)	42	[25] p14
	Exemption for lubricant produced from re-refined base oil	No	[30] p17
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	42	[25] p14
Costs	Collection (Euros/t)	44-110 (average: 53)	[30] p17
	Transportation (Euros/t)	Included	[30] p17
	Re-processing before energetic use (Euros/t)	Included	
	Regeneration (Euros/t)		
Subsidy	Collection of WO to be used as fuel (Euros/t)	101	[30] p17
	Collection of WO to be re-refined (Euros/t)	101	[30] p17
	Regeneration of WO (Euros/t)	0	[30] p17
Prices (tax excluded)	Price paid by WO holders / disposers for collection	No charge if the quantity of WO is higher than a ton, does not contain more than 10% water and excessive concentrations of PCB's, and has a flash point of at least 55°C. In all other cases, collection site operators and large industrial generators who give their WO directly to hauliers must pay freight cost that depend on the size of the load of used oil and the distance	[30] p17
	Purchasing price of collected WO for energetic use (Euros/t of WO)	28	[30] p17
	Purchasing price of collected WO for regeneration (Euros/t of WO)		
	Selling price of re-refined WO (Euros/t of oil)		
Comments		(1) Clean waste engine oils (2kt in 1993) are separated from the WO stream and used as lubricant for chains saws, without any real regeneration step (2) 25% are disposed of (see table page 17)	

NB: it has been possible to up-date all the data related to the French situation. WO quantities refer to the 1999 situation and all the other information to the 2000-2001 situation.

	Description of countries	**FRANCE**	**Source France**
Main philosophy		A subsidised system (through tax on polluting activities (TGAP), including a product charge on fuels and virgin or re-refined oils) which benefits to collectors & cement kilns	
Collection (5)	Quantities collected (kt)	243	[75]
	Collection rate (%)	56%	[75]
	Nb of licensed collectors	64	[65]
	Collection license granted by …	Local authorities (préfets de département) for a duration of 5 years	[65]
	Obligation of collectors	* Stations & garages: WO deposit points * Local authorities: WO deposit points for the public and SMEs * Licensed collectors: obligation to collect any quantities (within 15 days of above 600 L)	[65]
	Collection (circuits, destination…) organised by …	Each individual collector	[65]
	Existence of competition between collectors / hauliers	Yes, at a regional level	[65]
	Main transportation mode	Road	[65]
	Collection cost paid by …	Subsidies paid by Ademe, out of the TGAP tax on polluting activities (free of charge for individual holders & companies when WO water content is lower than 5%)	[65]
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(-) The minimum amount of WO to be collected free of charge was risen in 1999 from 200 to 600L (this induces the collection to be put back)	[65]
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(-) Under less than 600L, the collectors are not obliged to collect within 15 days, which may result in a competition between licensed collectors and illegal ones	[65]
Energetic use	Energetic use rate (%)	37%	calculation
	Nb of licensed plants	30 energy recovery plants, total capacity: 425kt * 21 cement kilns, total capacity: 233kt * 7 waste treatment plants, total capacity: 35kt * 2 lime kilns, total capacity: 32kt	[65]
	Existence of a re-processing step	-	
Regeneration	Regeneration rate (%)	19%	[65]
	Technology of regeneration	old process, upgraded in 2001 (SOTULUB Tunisian process)	[65]
	Number of plants (in 1998)	1 (1)	[65]
	Total capacity (kt) (in 1998)	110	[65]
	Capacity (Minimum - Maximum) (in 1998)	110	[65]
	Utilisation rate (%)	74% (2)	[65]
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(+) Selling revenues + subsidy received by collectors are the same wherever WO are sent (to energetic users or regeneration) so, if this measure were alone, there would be no strong incentive for regeneration. But in case of difficulty for ECO-HUILE to be supplied with WO, ADEME pays a temporarily bonus to collectors to reconstitute the ECO-HUILE stocks of WO (this situation occurred in 2000). (3) (-) subsidies to cover collection cost of WO to be re-refined are not apply to imported WO (only for WO collected in France) (-) in addition to WO, most of the collectors collect also other waste interesting cement kilns	[65] [76] (76]
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	TIPP: 18	[65]
	Exemption for WO incinerated as fuel	see next line	
	Tax on WO incinerated as fuel (Euros/t of WO)	TIPP: 0 but TGAP: 9	[65]
	Tax on lubricant consumption (Euros/t of oil)	38 Euros/t for lubricants generating WO	[65]
	Exemption for lubricant produced from re-refined base oil	No: 0	[65]
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	38 Euros/t for lubricants generating WO	[65]
Costs	Collection (Euros/t)	72	[65]
	Transportation (Euros/t)	15	[65]
	Re-processing before energetic use (Euros/t)		
	Regeneration (Euros/t)	140 (from 132 to 179 Euros/t)	[65]
Subsidy	Collection of WO to be used as fuel (Euros/t)	65	[65]
	Collection of WO to be re-refined (Euros/t)	68	[65]
	Regeneration of WO (Euros/t)	0	[65]
Prices (tax excluded)	Price paid by WO holders for collection	Free of charge for individual holders & companies (to the extent that WO water content is lower than 5%)	[65]
	Purchasing price of collected WO for energetic use (Euros/t of WO)	5 in average (4)	[65]
	Purchasing price of collected WO for regeneration (Euros/t of WO)	2.5	[65]
	Selling price of re-refined WO (Euros/t of oil)	lower thatn 200	[65]

Description of countries	FRANCE	Source France

Comments	(1) 2 out of the 3 regeneration plants were closed in 1994 because the shareholders (petroleum companies) were not keen on financing the capital costs necessary to upgrade the plants to fit the environmental constraints. Only the ECO-HUILE plant is still operated. A new 110 kt plant is on project in Rouen (see chapter 3.1.2 on page 32). (2) 82 kt of WO entering the 110 kt ECO-HUILE regeneration plant (3) it is the responsibility of regenerators to contract with collectors (4) Purchasing price of collected WO by: - cement kilns = 3.8 Euros/t - lime kilns = 9 Euros/t - other users of WO for energetic use = 17.3 Euros/t	[65]

(5) Collection system in France

The costs of the collectors are covered by:

- The revenue of the WO sold to cement kilns & to the regenerator ECO-HUILE,
- The subsidy granted by the French Agency for the Environment ADEME.

ADEME contracts with the collectors on one hand and with the cement kilns and regenerator on the other hand.

The obligations of the contractors are as follows:

- Collectors:
  - to collect WO and to deliver them to licensed treatment plants,
  - to report, every month to ADEME, the quantities per destination plant,
  - to report, every six month to ADEME, the level and structure of their collection costs;
- Treatment plants:
  - to be supplied with collected WO,
  - to report, every month to ADEME, the quantities treated,
  - to report, every three month to ADEME, the level of their purchasing price.
- ADEME:
  - to pay on a month basis the subsidy to collectors,
  - to adjust, every six month, the level of the average collection cost to be considered on the basis of the reporting of a representative sample of the 58 collectors,
  - to adjust the level of the subsidy every three month.

  For that purpose, the National Aid Commission for WO (CNA), gathering all involved parties (collectors, cement kilns, regenerator, government), meet every three month to decide on the purchasing price proposed by the treatment plants and to validate the average collection cost to be considered.

NB: it has been possible to up-date some of the data related to the German situation.

Description of countries		**GERMANY**	**Source Germany**
Main philosophy		A non subsidised system, largely financed by holders, which benefits to cement kilns	
Collection	Quantities collected (kt)	460	[75]
	Collection rate (%)	85%	[75]
	Nb of licensed collectors	About 100 companies, of which the 8 biggest have 56% of the collection market	[5] p14, [30] p28
	Collection license granted by …		
	Obligation of collectors	* Holders: WO must be stored and consolidated separately according to the various qualities. According to the decree for WO, regenerable and non-regenerable WO must be separated * Licensed collectors: transport the WO to temporary storage tanks or directly to the processing / regeneration industry or cement industry	[30] p 28
	Collection (circuits, destination…) organised by …	Each individual collector	[30] p 28
	Existence of competition between collectors / hauliers	Yes, at a national level	[30] p 28
	Main transportation mode	Rail	[30] p 28
	Collection cost paid by …	Mainly holders	[30] p 28
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(+) High level of demand from cement kilns and steel industry due to total tax exemption on WO used as fuel	[38] p12
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic use	Energetic use rate (%)	30%	calculation
	Nb of licensed plants	4 (cement kilns and steel industry)	[30] p 28
	Existence of a re-processing step	-	[30] p 28
Regeneration	Regeneration rate (%)	55%	[10]
	Technology of regeneration	TFE + clay TFE + solvent TFE + hydro (up-grading in progress?)	[76]
	Number of plants (in 1998)	6 (1)	ICIS-LOR (feb. 2000)
	Total capacity (kt) (in 1998)	280	[6] p21
	Capacity (Minimum - Maximum) (in 1998)	30 - 120	[6] p21
	Utilisation rate (%)	19%	[30] p 28
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) Because there is no financial aid to regeneration (no tax exemption, no subsidy), re-refiners can not pay as much as cement kilns or steel industry for collected WO (-) Total tax exemption on WO used as fuel	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	28	
	Exemption for WO incinerated as fuel	Total: 28	
	Tax on WO incinerated as fuel (Euros/t of WO)	0	
	Tax on lubricant consumption (Euros/t of oil)	16	[30] p30, 0 pour [25] p14
	Exemption for lubricant produced from re-refined base oil	No: 0	
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	16	[30] p30
Costs	Collection (Euros/t)	57-96	[76]
	Transportation (Euros/t)	Included	[30] p30
	Re-processing before energetic use (Euros/t)	-	
	Regeneration (Euros/t)	165	[30] p30
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p30
	Collection of WO to be re-refined (Euros/t)	0	[30] p30
	Regeneration of WO (Euros/t)	From 2001, companies regenerating WO into new base oils become eligible for subsidies worth Euros 2.6 Millions (DM5m) per year	[76]
Prices (tax excluded)	Price paid by WO holders for collection	45-80	[76]
	Purchasing price of collected WO for energetic use (Euros/t of WO)	45-65	[76]
	Purchasing price of collected WO for regeneration (Euros/t of WO)	50-80 (2)	[76]
	Selling price of re-refined WO (Euros/t of oil)	300-350	[76]
Comments		(1) Regeneration plants in Germany DOLLBERGEN 140 kt BAUFELD Chemnitz 60 kt BAUFELD Duisburg 100 kt FUHSE 100 kt SÜDÖL 40 kt KS RECYCLING 100 kt Some other three are in project	ICIS-LOR (feb. 2000)
		(2) 20-50 Euros/t in 2000 50-80 Euros/t in 2001, included WO imported from B…	[76]

Description of countries		GREECE	Source Greece
Main philosophy		A non subsidised system, with a low collection rate due to strong competition from illegal burning A regeneration plant which import WO to run at maximum capacity	[30] p 34
Collection	Quantities collected (kt)	22	[75]
	Collection rate (%)	37%	[75]
	Nb of licensed collectors	4 legal collectors contracted by the re-refinery plant + a large number of small illegal collectors	[30] p 34
	Collection license granted by …		
	Obligation of collectors		
	Collection (circuits, destination…) organised by …	Regeneration plant	[30] p 34
	Existence of competition between collectors / hauliers	Yes, a lot of small illegal collectors	[30] p 34
	Main transportation mode	Road / sea	[30] p 34
	Collection cost paid by …	Hauliers	[30] p 34
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(-) The decree on collection and treatment of WO is recent (January 1996) (-) Due to the mountainous nature of the country and the large number of islands, collection of WO is difficult (-) The collection system is not well organised	[30] p 34
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(-) a large number of illegal small collectors that sell untreated WO as fuel	[30] p 34
Energetic	Energetic use rate (%)	28%	calculation
	Nb of licensed plants	0	
	Existence of a re-processing step		
Regeneration	Regeneration rate (%)	8% (1)	[10]
	Technology of regeneration		
	Number of plants (in 1998)	1 (2)	[30] p 34
	Total capacity (kt) (in 1998)	36	[30] p 34
	Capacity (Minimum - Maximum) (in 1998)	36	[30] p 34
	Utilisation rate (%)	100% with WO importation	[30] p 34
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) Not enough domestic WO collected to run the regeneration plant at its maximum capacity of 36kt (-) Strong competition from illegal burning (+) 4 collectors are contracted with the regeneration plant	[30] p 34
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	39	[25] p14
	Exemption for WO incinerated as fuel	Total: 39	[25] p14
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	-	[25] p14
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)	47,2	[30] p 34
	Transportation (Euros/t)	Included	[30] p 34
	Re-processing before energetic use (Euros/t)		
	Regeneration (Euros/t)	158	[30] p 34
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p 35
	Collection of WO to be re-refined (Euros/t)	0	[30] p 35
	Regeneration of WO (Euros/t)	0	[30] p 35
Prices (tax excluded)	Price paid by WO holders / disposers for collection	0	[30] p 34
	Purchasing price of collected WO for energetic use (Euros/t of WO)		
	Purchasing price of collected WO for regeneration (Euros/t of WO)	70	[30] p 34
	Selling price of re-refined WO (Euros/t of oil)	268 - 276	[30] p 35
Comments		(1) LPC regeneration plant has to import 20 kt/year from North Africa and Saudi Arabia to run its plant (there are not accounted for in this regeneration rate of 8%). No subsidy is given to the re-refinery plant by the government (2) 'at least 10 companies in Greece regenerate WO' according to the letter of the Deputy Permanent Representative of Greece tot he EEC	[30] p 34 [67]

Description of countries		IRELAND	Source Ireland
Main philosophy		A non subsidised system, with no regeneration capacity and an insufficiently organised collection system	[30]p38
Collection	Quantities collected (kt)	17	[75]
	Collection rate (%)	86%	[75]
	Nb of licensed collectors	2	[30]p38
	Collection license granted by …	Local authorities where the collectors are based	[30]p38
	Obligation of collectors	* The 2 collectors, which collect, transport and reprocess WO, have to present figures to the local authority * Collection through garages, disposal sites for the public, the industry and ships * Collectors are not obliged to collect all of the WO presented to them	[30]p38
	Collection (circuits, destination…) organised by …	The 2 collectors	[30]p38
	Existence of competition between collectors / hauliers	No, as only 2 collectors	[30]p38
	Main transportation mode	Road	[30]p38
	Collection cost paid by …	Holders	[30]p38
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(-) Insufficiently organised collection system	
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic	Energetic use rate (%)	86%	calculated
	Nb of licensed plants		
	Existence of a re-processing step	Yes (integrated to collector activity)	[30]p38
Regeneration	Regeneration rate	0%	[10]
	Technology of regeneration	-	[30]p38
	Number of plants (in 1998)	0	[30]p38
	Total capacity (kt) (in 1998)	-	[30]p38
	Capacity (Minimum - Maximum) (in 1998)	-	[30]p38
	Utilisation rate (%)	-	[30]p38
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-)The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO (-) Total tax exemption for WO used as fuel	[30]p38
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	18	[25] p14
	Exemption for WO incinerated as fuel	Total: 18	[25] p14
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	-	[30]p38
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[30]p38
Costs	Collection (Euros/t)	38	[30]p38
	Transportation (Euros/t)	Included	[30]p38
	Re-processing before energetic use (Euros/t)	44	[30]p39
	Regeneration (Euros/t)	-	[30]p39
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30]p38
	Collection of WO to be re-refined (Euros/t)	-	[30]p38
	Regeneration of WO (Euros/t)	-	[30]p38
Prices (tax excluded)	Price paid by WO holders for collection	153 Euros/year for 3 collections	[30]p38
	Purchasing price of collected WO for energetic use (Euros/t of WO)	108-140	[30]p38
	Purchasing price of collected WO for regeneration (Euros/t of WO)	-	[30]p38
	Selling price of re-refined WO (Euros/t of oil)	-	[30]p38
Comments			

NB: it has been possible to up-date several data related to the Italian situation.

	Description of countries	**ITALY**	**Source Italy**
Main philosophy		A subsidised system (through a product charge on fuels and virgin or re-refined oils), managed by a private consortium (COOU) established by decree and whose priority is the regeneration of WO, which buy and sell collected WO and subsidy regeneration through tax exemption	
Collection	Quantities collected (kt)	200	[75]
	Collection rate (%)	74%	[75]
	Nb of licensed collectors	86 licensed collectors 6 main regional transportation co-ordination centres	[30] p43
	Collection license granted by …	Regional governments	[30] p43
	Obligation of collectors	* Licensed collectors: obligation to bring collected WO to 1 of the 6 main regional transportation co-ordination centres	[30] p43
	Collection (circuits, destination…) organised by …	Consorzio Obligatorio degli Oli Usati (COOU) created by decree in 1982	[30] p43
	Existence of competition between collectors / hauliers	No, hauliers are contracted by the Consortium	[30] p43
	Main transportation mode	Road	[30] p43
	Collection cost paid by …	The consortium	[30] p43
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(+) Existence of a compulsory consortium (COOU) dedicated to WO recovery, whose obligation is to collect and re-refine WO in priority. Obligation of all manufacturers and importers of virgin or re-refined lubricants in Italy to belong to the Consortium. Monitored by all the concerned ministries.	
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(+) Strong incentive to regeneration (50% discount on a high level tax on virgin oil...)	
Energetic	Energetic use rate (%)	18%	calculated
	Nb of licensed plants	Cement kilns and brick kilns	
	Existence of a re-processing step	-	
Regeneration	Regeneration rate (%)	55%	[10]
	Technology of regeneration	TDA + clay TDA + hydro (up-grading in progress?) PDA + hydro (up-grading in progress?)	[76]
	Number of plants (in 1998)	6 (1)	[6] p21
	Total capacity (kt) (in 1998)	239	[6] p21
	Capacity (Minimum – Maximum) (in 1998)	9 - 100	[6] p21
	Utilisation rate (%)	33%	
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(+) Existence of the consortium (+) Strong incentive to regeneration (50% discount on a high level tax on virgin oil...) (-) Total tax exemption on oils used as fuels	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	30 to government	[76]
	Exemption for WO incinerated as fuel	Total: 30	[76]
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[76]
	Tax on lubricant consumption (Euros/t of oil)	665-667 = 623 to government + 42-44 to consortium	[76]
	Exemption for lubricant produced from re-refined base oil	Partial: 296 (45%) (2)	[76]
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	369-371 = 327 to government + 42-44 to consortium	[76]
Costs	Collection (Euros/t)	100	[76]
	Transportation (Euros/t)	Included	[76]
	Re-processing before energetic use (Euros/t)	-	
	Regeneration (Euros/t)	260	[30] p43
Subsidy	Collection of WO to be used as fuel (Euros/t)	95	[76]
	Collection of WO to be re-refined (Euros/t)	100	[76]
	Regeneration of WO (Euros/t)	0	[76]
Prices (tax excluded)	Price paid by WO holders for collection	Free of charge	[76]
	Purchasing price of collected WO for energetic use (Euros/t of WO)	40	[76]
	Purchasing price of collected WO for regeneration (Euros/t of WO)	40	[76]
	Selling price of re-refined WO (Euros/t of oil)	360	[76]
Comments		(1) 6 regeneration plants: * VISCOLUBE (Pieve Fissiraga), capacity: 100kt * AGIP PETROLI (Ceccano), capacity: 65kt * DISTOM (Porto Torres), capacity: 20kt * RAMOIL (Napoli), capacity: 35kt * OMA (Torino), capacity: 10kt * SIRO (Milano), capacity: 9kt (2) this measures will end up at the end of 2001; there will be no exemption anymore	[76]

Description of countries		LUXEMBOURG	Source Luxembourg
Main philosophy		A non subsidised system, with a well organised collection system but no recovery plant (WO being exported to Belgian cement kilns)	
Collection	Quantities collected (kt)	2	[75]
	Collection rate (%)	39%	[75]
	Nb of licensed collectors	21 hauliers	
	Collection license granted by …		
	Obligation of collectors	* At least 1 collection site in each of the 118 municipalities * Besides 8 permanent collection sites * The transport and exportation of WO for recovery needs a permit	[30] p49
	Collection (circuits, destination…) organised by …	Each haulier	[30] p49
	Existence of competition between collectors / hauliers	Yes	[30] p49
	Main transportation mode	Road	[30] p49
	Collection cost paid by …	Holders	
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate		
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic	Energetic use rate (%)	0%	calculated
	Nb of licensed plants	0	[30] p49
	Existence of a re-processing step	No	
Regeneration	Regeneration rate (%)	39% (?)	[10]
	Technology of regeneration	-	[30] p49
	Number of plants (in 1998)	0	[30] p49
	Total capacity (kt) (in 1998)	-	[30] p49
	Capacity (Minimum - Maximum) (in 1998)	-	[30] p49
	Utilisation rate (%)	-	[30] p49
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-)The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO	[30] p49
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	6	[25] p14
	Exemption for WO incinerated as fuel	Total	[25] p14
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	Total	[25] p14
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)		
	Transportation (Euros/t)		
	Re-processing before energetic use (Euros/t)		
	Regeneration (Euros/t)		
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p49
	Collection of WO to be re-refined (Euros/t)	0	[30] p49
	Regeneration of WO (Euros/t)	0	[30] p49
Prices (tax excluded)	Price paid by WO holders for collection	* Individual: free of charge * Industrial: charge depending on the market	
	Purchasing price of collected WO for energetic use (Euros/t of WO)		
	Purchasing price of collected WO for regeneration (Euros/t of WO)		
	Selling price of re-refined WO (Euros/t of oil)		
Comments		Many gaps	

Description of countries		NETHERLANDS	Sources Netherlands
Main philosophy		A non subsidised system, with energetic use in shipment (no regeneration capacity is available)	[30] p65
Collection	Quantities collected (kt)	60	[75]
	Collection rate (%)	72%	[75]
	Nb of licensed collectors	6 licensed collectors in charge of the pre-treatment too	[30] p65
	Collection license granted by …	Dutch government	[30] p65
	Obligation of collectors	For each of the 6 zones, one of the six collectors is obliged to collect, while the others are allowed to collect, thus creating some competition (1)	[30] p65
	Collection (circuits, destination…) organised by …	Government and collectors	
	Existence of competition between collectors / hauliers	The country is divided in 6 areas in which each of the 6 collectors have the right to collect WO	[30] p65
	Main transportation mode	Road	
	Collection cost paid by …	WO holders	[30] p65
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(-) The government does not subsidise the collection through financial instruments (-) Existence of a disposal charge	[30] p30
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic	Energetic use rate (%)	72%	calculated
	Nb of licensed plants		
	Existence of a re-processing step	Yes (7)	[30] p65
Regeneration	Regeneration rate (%)	0%	[10]
	Technology of regeneration	-	[7]
	Number of plants (in 1998)	0 (2)	[7]
	Total capacity (kt) (in 1998)	-	[7]
	Capacity (Minimum - Maximum) (in 1998)	-	[7]
	Utilisation rate (%)	-	[7]
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-)The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO	[30] p30
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	31	[30] p65
	Exemption for WO incinerated as fuel	No: 0	
	Tax on WO incinerated as fuel (Euros/t of WO)	31	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[30] p65
	Exemption for lubricant produced from re-refined base oil	-	[30] p65
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[30] p65
Costs	Collection (Euros/t)	61	[30] p65
	Transportation (Euros/t)	Included	[30] p65
	Re-processing before energetic use (Euros/t)	58	[30] p67
	Regeneration (Euros/t)	-	[30] p65
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p65
	Collection of WO to be re-refined (Euros/t)	-	[30] p65
	Regeneration of WO (Euros/t)	-	[30] p65
Prices (tax excluded)	Price paid by WO holders for collection	81,5 (prices are freely determined by supply and demand with a ceiling price set monthly by the ministry of environment and tied to heavy fuel prices)	[30] p65
	Purchasing price of collected WO for energetic use (Euros/t of WO)	63	[30] p68
	Purchasing price of collected WO for regeneration (Euros/t of WO)	-	[30] p68
	Selling price of re-refined WO (Euros/t of oil)	-	[30] p68
Comments		(1) The six collectors process the WO into a heavy fuel substitute through separation of water and suspended solids (2) 1 regeneration plant was is project in 1993. At that time, the Dutch government was expecting that within a few years a high percentage of regeneration would be achieved. No information was available regarding the current situation of that project.	

Description of countries		PORTUGAL	Source Portugal
Main philosophy		A collection system that is not well-organised through insufficient control of the regulation and no regeneration	
Collection	Quantities collected (kt)	40 (1)	[75]
	Collection rate (%)	64%	[75]
	Nb of licensed collectors		
	Collection license granted by …	5 Energy Regional Authorities	[30] p52
	Obligation of collectors		
	Collection (circuits, destination…) organised by …	Each collector in its own dedicated working area	[30] p52
	Existence of competition between collectors / hauliers	No	[30] p52
	Main transportation mode		
	Collection cost paid by …		
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate		
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic	Energetic use rate (%)	64%	calculated
	Nb of licensed plants		
	Existence of a re-processing step		
Regeneration	Regeneration rate (%)	0%	[10]
	Technology of regeneration	-	[30] p52
	Number of plants (in 1998)	0	[30] p52
	Total capacity (kt) (in 1998)	-	[30] p52
	Capacity (Minimum - Maximum) (in 1998)	-	[30] p52
	Utilisation rate (%)	-	[30] p52
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) Low level of collection (-)The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO	[30] p54
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	12	[25] p14
	Exemption for WO incinerated as fuel	Total: 12	[25] p14
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	0	[25] p14
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)		
	Transportation (Euros/t)		
	Re-processing before energetic use (Euros/t)	-	[30] p54
	Regeneration (Euros/t)	-	[30] p54
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[25] p14
	Collection of WO to be re-refined (Euros/t)	-	[30] p54
	Regeneration of WO (Euros/t)	-	[30] p54
Prices (tax excluded)	Price paid by WO holders for collection		
	Purchasing price of collected WO for energetic use (Euros/t of WO)		
	Purchasing price of collected WO for regeneration (Euros/t of WO)	-	[30] p54
	Selling price of re-refined WO (Euros/t of oil)	-	[30] p54
Comments		Lots of missing information (1) 30 kt of WO collected according to [66]	

Description of countries		SPAIN	Source Spain
Main philosophy		A subsidised system (in Spain: through a governmental subsidy to collection and regeneration; in Catalonia: through a disposal charge, WO to be re-refined free of charge and no product charge on re-refined oil) but a non regulated and controlled collection system in some regions and competition between re-refined oil and existing virgin oil stocks	
Collection	Quantities collected (kt)	105	[75]
	Collection rate (%)	47%	[75]
	Nb of licensed collectors	17 licensed and 60 not licensed	[30] p55
	Collection license granted by …	Government	[30] p55
	Obligation of collectors		
	Collection (circuits, destination…) organised by …	Each individual collector	[30] p55
	Existence of competition between collectors / hauliers	Yes	[30] p55
	Main transportation mode	Road	[30] p55
	Collection cost paid by …	* Spain: Treatment operators + subsidy from government * Catalonia: Holders	[30] p55
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(-) No regulated and controlled collection system in some regions (-) Existence of many non-licensed hauliers * Spain: (+) WO bought by collectors/hauliers to holders (+) Govermental subsidy to collection * Catalonia: (-) Disposal charge	
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(-) No regulated and controlled collection system in some regions (-) Existence of many non-licensed hauliers	
Energetic	Energetic use rate (%)	31%	calculated
	Nb of licensed plants		
	Existence of a re-processing step	Sometimes	[30] p55
Regeneration	Regeneration rate	16%	[10]
	Technology of regeneration		
	Number of plants (in 1998)	8 (?)	[6] p21[7] p18
	Total capacity (kt) (in 1998)	190	
	Capacity (Minimum - Maximum) (in 1998)		
	Utilisation rate (%)	6%	
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(+) Available regeneration capacities * Spain: (+) Governmental subsidy to regeneration * Catalonia: (+) Collected WO are free of charge for re-refiners (+) Total tax exemption on re-refined oil (-) Total tax exemption on WO used as fuel oil	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	13	[25] p14
	Exemption for WO incinerated as fuel	Total: 13	[30] p60
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[30] p57
	Tax on lubricant consumption (Euros/t of oil)	Spain: 0 ; Catalonia: 78.5	[30] p57
	Exemption for lubricant produced from re-refined base oil	Spain: - ; Catalonia: total (78.5)	[30] p57
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	
Costs	Collection (Euros/t)	25-38	[30] p57
	Transportation (Euros/t)	Included	[30] p57
	Re-processing before energetic use (Euros/t)		
	Regeneration (Euros/t)	78,5	[30] p57
Subsidy	Collection of WO to be used as fuel (Euros/t)	31-50	
	Collection of WO to be re-refined (Euros/t)	31-50	
	Regeneration of WO (Euros/t)	Spain: 88-94 ; Catalonia: -	
Prices (tax excluded)	Price paid by WO holders for collection	Spain: WO is bought 18.9 and 62.8 by collectors/hauliers to holders Catalonia: holders pay 78.5 to collectors/hauliers	[30] p57
	Purchasing price of collected WO for energetic use (Euros/t of WO)	62-120	[30] p57
	Purchasing price of collected WO for regeneration (Euros/t of WO)	Spain: 44 ; Catalonia: 0	[30] p57
	Selling price of re-refined WO (Euros/t of oil)	258	[30] p57
Comments		Project to create a national Eco-tax on all oils Regeneration plants * CATOR (Alcover), capacity: 42kt * ECOLUBE, capacity: 27kt * URBASER, capacity: 40kt Cracking plant * GUASCOR, capacity: 14kt	[7] p18

Description of countries		SWEDEN	Source Sweden
Main philosophy		A non subsidised system, with no regeneration capacity and a strong demand for energetic use from an extensive cement industry	[30] p61
Collection	Quantities collected (kt)	63	[75]
	Collection rate (%)	80%	[75]
	Nb of licensed collectors	10 - 20	[30] p61
	Collection license granted by …	Municipalities	[30] p61
	Obligation of collectors	WO is collected by municipalities and private companies dependent of the region. Municipalities are permitted to monopolise the collection of WO in their region. DIY-ers can bring their WO to gas-stations without any charge	[30] p61
	Collection (circuits, destination…) organised by …		
	Existence of competition between collectors / hauliers	Not really, as municipalities are permitted to monopolise the collection of WO	[30] p61
	Main transportation mode	Road	[30] p61
	Collection cost paid by …	* Re-processors for DIY-ers * Industrial generators of WO	[30] p61
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate	(-) Existence of a disposal charge for industrial holders	
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits		
Energetic use	Energetic use rate (%)	80%	calculation
	Nb of licensed plants	Mainly cement industry (90% of WO burnt) Some waste incineration plants (10% of WO burnt)	[30] p61
	Existence of a re-processing step	Yes, 3 re-processors (RECI, Lundstams, SAKAB) or directly	[30] p61
Regeneration	Regeneration rate (%)	0%	[10]
	Technology of regeneration	-	[30] p61
	Number of plants (in 1998)	0	[30] p61
	Total capacity (kt) (in 1998)	-	[30] p61
	Capacity (Minimum - Maximum) (in 1998)	-	
	Utilisation rate (%)	-	
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) Strong demand from an extensive cement industry (-)The current level of collected WO is low for a regeneration plant which would be fed only with domestic WO	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	238	[25] p14
	Exemption for WO incinerated as fuel	Partial: 178 (75%)	[30] p61
	Tax on WO incinerated as fuel (Euros/t of WO)	60	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	-	[30] p61
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)	28,9 - 35,8	[30] p61
	Transportation (Euros/t)	Included	[30] p61
	Re-processing before energetic use (Euros/t)	30	[30] p61
	Regeneration (Euros/t)	-	[30] p61
Subsidy	Collection of WO to be used as fuel (Euros/t)	0	[30] p61
	Collection of WO to be re-refined (Euros/t)	-	[30] p61
	Regeneration of WO (Euros/t)	-	[30] p61
Prices (tax excluded)	Price paid by WO holders for collection	DIY (Do It Yourself): 0 Industrials: about 30	[30] p61
	Purchasing price of collected WO for energetic use (Euros/t of WO)	35,8 - 47,8	[30] p61
	Purchasing price of collected WO for regeneration (Euros/t of WO)		
	Selling price of re-refined WO (Euros/t of oil)	-	
Comments			

NB: it has been possible to up-date some of the data related to the UK situation thanks to the UK report [40].

Description of countries		UNITED KINGDOM	Source United Kingdom
Main philosophy		A partial market-based situation: * No subsidy for regeneration, no product charge on oils * WO bought by collectors to holders * Incentives to energy recovery routes (tax exemption on WO used as fuel, no stringent emission standards) * Large variety of plants burning WO (including power plants).	[30] p72
Collection	Quantities collected (kt)	353	[75]
	Collection rate (%)	86%	[75]
	Nb of licensed collectors	40 - 50 collections companies	[30] p72
	Collection license granted by …		
	Obligation of collectors		
	Collection (circuits, destination…) organised by …	Each individual collector	[30] p72
	Existence of competition between collectors / hauliers	Yes, strong	[30] p72
	Main transportation mode	Road	[30] p72
	Collection cost paid by …	Treatment operators (regeneration and energy recovery)	[30] p72
	Factors favourable (+) / unfavourable (-) to the increase of the collection rate		
	Factors favourable (+) / unfavourable (-) to the decrease of illegal collection circuits	(-) The adopted Waste Incineration Directive applies more stringent emission standards (compared to the current situation in UK) to any plant burning wastes, including WO. This will significantly restrict the number of existing furnaces in the UK where WO can be burned and, as a consequence, will probably reduce the amount of WO managed in this way.	[39] p129
Energetic use	Energetic use rate (%)	85%	calculated
	Nb of licensed plants	Energy recovery plants (1): * 7 large coal or oil-fired power stations * 5 road stone users at 125 sites * 2 cement and lime kilns * dozens of industrial furnaces	[40] p2
	Existence of a re-processing step	Yes	[40] p2
Regeneration	Regeneration rate (%)	0%	[10]
	Technology of regeneration	-	
	Number of plants (in 1998)	0	[30] p72
	Total capacity (kt) (in 1998)	0	[30] p72
	Capacity (Minimum - Maximum) (in 1998)	0	[30] p72
	Utilisation rate (%)	-	
	Factors favourable (+) / unfavourable (-) to the increase of the re-generation rate	(-) existence of several routes, with which regeneration is in competition (+) project to abandon tax exemption on oils used as fuels (+) project to create a tax on lubricants	
Taxes	Tax on heavy fuel consumption (Euros/t of fuel)	43	[25] p14
	Exemption for WO incinerated as fuel	Total	
	Tax on WO incinerated as fuel (Euros/t of WO)	0	[25] p14
	Tax on lubricant consumption (Euros/t of oil)	0	[25] p14
	Exemption for lubricant produced from re-refined base oil	-	[25] p14
	Tax on lubricant produced from re-refined base oil (Euros/t of oil)	0	[25] p14
Costs	Collection (Euros/t)	30,5 - 46	[30] p72
	Transportation (Euros/t)	Included	[30] p72
	Re-processing before energetic use (Euros/t)	21	[30] p72
	Regeneration (Euros/t)	63	[30] p72
Subsidy	Collection of WO to be used as fuel (Euros/t)	-	
	Collection of WO to be re-refined (Euros/t)	-	
	Regeneration of WO (Euros/t)	-	
Prices (tax excluded)	Price paid by WO holders for collection	Collectors pay up to 30 Euros/t or receive up to 45 Euros /t of WO depending upon the degree of contamination with water and other materials For automotive WO, they pay between 0 to 15 Euros/t	[40] p12
	Purchasing price of collected WO for energetic use (Euros/t of WO)	For WO collected in the UK: 156 Euros/ton paid by cement kilns and British power stations For imported WO (e.g. from Germany) to cement kilns: 61 Euros/ton are paid to companies holding WO in Germany by UK importers	[40] p18 [40] p17
	Purchasing price of collected WO for regeneration (Euros/t of WO)		
	Selling price of re-refined WO (Euros/t of oil)		
Comments		(1) However, from 2006, the Waste Incineration Directive will prevent many of the current RFO (Replacement Fuel Oil) users from burning it. The majority of WO will be directed to cement and lime kilns, which may be paid 32 Euros/ton to accept it.	

Appendix 5

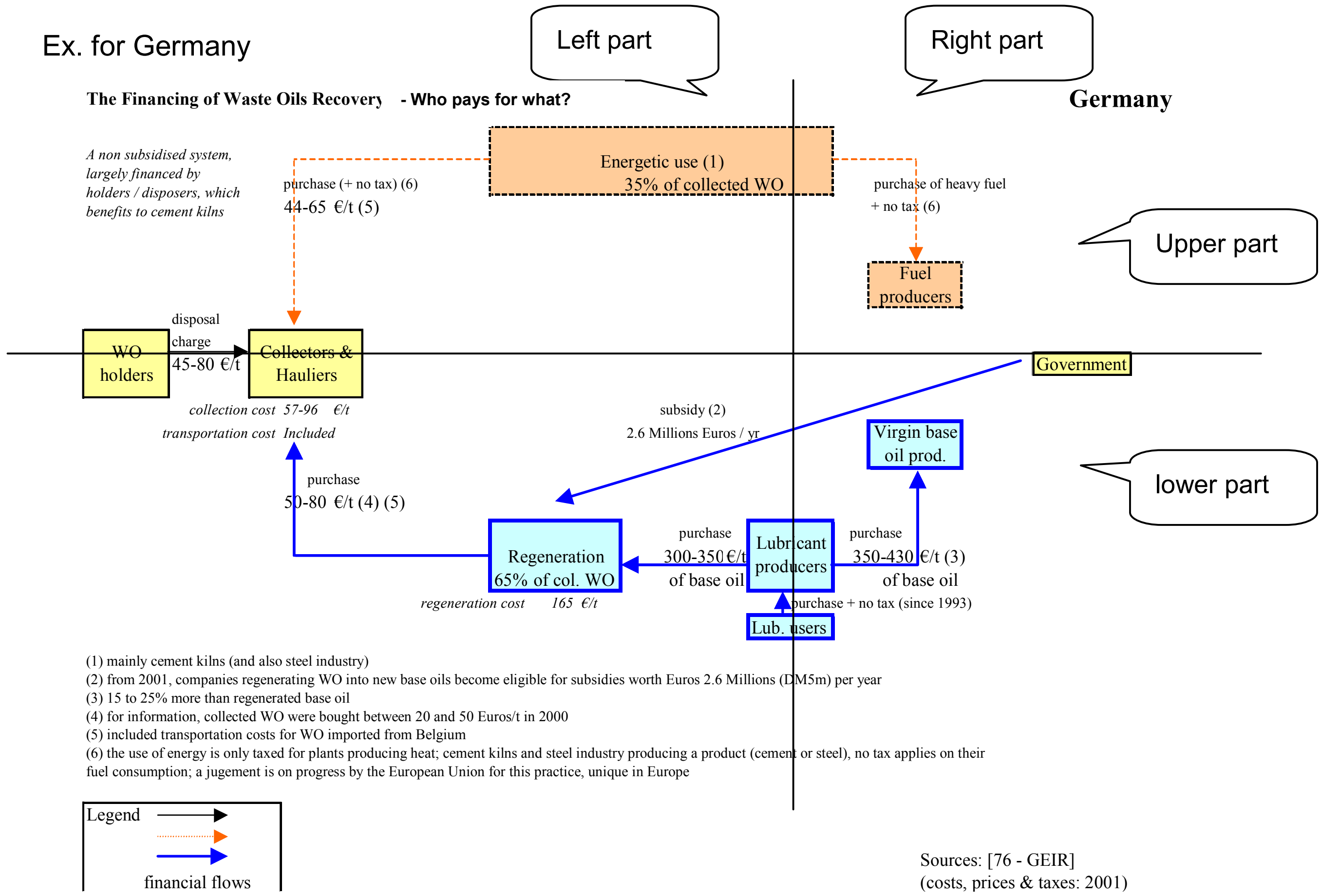
Financial Flows between Actors

Financial Flows between Actors

A systematic financial flow diagram has been elaborated for each country, aiming at:

- describing who pay for what and what is the situation in terms of financial incentives and taxes,
- allowing an easy comparison between the countries.

Ex. for Germany



Only the financial flows are represented (not the physical flows of WO).

In both cases of energetic use (upper part of the diagram) and regeneration (lower part of the diagram), two situations are represented:

- the use of collected WO (the left part of the diagram),
- the use of alternative products: alternative fuels in the case of energetic use and virgin base oil in the case of regeneration (the right part of the diagram).

As far as the units are concerned, when not indicated, the €/t refer to one ton of WO. But some figures do not concern WO: in these cases, the concerned ton is mentioned (t of base oil, t of lubricant…).
As a consequence, all the figures can not be added together.

The main sources of information have been:

- for B, D, F, It and the UK: recent data from either the MS (F [65]) or the GEIR (B, D, It [76]) or a report (UK, [40],
- for the other countries: IBC [25] (1999 data for taxes and subsidies) and Coopers & Lybrand report [30] (1993 data for costs and prices).

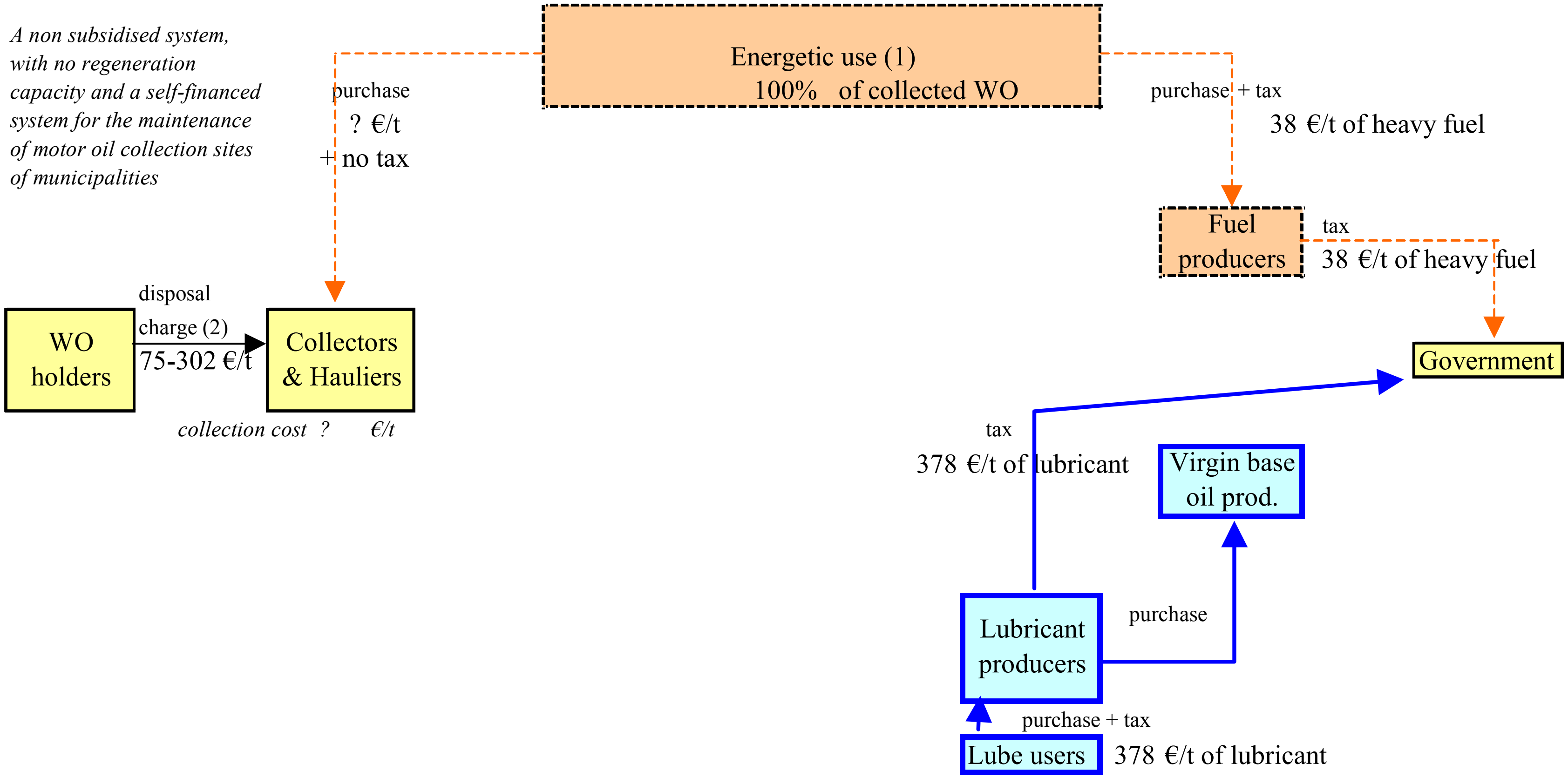
This has allowed to up-date information regarding the tax situation in each country to the 1999 situation (but evolution have already occurred; e.g. Germany where regenerators receive a subsidy from 2001 – see chapter 3.2.3 and appendix 4). As far as the costs are concerned, it is likely that only minor changes may have occurred (insofar as the processes are the same of course). On the contrary, the purchasing and selling prices may have evolved since 1993.

NB: in the countries where cement kilns represent the predominant energetic use (D, Sw and, to a lower extent, B, It and the UK), the alternative fuel indicated, heavy fuel, may not be representative of the reality (since when cement kilns are not supplied with WO, they might burn either coke or other industrial wastes (used tires, greases, animal flours…).

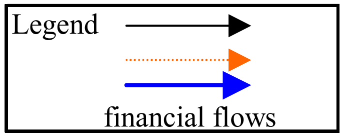
The Financing of Waste Oils Recovery - Who pays for what?

Austria

A non subsidised system, with no regeneration capacity and a self-financed system for the maintenance of motor oil collection sites of municipalities

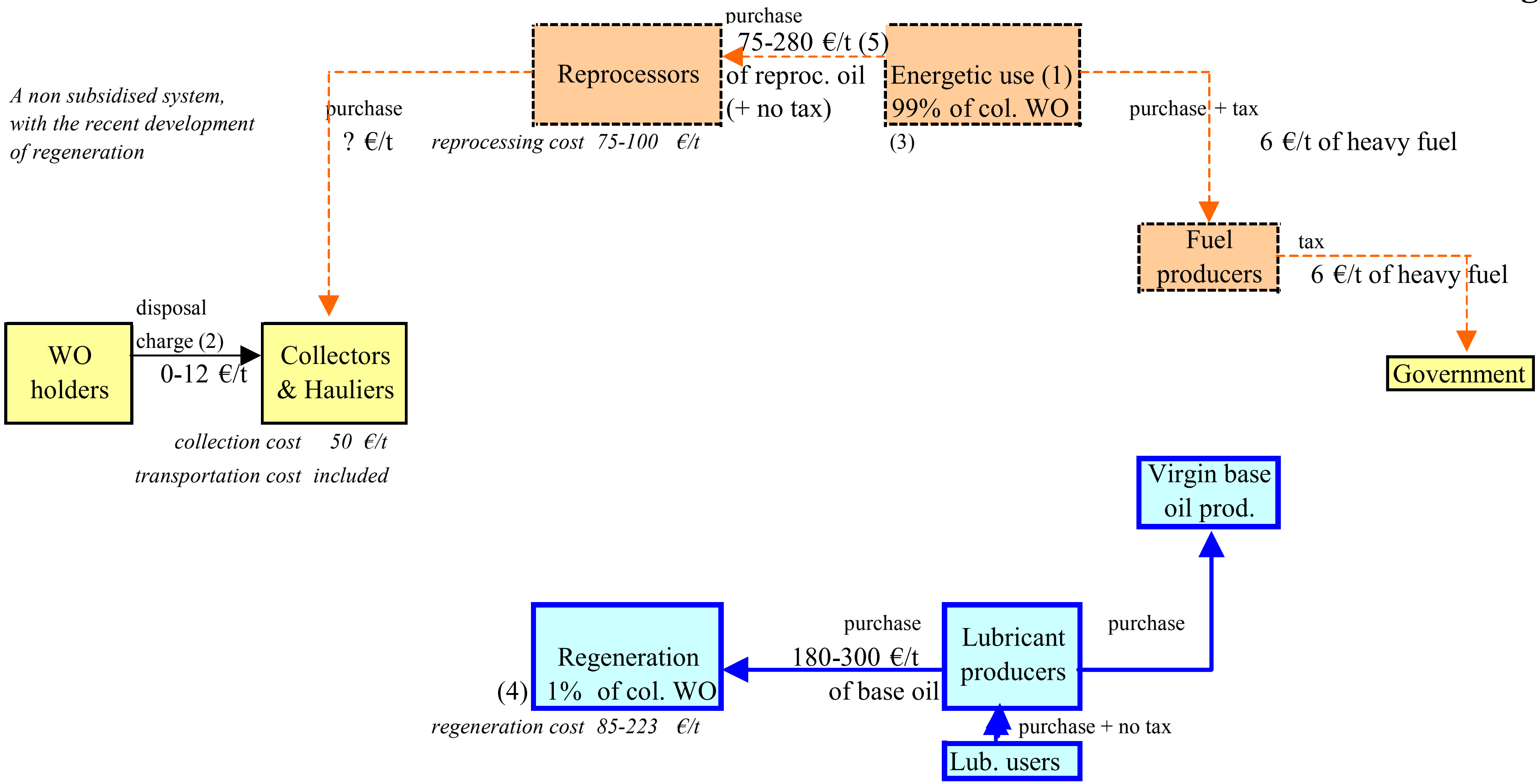


(1) 2 cement kilns and 2 incineration plants
(2) paid by stations and garages, near which the municipalities have built the collection points for motor oil they are obliged to

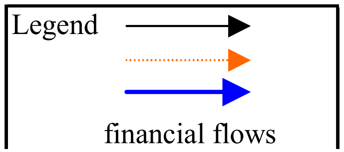


Sources: [30] p2, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what? **Belgium**



(1) cement kilns, road making industry, lime kilns
(2) according to the degree of contamination (if less than 3000 L and no contamination: free of charge)
(3) 99% according to the MS in 1997 [10] and about 50% according to WATCO in 2001 [76]
(4) 1% according to the MS in 1997 [10] and about 50% according to WATCO in 2001 [76]



(5) varies according to the type of re-processed product:
75 to 185 Euros/t of fuel for road making industry, lime kiln
220 to 280 Euros/t of gasoil
130 to 160 Euros/t of flux-oil
80 to 100 Euros/t of reducing agent

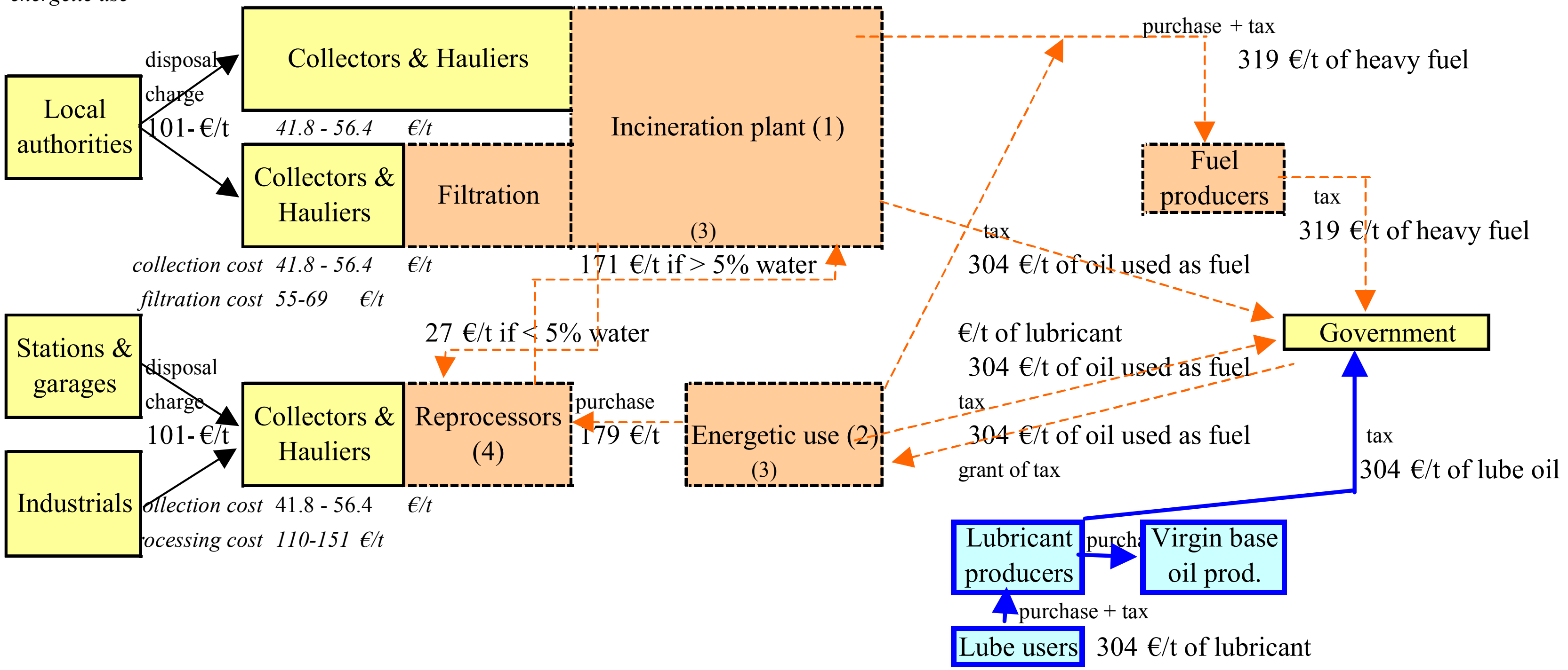
Sources: [76], [25] p14
(costs & prices: 2001; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what?

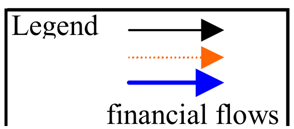
Denmark

A subsidised system, which benefits to collection and energetic use

NB: the current situation has apparently quiet evolved compared to the one described here



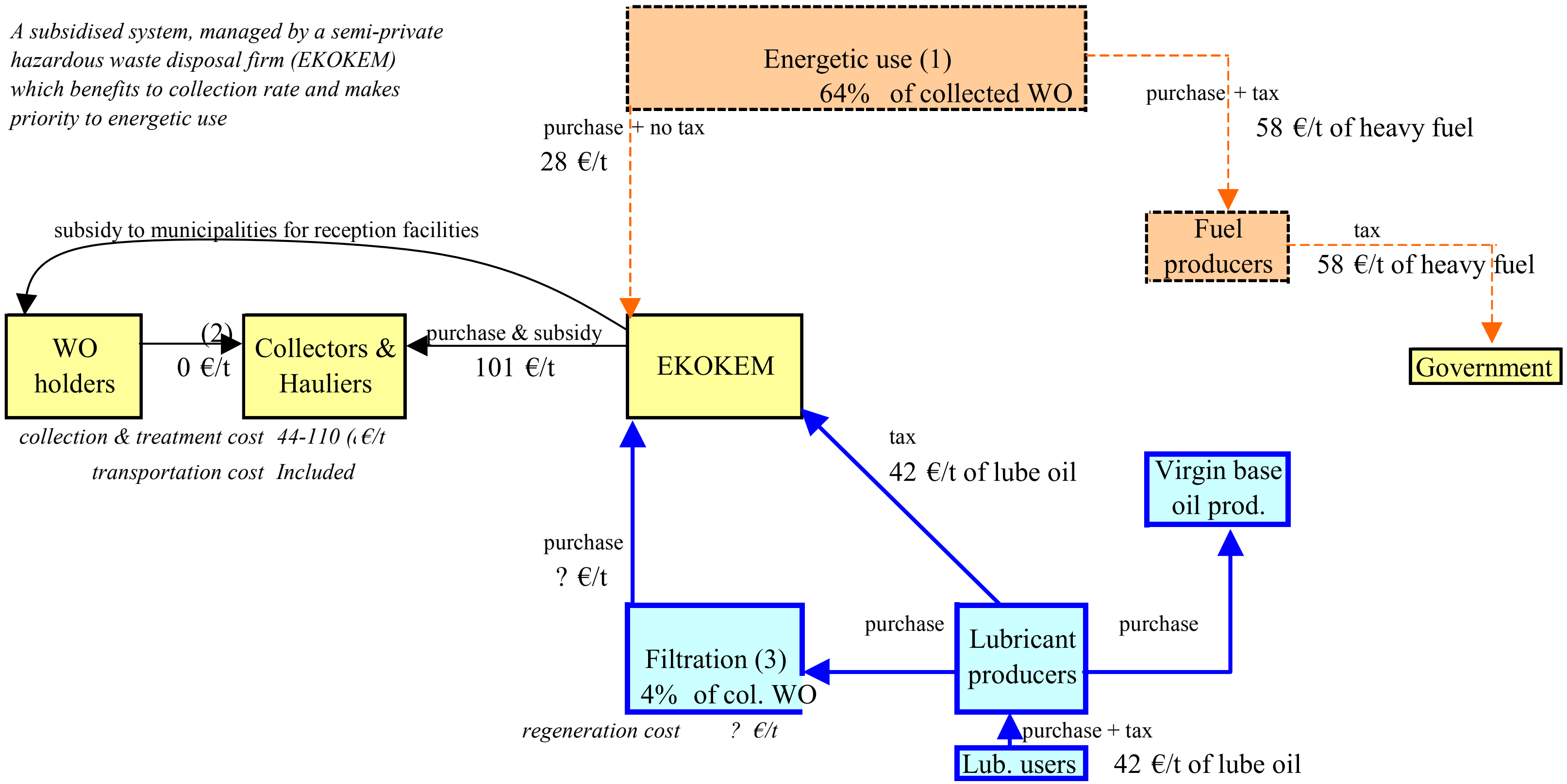
(1) Kommunekemi SA
(2) heating plants (or oil used as bitumen in asphalt)
(3) total energetic use= 100% of collected WO
(4) DOG



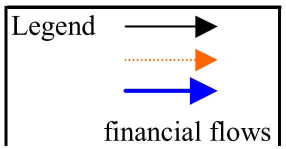
Sources: [30] p11, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery **- Who pays for what?** **Finland**

A subsidised system, managed by a semi-private hazardous waste disposal firm (EKOKEM) which benefits to collection rate and makes priority to energetic use



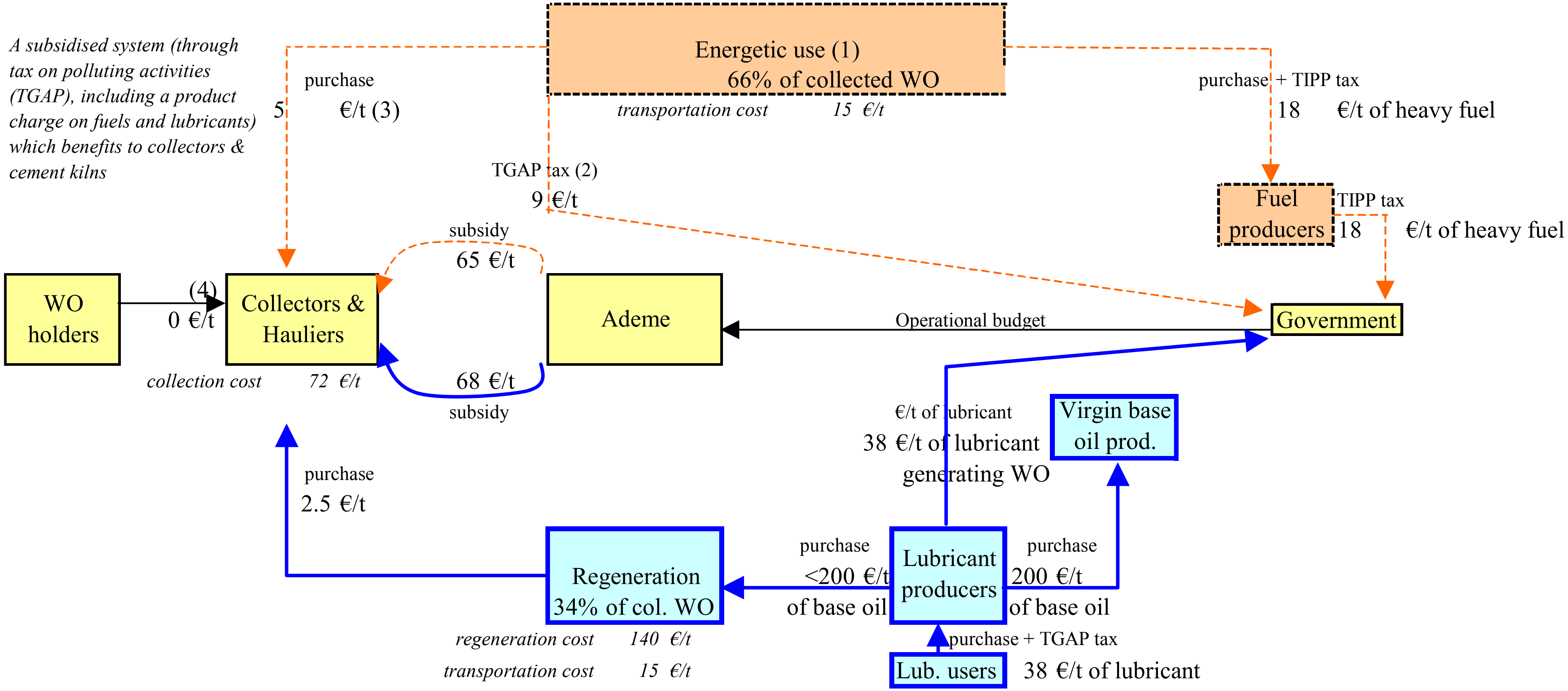
(1) half with no reprocessing step (incineration & several firms) and half with a reprocessing step (power plants)
(2) if the quantity of WO is greater than 1 t, does not contain more than 10% water and excessive concentrations of PCB's, and has a flash point of at least 55°C
(3) clean waste engine lubricants separated from the WO stream and used as lubricating oil for chain saws



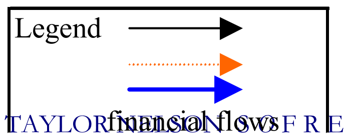
Sources: [30] p28, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what? **France**

A subsidised system (through tax on polluting activities (TGAP), including a product charge on fuels and lubricants) which benefits to collectors & cement kilns

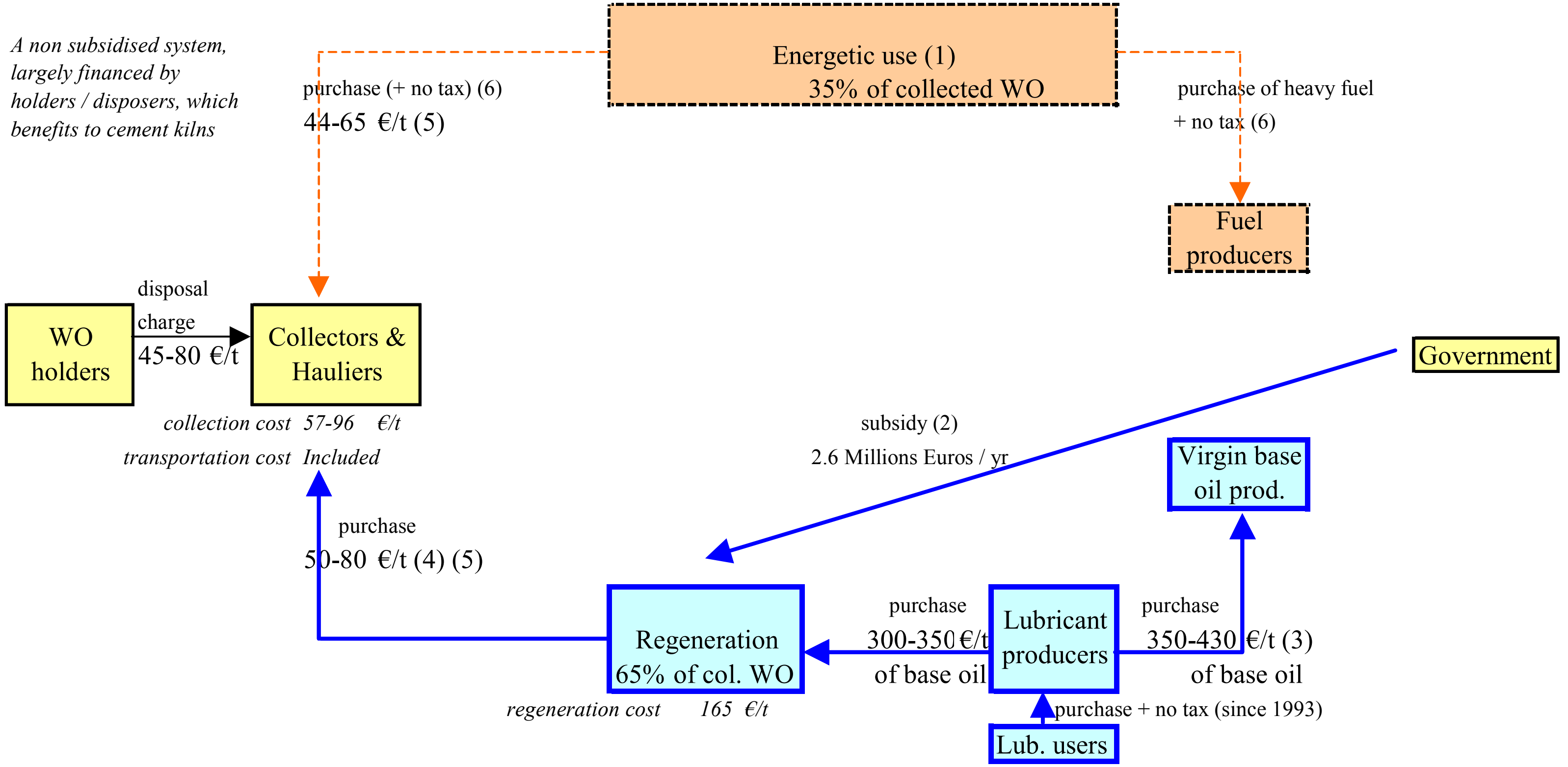


(1) mainly cement kilns
(2) TGAP tax on the elimination of industrial waste
(3) cement kilns: 3.8 €/t; lime kilns: 9 €/t; other energetic use: 17.3 €/t
(4) if WO water content is lower than 5%

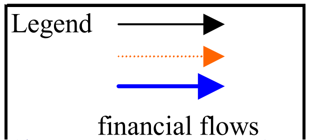


Sources: [65 - ADEME]
(costs, prices & taxes: 2001)

The Financing of Waste Oils Recovery - Who pays for what? **Germany**



(1) mainly cement kilns (and also steel industry)
(2) from 2001, companies regenerating WO into new base oils become eligible for subsidies worth Euros 2.6 Millions (DM5m) per year
(3) 15 to 25% more than regenerated base oil
(4) for information, collected WO were bought between 20 and 50 Euros/t in 2000
(5) included transportation costs for WO imported from Belgium
(6) the use of energy is only taxed for plants producing heat; cement kilns and steel industry producing a product (cement or steel), no tax applies on their fuel consumption; a judgement is on progress by the European Union for this practice, unique in Europe

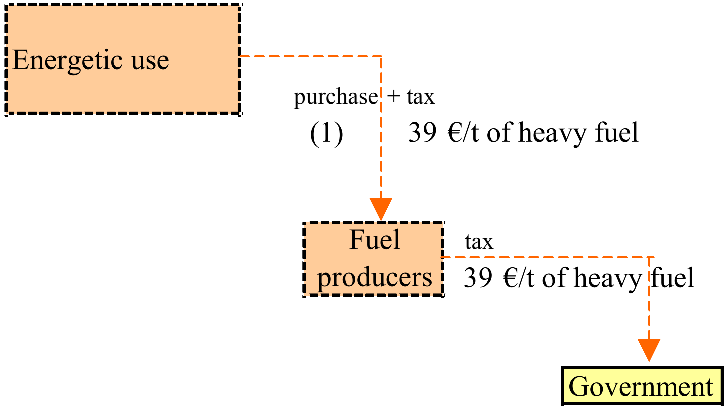


Sources: [76 - GEIR]
(costs, prices & taxes: 2001)

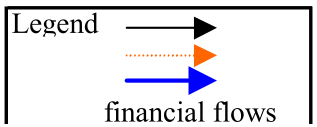
The Financing of Waste Oils Recovery **- Who pays for what?**

Greece

A non subsidised system, with a low collection rate and a regeneration plant running at full capacity with imported WO



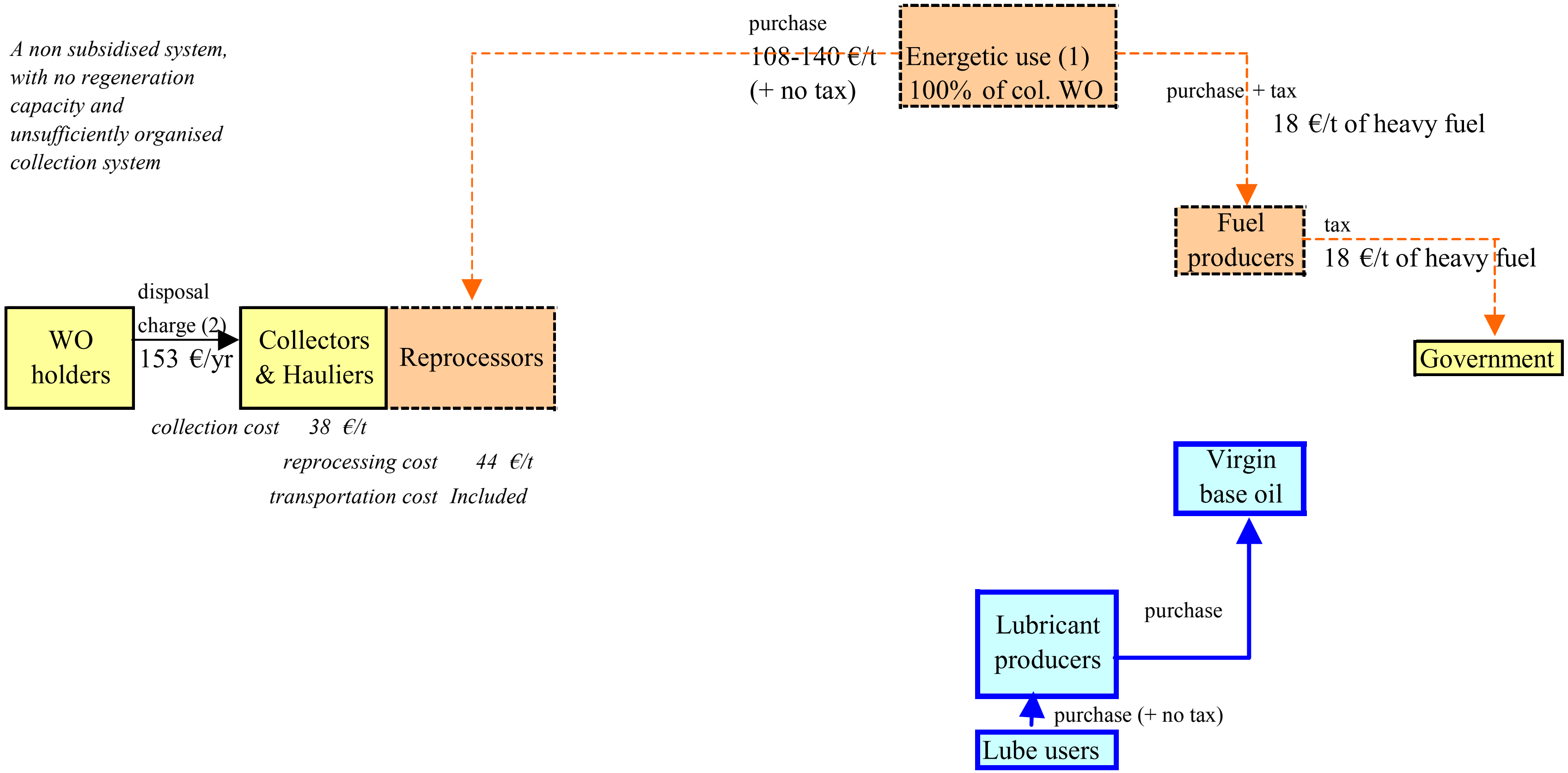
(1) about 130-150 €/t of fuel in April 2001 (tax not included)
(2) 20% less than virgin base oil



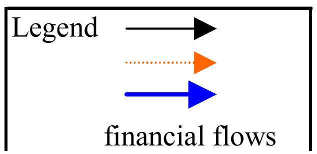
Sources: [30] p34, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what? **Ireland**

A non subsidised system, with no regeneration capacity and unsufficiently organised collection system



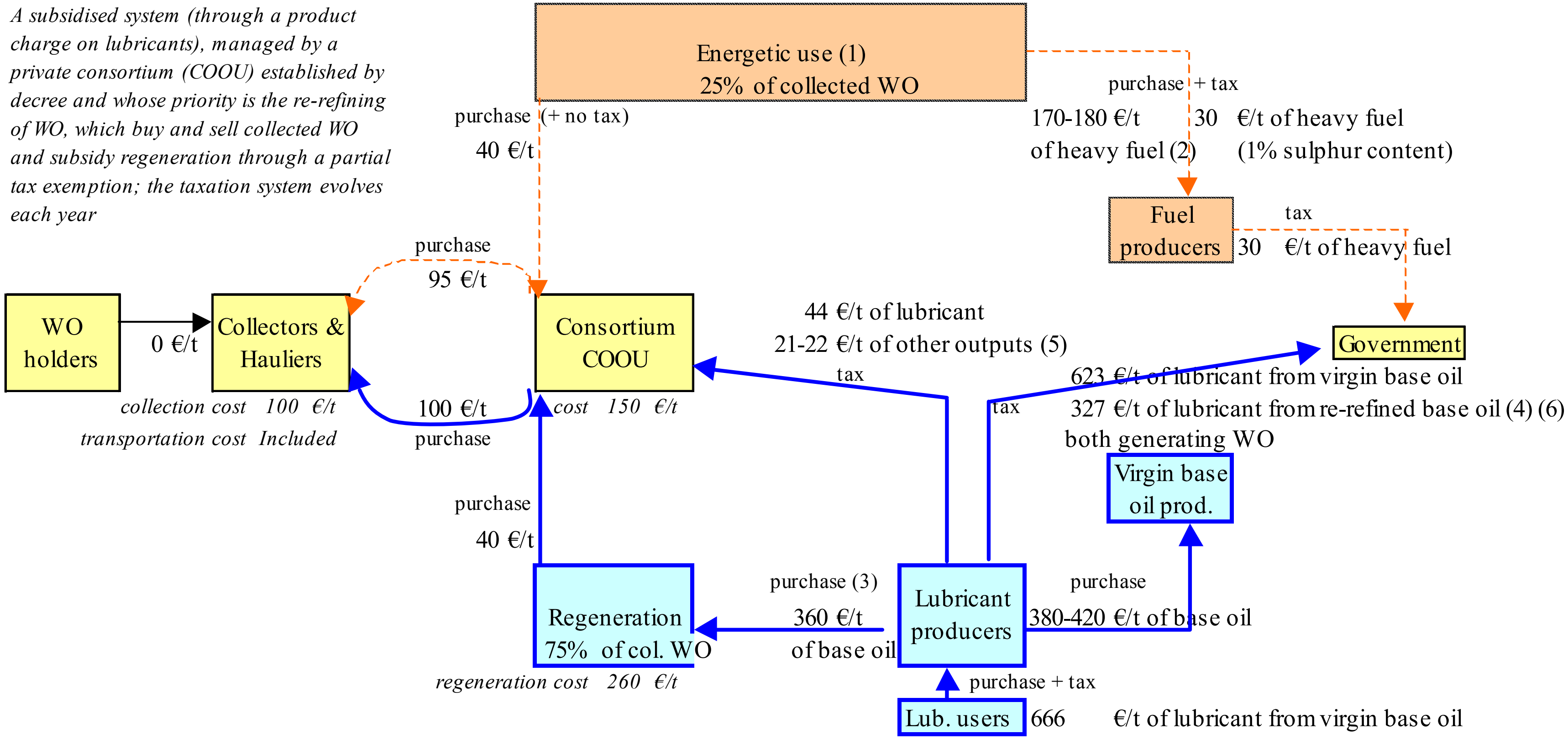
(1) road making industry and power stations
(2) for 3 collections per year



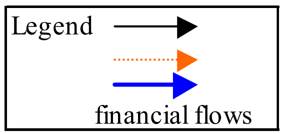
Sources: [30] p38, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what? **Italy**

A subsidised system (through a product charge on lubricants), managed by a private consortium (COOU) established by decree and whose priority is the re-refining of WO, which buy and sell collected WO and subsidy regeneration through a partial tax exemption; the taxation system evolves each year



(1) mainly cement kilns and brick kilns
(2) in July 2001 (tax not included)
(3) 10-15% less than virgin base oil price
(4) about 45% of tax exemption
(5) next year, all the outputs will be taxed at the same level: 42 to 44 Euros/t of output
(6) this partial exemption on the taxation on lubricants, unique in Europe, will be suppressed at the end of 2001

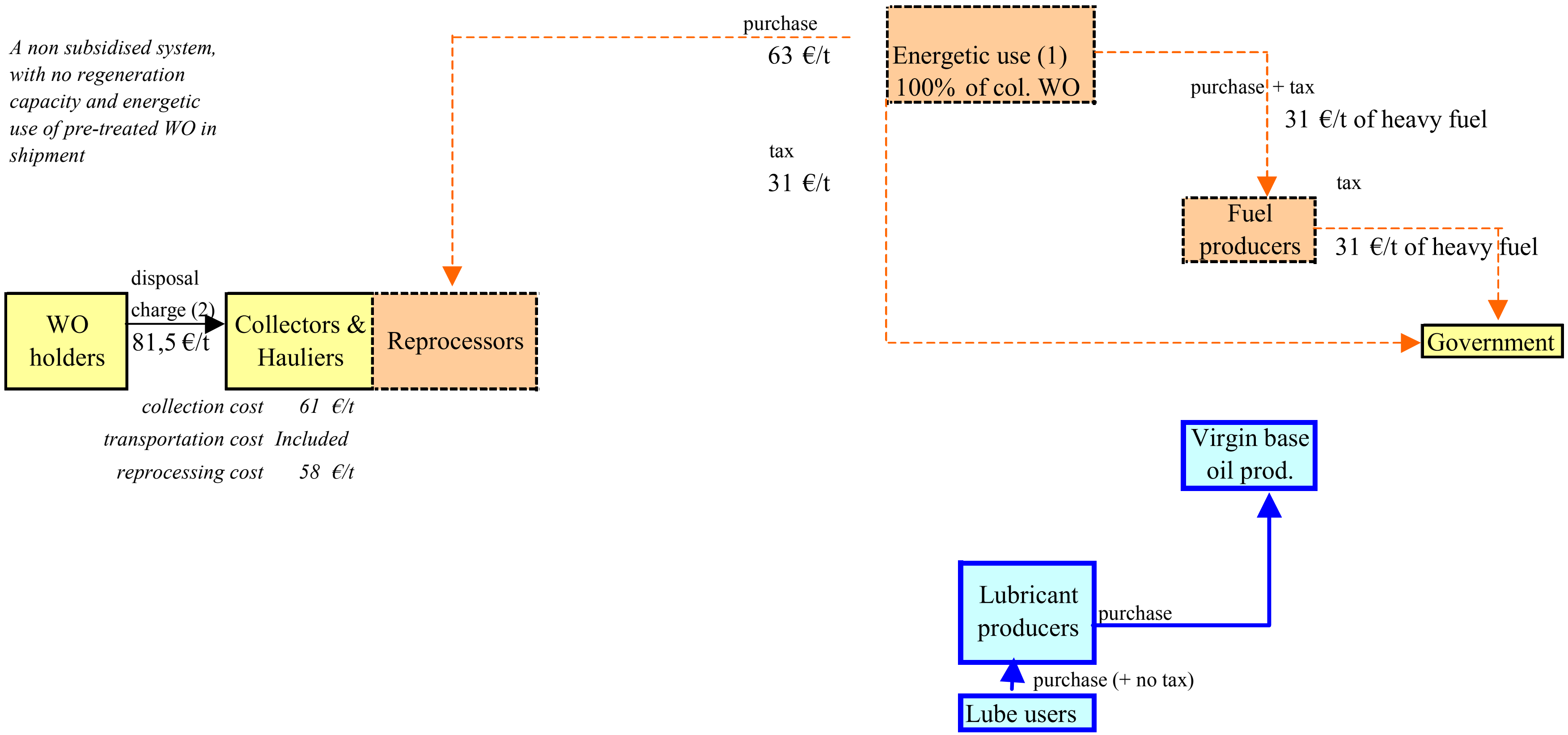


Sources: [66 - GEIR]
(costs, prices & taxes: 2001)

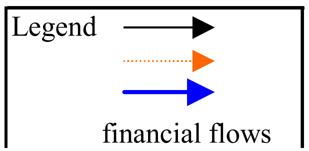
The Financing of Waste Oils Recovery - Who pays for what?

Netherlands

A non subsidised system, with no regeneration capacity and energetic use of pre-treated WO in shipment



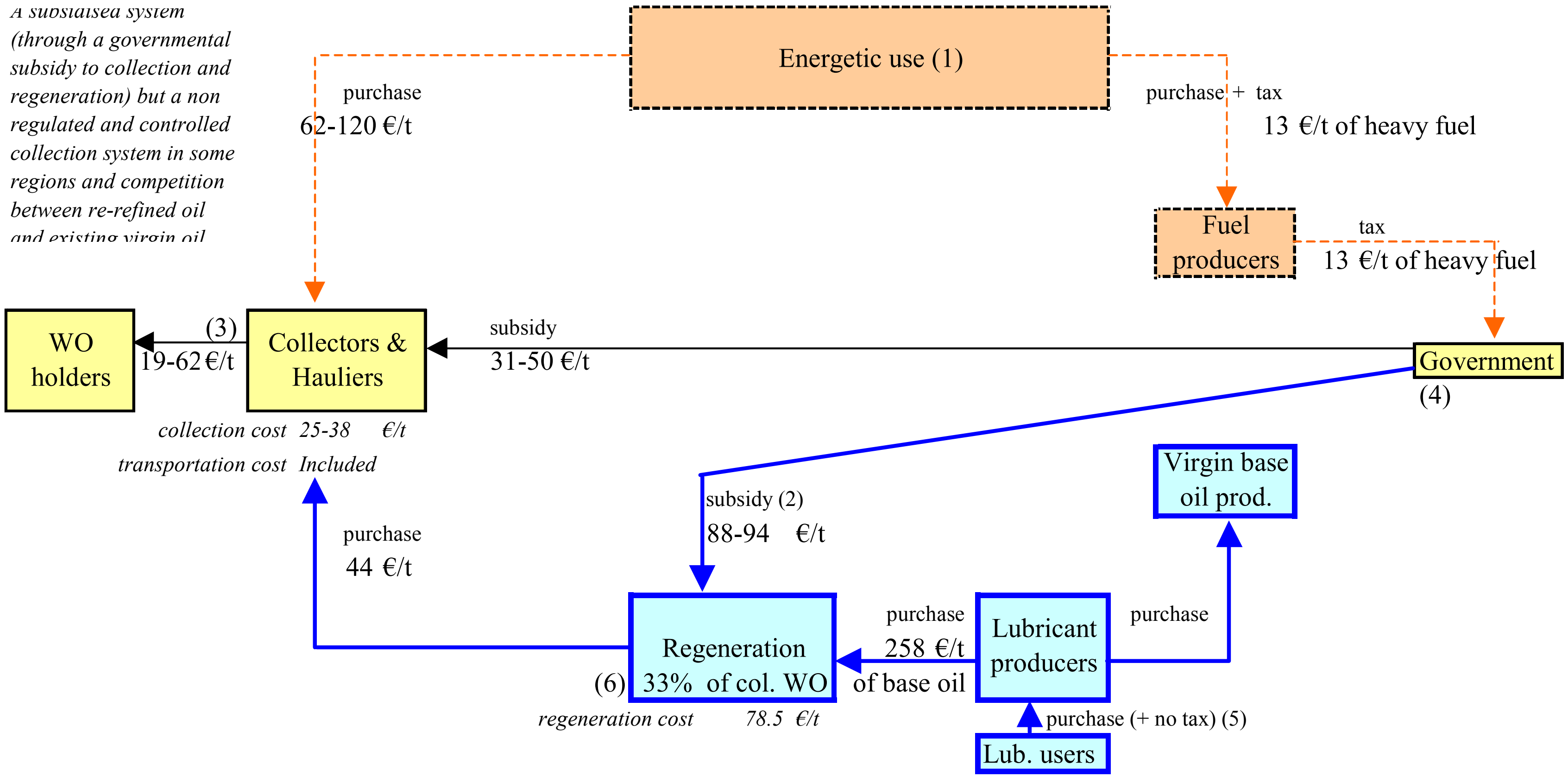
(1) bunker oil used as fuel for ships
(2) prices determined by supply and demand, with a ceiling price set monthly by the Ministry of Environment and tied to heavy oil prices (81.5 €/t in 1995)



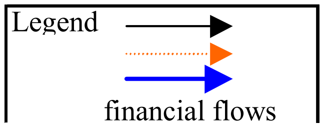
Sources: [30] p65, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what?

Spain (except Catalonia)

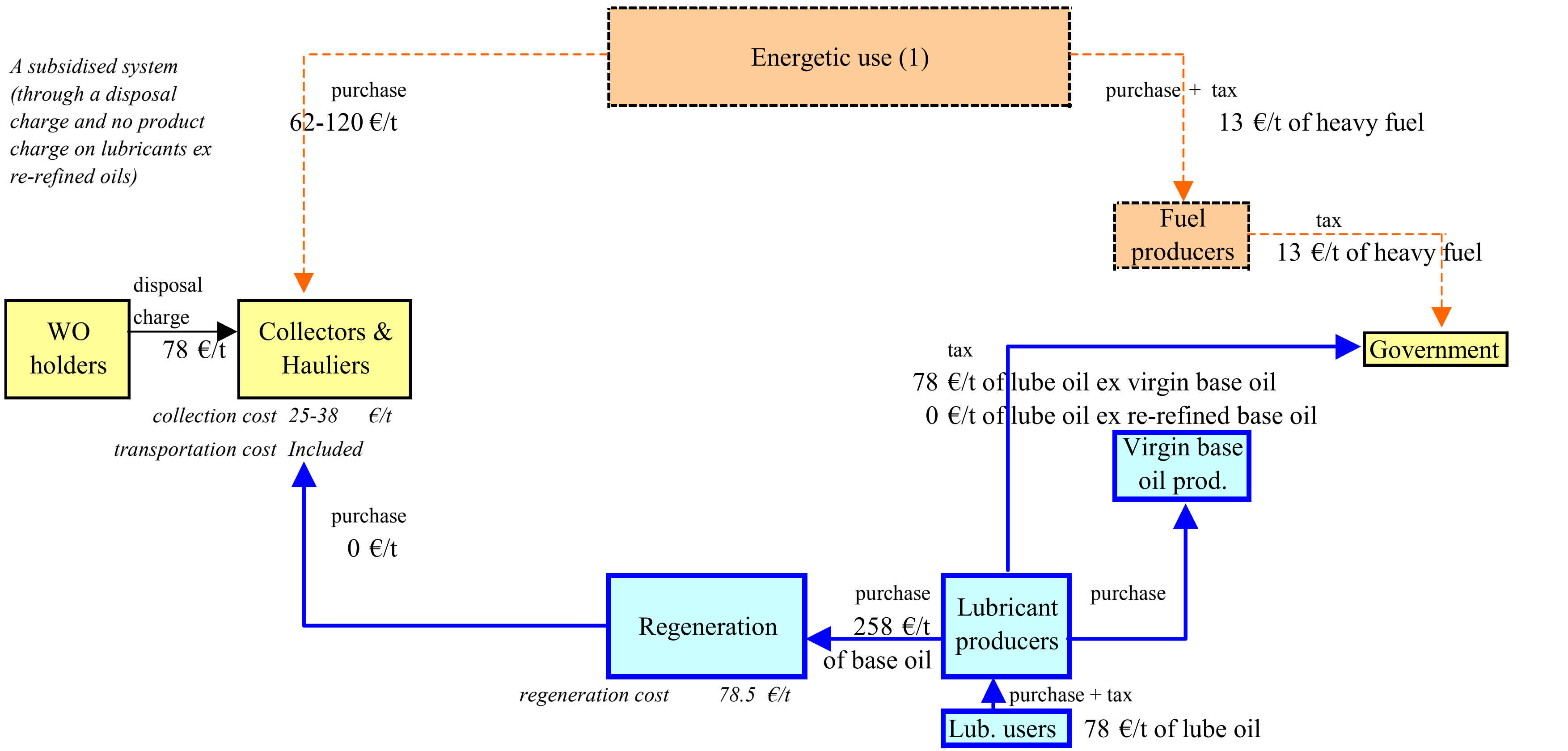


(1) split between 'with no reprocessing step' (power plants) and 'with a reprocessing step'
(2) before 7/2000, subsidy to energetic use too (6 Euros/t for burners if they made treatments of decontamination and demetallisation (Icis-Lor p14))
(3) depending on the quality of the WO and the distance
(4) Ministry of the Environment
(5) project to create an eco-tax
(6) for Spain and Catalonia

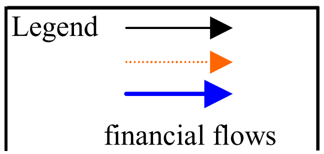


Sources: [30] p23, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what? **Catalonia**



(1) split between 'with no reprocessing step' (power plants) and 'with a reprocessing step'

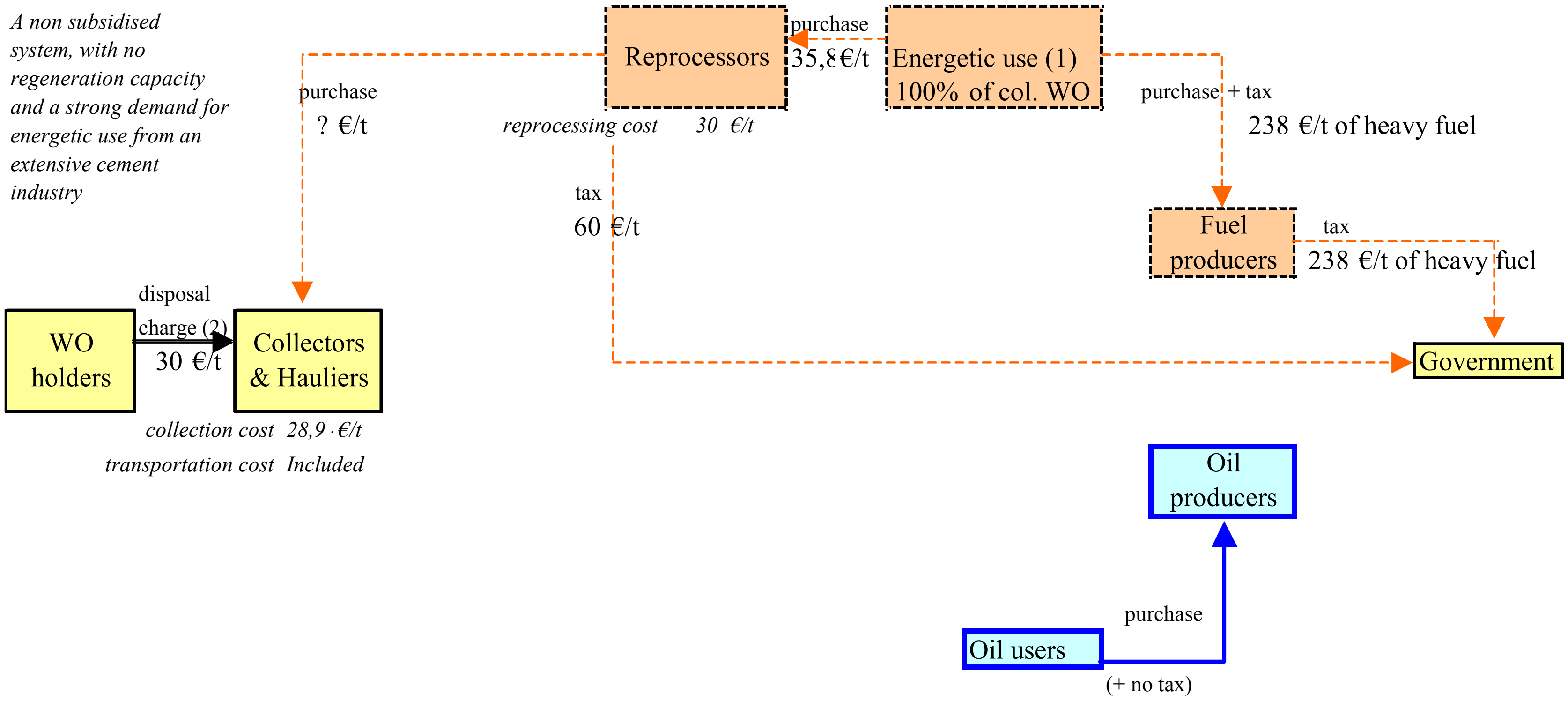


Sources: [30] p28, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what?

Sweden

A non subsidised system, with no regeneration capacity and a strong demand for energetic use from an extensive cement industry



(1) mainly cement kilns

(2) several tens of Euros/t in the case of industrial holders; free of charge in the case of DIYers

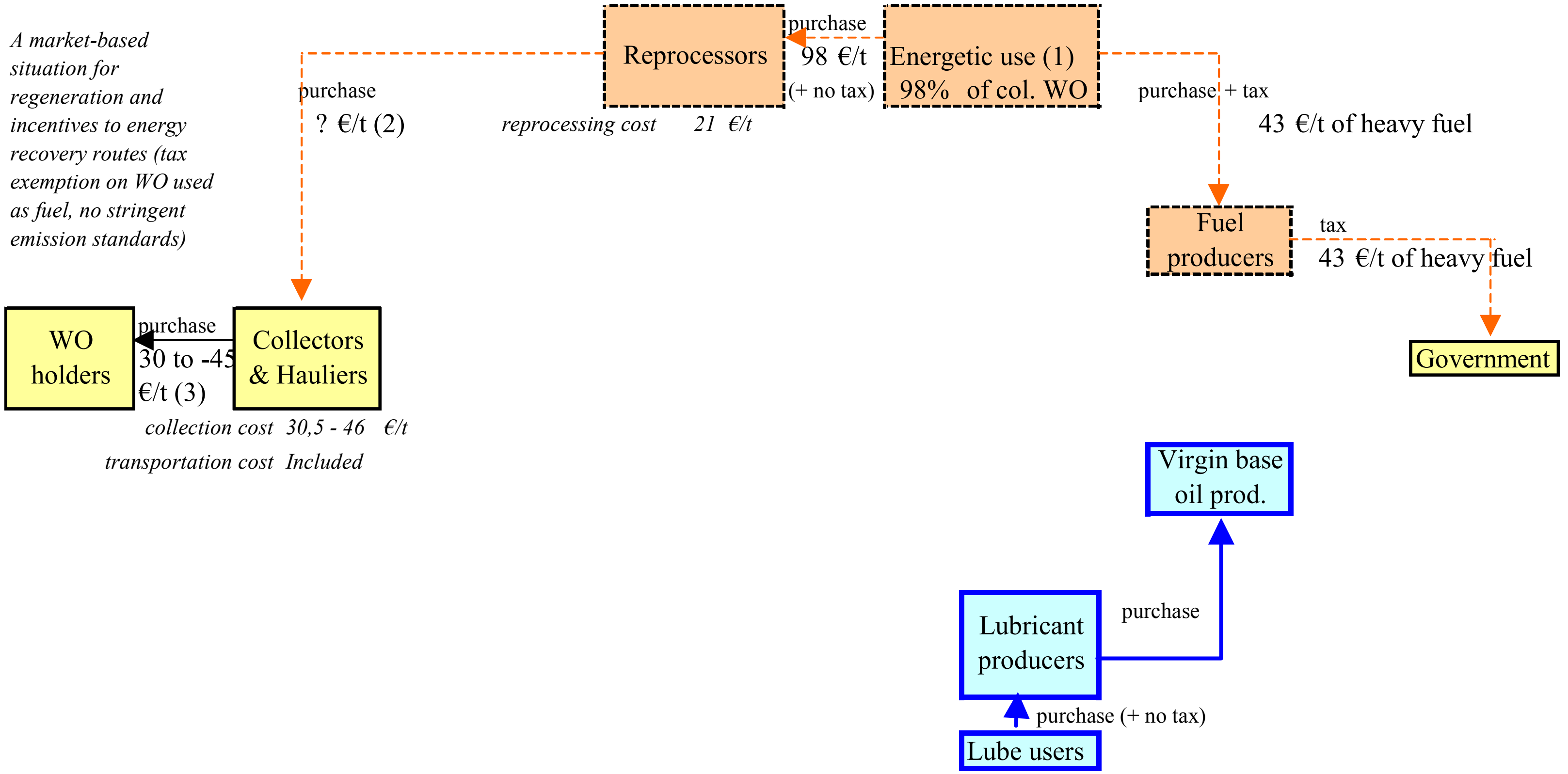
Legend

financial flows

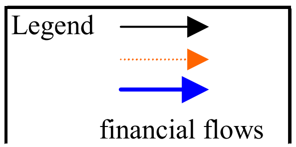
Sources: [30] p61, [25] p14
(costs & prices: 1993; taxes: 1999)

The Financing of Waste Oils Recovery - Who pays for what?

United Kingdom



(1) mainly power stations, heaters, cement kilns…
(2) in the case of imported WO, disposers have to pay for the treatment
(3) collectors pay up to 30 Euros/t or receive up to 45 Euros /t of WO depending upon the degree of contamination with water and other materials ([40] p12 - 1999 data)
For automotive WO, they pay between 0 to 15 Euros/t



Sources: [30] p72, [25] p14, [40]
(costs & prices: mostly 1993; taxes: 1999)

Appendix 6

Cost and WO Gate Fee for a Regeneration Plant

Cost and WO Gate Fee for a Regeneration Plant

The detailed figures related to the economics of regeneration are presented on the following pages.

An economic model has been developed to assess the regeneration cost and the WO gate fee.

Each of the following pages refers to one of the 7 regeneration processes assessed. All the data gathered from different plants for a same process are presented on the same page, to allow an easier comparative analysis.

On each page are presented 4 categories of information (from the top to the bottom):

- Description:
  - the name of the process and the status (existing plant or project),
  - the localisation of the existing plants (information not necessary comprehensive),
  - the quality level of the re-refined base oil produced,
- Parameters of operation, common to the different plants:
  - yields,
  - main inputs (quantity and purchasing price),
  - main outputs sold (quantity and selling price),
  - main residues (quantity as well as treatment cost for those treated and selling price for those sold),
- Other parameters of operation, specific to each plant:
  - capacity,
  - utilisation rate,
  - operational duration,
- Cost:
  - hypotheses (number of years of depreciation for the capital costs, risk adjusted rate of return on finance),
  - different types of cost (capital costs, operational costs),
  - revenues (sales of products, sales of residues),
  - WO gate fee.

The overall methodology, detailed hypotheses and the selected sources of information are described in chapter 4.5 on page 46.

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology		**Re-refining**					Existing plants	Projects
de-asphalting, demetalisation		**Sulfuric acid**						
finishing		**Clay treatment**					+	
Localisation		Europe	G	It	Sp	Fr	other MS	Non Eur
total existing capacity	*kt*							
nb of plants	*units*	more than 60 plants						
		min	max					
capacity of existing plants	*kt*							
Main output & quality		Low quality re-refined base oil						

Parameters of operation

		de-watering, de-fueling	de-asphalting	total
Yields	*% on a dry basis*	73%	85%	62%

Main inputs		quantity *kg/t of WO*		purchasing price *Euros/t of input*
waste oil	*a1*	1000		
clay	*a2*	36	*b2*	n.a.
________	*a3*		*b3*	
________	*a4*		*b4*	

Main products (outputs sold)		quantity *kg/t of WO*		selling price *Euros/t of output*
re-refined base oil	*c1*	621	*d1*	250
gasoil	*c2*	70	*d2*	150
________	*c3*		*d3*	
________	*c4*		*d4*	

Main residues (outputs treated or sold)		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*	
clay	*e1*	n.a.	*f1*	n.a.		*g1*
bitumen (metals & additives)	*e2*	n.a.	*f2*		n.a.	*g2*
________	*e3*		*f3*			*g3*
________	*e4*		*f4*			*g4*

Source — **Concawe - 1994** (4)
grass-root plant

Other parameters of operation

Capacity	*g*	**100**	*kt/yr*
Utilisation rate (input / capacity)	*h*	85%	
Operational duration		n.a.	*hours/yr*

		$ 1994 / t of WO		**Euros 2001 / t of WO** (6)	
Cost	*C=o+p+q+u*	*in$ 94*	**128**	*inEuros 01*	**152**
Capital cost	*i=j+k+l+m*	**24.3**		**34**	
Engineering	*k*				
Core processes	*l*	*14.3*		*20*	
Site acquisition	*j*				
Non core processes	*m*	*10*		*14*	
Depreciation cost	*o=(k+l)*1000/yrs/(g*h)*	*yrs*	**29**	*yrs*	**32**
Core processes & engineering		10	17	10	24
Site & non core processes	*o=(j+m)*1000/yrs/(g*h)*	10	12	20	8
		%		%	
Risk adjusted rate of return on finance	*p=i*%*1000/(g*h)*	15.0%	**43**	10.0%	**40**
Fixed operational cost	*q=r+s+t*	*nb (1)*	**27**		**38**
Staff	*r*	*24*	*12.80*		*18*
Equipements maintenance	*s*		*14.58*		*20*
Sg&a (2)	*t*				
Variable operational cost	*u=v+w+x*	*nb (1)*	**25**		**35**
Staff	*v*	*included*	*included*		*included*
Utilities & chemicals	*w*		*25.15*		*35*
Residues treatment	*x=e1*f1+e2*f2+...*				
Other costs		(5)	**4**		**6**
Revenues	*Y=z+ae*		**184.39**	(7)	**177**
Sales of products	*z=aa+ab+ac*		**172.89**		**166**
re-refined base oil	*aa=c1*d1*		*158.76*		*155*
gasoil	*ab=c2*d2*		*14.13*		*11*
________	*ac=c3*d3*				
________	*ad=c4*d4*				
Sales of residues	*ae=e1*g1+e2*g2+...*		**11.5**		**12**
WO gate fees	*ae=C-Y*	$ 1994/t	**-55.93**	Euros/t	**-25**

(1) nb of persons equivalent full time (all shifts included)
(2) Sales, General & Administration
(5) Financial burden
(4) source: report [19] page 104; investment based on the licensor declaration (+30% not considered)
(7) Because the selling prices depends on the crude oil price, the actualisation formula is senseless. The GEIR 2001 hypotheses are considered instead.

(6) Hypotheses: inflation rate = 2 % / yr
1 $ 2001 = 1.22 Euros 2001
calculation formula: X $ 1994 = [X * $(1+0.02)^{2001-1994}$ * 1.22] Euros 2001

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology	**Re-refining**					Existing plants	Projects
de-asphalting, demetallisation	**TFE (Thin Film Evaporation)**						
finishing	**Clay treatment**					+	
Localisation	Europe	D	I	Sp	Fr	other MS	Non Eur
total existing capacity (kt)		160					
nb of plants (units)		1					
	min	max					
capacity of existing plants (kt)	55	100					
Main output & quality	Medium quality re-refined base oil						

Parameters of operation

	de-watering	TFE distillation	vacuum distillation	total
Yields (% on a dry basis)	89%	81%	76%	**54%**

Main inputs		quantity (kg/t of WO)		purchasing price (Euro/t of input)
waste oil	a1	1000		
clay	a2	40	b2	350
____________	a3		b3	
____________	a4		b4	

Main products (outputs sold)		quantity (kg/t of WO)		selling price - Euro/t of output: GEIR G 1	GEIR G 2
re-refined base oil	c1	530	d1	300	300
gasoil	c2	150	d2	230	130
____________	c3		d3		
____________	c4		d4		

Main residues (outputs treated or sold)		quantity (kg/t of WO)		treatment cost (Euro/t of output)	or selling price (Euro/t of output)	
clay	e1	50	f1	128		g1
bitumen (metals & additives)	e2	130	f2		127	g2
water	e3	90	f3	20		g3
sludge/light end	e4	35	f4	65		g4

Source		**GEIR : 2001 (G 1) grass-root plant**		**GEIR : 2001 (G 1) grass-root plant**		**GEIR : 2001 (G 1) grass-root plant**		**GEIR : 2001 (G 2) grass-root plant**		**UK report : 2001 [3] grass-root plant**		**UK report : 2001 [3] built on an existing site**	
Other parameters of operation													
Capacity	g	**35**	kt/yr	**50**	kt/yr	**88**	kt/yr	**158**	kt/yr	**35**	kt/yr	**35**	kt/yr
Utilisation rate (input / capacity)	h	89%		89%		89%		89%		85%		85%	
Operational duration		7 900	hours/yr	7 900	hours/yr	7 900	hours/yr	8 760	hours/yr	n.a.	hours/yr	n.a.	hours/yr
			Euros / t of WO		*Euros / t of WO*		*Euros / t of WO*		*Euros / t of WO*		*Euros / t of WO*		*Euros / t of WO*
Cost	C=o+p+q+s	millions	**242**	millions	**221**	millions	**178**	millions	**148**	millions	**237**	millions	**204**
Capital cost	m=j+k+l+m	**20.1**		**25.0**		**33.4**		**49.8**		**14.6**		**8.1**	
Engineering	k	1.6		2.3		3.9		1.6		1.6		1.6	
Core processes	l	8.4		11.5		15.4		40		6.5		6.5	
Site acquisition	j	1.96		2.4		3.9		4.7		1.0			
Non core processes	m	7.9		8.8		10.2		4.1		5.6			
Depreciation cost	o	yrs	**49**	yrs	**44**	yrs	**37**	yrs	**32**	yrs	**38**	yrs	**27**
Core processes & engineering		10	33	10	31	10	27	10	29	10	27	10	27
Site & non core processes		20	16	20	13	20	10	20	2	20	11	20	
		%		%		%		%		%		%	
Risk adjusted rate of return on finance	p	10.0%	**64**	10.0%	**56**	10.0%	**47**	10.0%	**35**	10.0%	**49**	10.0%	**27**
Fixed operational cost	q=r+s+t	nb (1)	**47**	nb (1)	**43**	nb (1)	**38**	nb (1)	**40**	nb (1)	**150**	nb (1)	**150**
Staff	r	13	13.6	13	12.1	13	9.5	30	13	13		13	
Equipements maintenance	s		13.4		12.8		11.4		8				
SG&A (2)	t		19.9		18.3		16.7		19				
Variable operational cost	u=v+w+x	nb (1)	**82**	nb (1)	**78**	nb (1)	**76**	nb (1)	**40**	nb (1)		nb (1)	
Staff	v	included	22.3	included	20.9	included	19.3	18	7	included		included	
Utilities & chemicals	w		48.7		46.9		45.6		27				
Residues treatment	x=e1*f1+e2*f2+...		10.5		10.5		10.5		6				
Other costs													
Revenues	Y=z+ae		**210**		**210**		**210**		**195**		**214**		**214**
Sales of products	z=aa+ab+ac		**194**		**194**		**194**		**179**				
re-refined base oil	aa=c1*d1		159		159		159		159				
gasoil	ab=c2*d2		35		35		35		20				
____________	ac=c3*d3												
____________	ad=c4*d4												
Sales of residues	ae=e1*g1+e2*g2+...		17		17		17		17				
WO gate fees	af=C-Y	Euro/t	32	Euro/t	11	Euro/t	-32	Euro/t	-47	Euro/t	23	Euro/t	-10

(0) the letter (and number if any) indicates that the data come from a GEIR member having a plant in the country (I for Italy and D for Germany - 2 industrialists having plants (or projects) in Germany are distinguished)

(1) nb of persons equivalent full time (all shifts included)

(2) Sales, General & Administration

(3) source: report [90] p.28-30, average values of the ranges indicated in the report are considered here; hyp: 1 £ = 1.68 Euros

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology		**Re-refining**					Existing plants	Projects
de-asphalting, demetalisation		**TFE (Thin Film Evaporation)**						
finishing		**Hydro finishing**						x
Localisation		Europe	G	It	Sp	Fr	other MS	Non Eur
total existing capacity	kt							
nb of plants	units							
		min	max					
capacity of existing plants	kt	50		project				
Main output & quality		High quality re-refined base oil						

Parameters of operation

		dehydra distillation	TFE dest distillation	finishing hydrof	total
Yields	% on a dry basis	88%	94%	96%	64%

		quantity kg/t of WO		purchasing price Euros/t of input
Main inputs				
waste oil	a1	1000		
hydrogen (catalyst)	a2	n.a.	b2	n.a.
	a3		b3	
____________	a4		b4	

		quantity kg/t of WO		selling price Euros/t of output
Main products (outputs sold)				
re-refined base oil	c1	630	d1	325
gasoil	c2	100	d2	298
	c3		d3	
____________	c4		d4	

		quantity kg/t of WO		treatment cost Euros/t of output	or selling price Euros/t of output	
Main residues (outputs treated or sold)						
Bitumen	e1	130	f1		128	g1
Water	e2	90	f2	20		g2
Sludge/light end	e3	30	f3	65		g3
Sulphur	e4	35	f4		90	g4

Source		**GEIR - 2001 (G 1[0]) grass-root plant**		**GEIR - 2001 (G 1[0]) grass-root plant**		**UK report - 2001 [4] grass-root plant**		**UK report - 2001 [4] built on an existing site**		**Concawe - 1994 [3] grass-root plant**			
Other parameters of operation													
Capacity	g	**50**	kt/yr	**80**	kt/yr	**35**	kt/yr	**35**	kt/yr	**100**	kt/yr		
Utilisation rate (input / capacity)	h	90%		90%		85%		85%		85%			
Operational duration		7 000	hours/yr	7 000	hours/yr	n.a.	hours/yr	n.a.	hours/yr		hours/yr		
			Euros / t of WO		*Euros / t of WO*		*Euros / t of WO*		*Euros / t of WO*		*$ 1994 / t of WO*		*Euros 2001 / t of WO [6]*
Cost	C=o+p+q+r+s	mEuros	333	mEuros	275	mEuros	289	mEuros	262	m$ 94	168	mEuros 01	197
Capital cost	i+j+k+l+m	**42.5**		**50.3**		**26.7**		**18.8**		**38**		**53**	
Engineering	i	5.1		8.2		1.6		1.6					
Core processes	j	25.9		30.1		17.2		17.2		28		39	
Site acquisition	k	2.4		4.2		1.2							
Non core processes	m	9.1		9.8		6.8				10		14	
Depreciation cost	o=(i+j)*1000/(yrs/g/h)...	yrs	**82**	yrs	**60**	yrs	**51**	yrs	**42**	yrs	**45**	yrs	**54**
Core processes & engineering		10	69	10	50	10	42	10	42	10	33	10	46
Site & non core processes	o=(k+m)*1000/yrs/g/h	20	13	20	10	20	9	20		10	12	20	8
		%		%		%		%		%		%	
Risk adjusted rate of return on finance	p=l*%/1000/g/h	10.0%	**94**	10.0%	**76**	10.0%	**59**	10.0%	**42**	15.0%	**67**	10.0%	**63**
Fixed operational cost	q=r+s+t	nb (1)	**64**	nb (1)	**57**	nb (1)	**179**	nb (1)	**179**	nb (1)	**36**		**50**
Staff	r		22.6		20.7	13		13		24	12.80		18
Equipements maintenance	s		18.9		17.3						22.8		32
SG&A (2)	t		22.7		18.9								
Variable operational cost	u=v+w+x	nb (1)	**93**	nb (1)	**88**	nb (1)		nb (1)		nb (1)	**14**		**20**
Staff	v		29.4		26.8	included		included		included	included		included
Utilities & chemicals	w		60.7		57.9						14.06		20
Residues treatment	x=e1*f1+e2*f2+...		3.55		3.55								
Other costs										(5)	7		10
Revenues	Y=Z+ae		**254**		**254**		**321**		**321**		**202.57**	(7)	**235**
Sales of products	Z=aa+ab+ac+ad		236		236						195.57		235
re-refined base oil	aa=c1*d1		205		205						181.44		205
gasoil	ab=c2*d2		30		30						14.13		30
	ac=c3*d3												
____________	ad=c4*d4												
Sales of residues	ae=e1*g1+e2*g2+...		20		20						7		
WO gate fees	af=C-Y	Euros/t	**79**	Euros/t	**21**	Euros/t	**-32**	Euros/t	**-58**	$ 1994/t	**-34.17**	Euros/t	**-38**

(0) the letter (and number if any) indicates that the data come from a GEIR member having a plant in the country (I for Italy and G for Germany ; 3 industrialists having plants (or projects) in Germany are distinguished)

(1) nb of persons equivalent full time (all shifts included) (6) Hypotheses: inflation rate = 2 % / yr

(2) Sales, General & Administration 1 $ 2001 = 1.22 Euros 2001

(5) Financial burden calculation formula: X $ 1994 = [X * (1+0.02)^(2001-1994) * 1.22] Euros 2001

(3) source: report [19] page 107; investment based on the licensor declaration (+30% not considered)

(4) source: report [40] p.28-30, average values of the ranges indicated in the report are considered here; hyp: 1 £ = 1.59 Euros

(7) Because the selling prices depends on the crude oil price, the actualisation formula is senseless. The GEIR 2001 hypotheses are considered instead.

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology		**Regeneration**					Existing plants	Projects
de-asphalting, demetalisation		**TFE (Thin Film Evaporation)**						
finishing		**Solvent extraction**					*	
Localisation		Europe	G	It	Sp	Fr	other MS	Non Eur
total existing capacity	*kt*	85	85					
nb of plants	*units*	1	1					
		min	max					
capacity of existing plants	*kt*	25	100	projects				
Main output & quality		High quality re-refined base oil						

Parameters of operation

		dehydration distillation	vacuum distillation	finishing extraction	total	
Yields	*% on a dry basis*	88%	82%	83%	**60%**	G 1
		69%	91%	89%	**50%**	G 2

Main inputs		quantity *kg/t of WO*		purchasing price *Euros/t of input*
waste oil	*a1*	1000		
hydrogen (catalyst)	*a2*	n.a.	*b2*	n.a.
	a3		*b3*	
____________	*a4*		*b4*	

Main products (outputs sold)		quantity - *kg/t of WO* GEIR G 1	GEIR G 2		selling price - *Euros/t of output* GEIR G 1	GEIR G 2
re-refined base oil	*c1*	600	503	*d1*	320	320
gasoil	*c2*	120	239	*d2*	261	130
	c3			*d3*		
____________	*c4*			*d4*		

Main residues (outputs treated or sold)		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*	
extract	*e1*	60	*f1*		143	*g1*
bitumen	*e2*	130	*f2*		128	*g2*
water	*e3*	90	*f3*	20		*g3*
sludge/light end	*e4*	30	*f4*	65		*g4*

Source		**GEIR - 2001 (G 1[i]) grass-root plant**		**GEIR - 2001 (G 1[i]) grass-root plant**		**GEIR - 2001 (G 1[i]) grass-root plant**		**GEIR - 2001 (G 2[i]) grass-root plant**	
Other parameters of operation									
Capacity	*g*	**35**	*kt/yr*	**50**	*kt/yr*	**80**	*kt/yr*	**160**	*kt/yr*
Utilisation rate (input / capacity)	*h*	89%		89%		89%		88%	
Operational duration		7 800	*hours/yr*	7 800	*hours/yr*	7 800	*hours/yr*	8 760	*hours/yr*
			Euros / t of WO		***Euros / t of WO***		***Euros / t of WO***		***Euros / t of WO***
Cost	*C=o+p+q+u*	*mEuros*	**350**	*mEuros*	**308**	*mEuros*	**258**	*mEuros*	**148**
Capital cost	*i=j+k+l+m*	**31.0**		**37.3**		**44.4**		**59.7**	
Engineering	*k*	2.8		3.4		4.2		2.1	
Core processes	*l*	18.3		22.6		25.9		49.42	
Site acquisition	*j*	2.1		2.4		4.1		4.1	
Non core processes	*m*	7.8		8.9		10.2		4.1	
Depreciation cost	*n=(k+l)*1000/yrs/(g*h)*	yrs	**84**	yrs	**71**	yrs	**52**	yrs	**40**
Core processes & engineering		10	68	10	58	10	42	10	37
Site & non core processes		20	16	20	13	20	10	20	3
	*o=(j+m)*1000/yrs/(g*h)*	%		%		%		%	
Risk adjusted rate of return on finance	*p=i*%*1000/(g*h)*	10.0%	**100**	10.0%	**84**	10.0%	**62**	10.0%	**42**
Fixed operational cost	*q=r+s+t*	*nb (1)*	**67**	*nb (1)*	**61**	*nb (1)*	**55**	*nb (1)*	**42**
Staff	*r*		26.5		23.9		20.1	30	13
Equipements maintenance	*s*		18.9		17.2		16.4		9
Sg&a (2)	*t*		21.6		19.8		18.1		19
Variable operational cost	*u=v+w+x*	*nb (1)*	**100**	*nb (1)*	**93**	*nb (1)*	**88**	*nb (1)*	**24**
Staff	*v*		33.5		29.2		27.8	18	7
Utilities & chemicals	*w*		63.2		59.7		56.8		17
Residues treatment	*x=e1*f1+e2*f2+...*		3.75		3.75		3.75		
Other costs									
Revenues	*Y=z+ae*		**249**		**249**		**249**		**202**
Sales of products	*z=aa+ab+ac*		**223**		**223**		**223**		**192**
re-refined base oil	*aa=c1*d1*		192		192		192		161
gasoil	*ab=c2*d2*		31		31		31		31
	*ac=c3*d3*								
____________	*ad=c4*d4*								
Sales of residues	*ae=e1*g1+e2*g2+...*		**25**		**25**		**25**		**10**
WO gate fees	*af=C-Y*	Euros/t	**102**	Euros/t	**60**	Euros/t	**9**	Euros/t	**54**

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- 3 industrialists having plants (or projects) in Germany are distinguished)

(1) nb of persons equivalent full time (all shifts included)

(2) Sales, General & Administration

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology	**Regeneration**		Existing plants	Projects
de-asphalting, demetalisation	**TFE + solvent extraction**			
finishing	**Hydro-finishing**			+
Main output & quality	High quality re-refined base oil			

Localisation		Europe	G	It	Sp	Fr	other MS	Non Eur
total existing capacity	*kt*	85	85					
nb of plants	*units*	1	1					
		min	max					
capacity of existing plants	*kt*	25	85					

Parameters of operation

		dehydration distillation	vacuum distillation	finishing extraction	total
Yields	*% on a dry basis*	91%	81%	97%	71%

Main inputs		quantity *kg/t of WO*		purchasing price *Euros/t of input*
waste oil	*a1*	1000		
hydrogen (catalyst)	*a2*	0.25	*b2*	10000
Mohawk Chemical	*a3*	12	*b3*	225
hydrogen gas	*a4*	2	*b4*	3600

Main products (outputs sold)		quantity *kg/t of WO*		selling price *Euros/t of output*
Group II re-refined base oil	*c1*	370	*d1*	325
Group I re-refined base oil	*c2*	300	*d2*	260
Gas Oil	*c3*	85	*d3*	100
______________	*c4*		*d4*	

Main residues (outputs treated or sold)		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*	
sulphur	*e1*	4	*f1*			*g1*
bitumen	*e2*	160	*f2*		75	*g2*
water	*e3*	65	*f3*	30		*g3*
sludge/light end	*e4*	20	*f4*	400		*g4*

Source: **GEIR - 2001 (G 3[0])** **grass-root plant**

Other parameters of operation

Capacity	*g*	**85**	*kt/yr*
Utilisation rate (input / capacity)	*h*	89%	
Operational duration		7 800	*hours/yr*

			Euros / t of WO
Cost	*C=o+p+q+u*	*in Euros*	**204**
Capital cost	*I=j+k+l+m*	**47.0**	
Engineering	*k*	7	
Core processes	*l*	32	
Site acquisition	*j*	1	
Non core processes	*m*	7	
Depreciation cost	*o=(k+l)*1000/yrs/(g*h)*	*yrs*	**57**
Core processes & engineering		10	52
Site & non core processes	*o=(j+m)*1000/yrs/(g*h)*	20	5
		%	
Risk adjusted rate of return on finance	*p=I*%*1000/(g*h)*	10.0%	**62**
Fixed operational cost	*q=r+s+t*	*nb (1)*	**47**
Staff	*r*	68	24
Equipements maintenance	*s*		8
Sg&a (2)	*t*		15
Variable operational cost	*u=v+w+x*	*nb (1)*	**38**
Staff	*v*	*included*	
Utilities & chemicals	*w*		28
Residues treatment	*x=e1*f1+e2*f2+…*		10
Other costs			
Revenues	*Y=z+ae*		**219**
Sales of products	*z=aa+ab+ac*		**207**
Group II re-refined base oil	*aa=c1*d1*		120
Group I re-refined base oil	*ab=c2*d2*		78
Gas Oil	*ac=c3*d3*		9
______________	*ad=c4*d4*		
Sales of residues	*ae=e1*g1+e2*g2+…*		**12**
WO gate fees	*ze=C-Y*	Euros/t	**-15**

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(1) nb of persons equivalent full time (all shifts included)

(2) Sales, General & Administration

Cost analysis of processes

Euros / t of WO (water included)

Description

Type of process & technology		**Re-refining**						Existing plants	Projects
de-asphalting, demetalisation		**TDA (Thermal De-Asphalting)**							
finishing		**Clay treatment**						+	
Localisation		Europe	G	It	Sp	Fr		other MS	Non Eur
total existing capacity	kt	100		100					
nb of plants	units	1		1					
		min	max						
capacity of existing plants	kt	100	100						
Main output & quality		Medium quality re-refined base oil							

Parameters of operation

		de-watering de-fueling	de-asphalting	finishing	total
Yields	*% on a dry basis*	97%	80%	95%	74%

		quantity *kg/t of WO*		purchasing price *Euros/t of input*
Main inputs				
waste oil	a1	1000		
clay	a2	100	b2	180
____________	a3		b3	
____________	a4		b4	

		quantity *kg/t of WO*		selling price *Euros/t of output*	possible quantity range: min *kg/t of WO*	max *kg/t of WO*
Main products (outputs sold)						
re-refined base oil	c1	560	d1	300	500	600
gasoil	c2	70	d2	150	60	80
naphta	c3	110	d3	130	60	160
____________	c4		d4			

		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*	
Main residues (outputs treated or sold)						
clay	e1	130	f1	120		g1
bitumen (metals & additives)	e2	120	f2		155	g2
light ends/solvents	e3	35	f3	80		g3
waste waters	e4	770	f4	6		g4

Source		**GEIR - 2001 (I[0]) grass-root plant**		**GEIR - 2001 (I[0]) built on an existing site**		**Concawe - 1994 [4] grass-root plant**			
Other parameters of operation									
Capacity	g	**100**	kt/yr	**100**	kt/yr	**100**	kt/yr		
Utilisation rate (input / capacity)	h	85%		85%		85%			
Operational duration		7 200	hours/yr	7 200	hours/yr	n.a.	hours/yr		
			Euros / t of WO		***Euros / t of WO***	***$ 1994 / t of WO***		***Euros 2001 / t of WO*** [5]	
Cost	C=o+p+q+u	mEuros	**280**	mEuros	**224**	m$ 94	**137**	mEuros 01	**162**
Capital cost	m=j+k+l+m	**45**		**19**		**26.5**		**37**	
Engineering	k	3.5		3.5					
Core processes	l	15.5		15.5		16.5		23	
Site acquisition	j	5							
Non core processes	m	21				10		14	
Depreciation cost	o=(k+l)*1000/yrs/(g*h)	yrs	**38**	yrs	**22**	yrs	**31**	yrs	**35**
Core processes & engineering		10	22	10	22	10	19	10	27
Site & non core processes	o=(j+m)*1000/yrs/(g*h)	20	15	20		10	12	20	8
		%		%		%		%	
Risk adjusted rate of return on finance	p=i*%/1000/(g*h)	10.0%	**53**	10.0%	**22**	15.0%	**47**	10.0%	**44**
Fixed operational cost	q=r+s+t	nb (1)	**64**	nb (1)	**54**	nb (1)	**29**		**40**
Staff	r	25	15	10	6	24	12.80		18
Equipements maintenance	s		23		23	(8)	15.9		22
Sg&a (2)	t		25		25				
Variable operational cost	u=v+w+x	nb (1)	**94**	nb (1)	**94**	nb (1)	**25**		**35**
Staff	v	30	18	30	18	*included*	*included*		*included*
Utilities & chemicals	w		53		53	(8)	25.15		35
Residues treatment	x=e1*f1+e2*f2+...		23		23				
Other costs		(3)	**31**	(3)	**31**	(6)	**5**		**7**
Revenues	Y=z+ae		**211**		**211**		**195.11**	(7)	**211**
Sales of products	z=aa+ab+ac		**193**		**193**		**188.01**		**193**
re-refined base oil	aa=c1*d1		168		168		173.88		168
gasoil	ab=c2*d2		11		11		14.13		11
naphta	ac=c3*d3		14		14				14
____________	ad=c4*d4								
Sales of residues	ae=e1*g1+e2*g2+...		**19**		**19**		**7.1**		**19**
WO gate fees	af=C-Y	Euros/t	**68**	Euros/t	**13**	$ 1994/t	**-58.46**	Euros/t	**-50**

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(1) nb of persons equivalent full time (all shifts included) (5) Hypotheses: inflation rate = 2 % / yr
(2) Sales, General & Administration 1 $ 2001 = 1.22 Euros 2001
(3) Production losses and transport costs calculation formula: X $ 1994 = [X * (1+0.02)$^{2001-1994}$ * 1.22] Euros 2001
(4) source: report [19] page 106, investment based on the licensor declaration (+30% not considered)
(6) Financial burden
(7) Because the selling prices depends on the crude oil price, the actualisation formula is senseless. The GEIR 2001 hypotheses are considered instead.
(8) the Concawe data differ from the GEIR data because they include only utilities and operating workers relating to the technological area (the GEIR data are related to the whole factory, including the services not directly connected with the technology (for re-refining, i.e. lighting, office heating and all other electrical and energetical consumptions connected with all the infrastructures)

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology		**Re-refining**					Existing plants	Projects
de-asphalting, demetalisation		**TDA (Thermal De-Asphalting)**						
finishing		**Hydro finishing (High Pressure)**						+
Localisation		Europe	G	It	Sp	Fr	other MS	Non Eur
total existing capacity	*kt*	140		100	40			120
nb of plants	*units*	2		1	1			2 (5)
		min	max					
capacity of existing plants	*kt*	40	100					
Main output & quality		High quality re-refined base oil						

Parameters of operation

		de-watering de-fueling	*de-asphalting*	*finishing*	*total*
Yields	*% on a dry basis*	97%	80%	95%	74%

Main inputs		quantity *kg/t of WO*		purchasing price *Euros/t of input*
waste oil	*a1*	1000		
catalyst	*a2*	0.5	*b2*	14000
______	*a3*		*b3*	
______	*a4*		*b4*	

Main products (outputs sold)		quantity *kg/t of WO*		selling price *Euros/t of output*
re-refined base oil	*c1*	670	*d1*	325
gasoil	*c2*	70	*d2*	220
______	*c3*		*d3*	
______	*c4*		*d4*	

Main residues (outputs treated or sold)		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*		
spent catalyst	*e1*	0.5	*f1*	465		*g1*	
bitumens	*e2*	120	*f2*		155	*g2*	(4)
light ends/solvents	*e3*	35	*f3*	80		*g3*	(4)
waste waters	*e4*	770	*f4*	6		*g4*	

Source		**GEIR - 2001 (I[1]) grass-root plant**			**GEIR - 2001 (I[1]) built on an existing site**		
Other parameters of operation							
Capacity	*g*	**100**	*kt/yr*		**100**	*kt/yr*	
Utilisation rate *(input / capacity)*	*h*	85%			85%		
Operational duration		7 200	*hours/yr*		7 200	*hours/yr*	
			Euros / t of WO			**Euros / t of WO**	
Cost	*C=n+p+q+u+y*	mEuros	**304**		mEuros	**227**	
Capital cost	*h=i+j+l+m*	**69**			**31**		
Engineering	*i*	5			5		
Core processes	*j*	26			26		
Site acquisition	*l*	5					
Non core processes	*m*	33					
Depreciation cost *n=(i+j)*1000/yrs/(g*h)*		yrs	**59**		yrs	**36**	
Core processes & engineering		10	36		10	36	
Site & non core processes *o=(l+m)*1000/yrs/(g*h)*		20	22		20		
Risk adjusted rate of return on finance *p=f*%*1000/(g*h)*		% 10.0%	**81**		% 10.0%	**36**	
Fixed operational cost	*q=r+s+t*	nb (1)	**57**		nb (1)	**47**	
Staff	*r*	25	16		10	6	
Equipements maintenance	*s*		16			16	
Sg&a (2)	*t*		25			25	
Variable operational cost	*u=v+w+x*	nb (1)	**76**		nb (1)	**76**	
Staff	*v*	30	18		30	18	
Utilities & chemicals	*w*		50			50	
Residues treatment	*x=e1*f1+e2*f2+...*		8			8	
Other costs		(3)	**31**		(3)	**31**	
Revenues	*Y=z+ae*		**252**			**252**	
Sales of products	*z=aa+ab+ac*		**233**			**233**	
re-refined base oil	*aa=c1*d1*		218			218	
gasoil	*ab=c2*d2*		15			15	
______	*ac=c3*d3*						
______	*ad=c4*d4*						
Sales of residues	*ae=e1*g1+e2*g2+...*		**19**			**19**	
WO gate fees	*af=C-Y*	Euros/t	**52**		Euros/t	**25**	

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(1) nb of persons equivalent full time (all shifts included)

(2) Sales, General & Administration

(3) Production losses and transport costs (5) 80 kt in Poland and 40 kt in Indonesia

(4) The bitumens selling price and the light ends treatment cost differ from those considered in the PDA + hydro process because of different qualities and transportation costs

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology		**Re-refining**					Existing plants	Projects
de-asphalting, demetallisation		**PDA (Propane De-Asphalting)**						
finishing		**Hydro finishing (Medium Pressure)**						+
Localisation		Europe [11]	G	I [10]	Sp	Fr	other MS	Non Eur
total existing capacity	kt	57		57				
nb of plants	units	1		1				
		min	max					
capacity of existing plants	kt	57	57					
Main output & quality		High quality re-refined base oil						

Parameters of operation

		de-watering de-fueling	de-asphalting	PDA + vacuum	total
Yields	*% on a dry basis*	97%	80%	95%	74%

Main inputs		quantity *kg/t of WO*		purchasing price *Euros/t of input*
waste oil	a1	1000		
propane	a2	8.25	b2	530.4
________	a3		b3	
________	a4		b4	

Main products (outputs sold)		quantity *kg/t of WO*		selling price *Euros/t of output*	possible quantity range min *kg/t of WO*	max *kg/t of WO*
re-refined base oil	c1	670	d1	320 [5]	660	698
gasoil	c2	47	d2	150	43	55
________	c3		d3			
________	c4		d4			

Main residues (outputs treated or sold)		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*	
light ends/solvents	e1	30	f1	115		g1
bitumens	e2	130	f2		20	g2
waste waters	e3	770	f3	6		g3
________	e4		f4			g4

Source		**GEIR - 2001 (I*) grass-root plant**		**GEIR - 2001 (I*) built on an existing site**		**Concawe - 1996 [4] grass-root plant**			
Other parameters of operation									
Capacity	g	**57**	*kt/yr*	**57**	*kt/yr*	**100**	*kt/yr*		
Utilisation rate *(input / capacity)*	h	88%		88%		85%			
Operational duration		7 600	*hours/yr*	7 600	*hours/yr*	n.a.	*hours/yr*		
			Euros / t of WO		***Euros / t of WO***		***$ 1994 / t of WO***		***Euros 2001 / t of WO*** [6]
Cost *C=o+p+q+u*		*mEuros*	**320**	*mEuros*	**247**	*m$ 94*	**230**	*mEuros 01*	**269**
Capital cost *m=h+i+j+m*		**41.6**		**20**		**55**		**77**	
Engineering	h	4		4					
Core processes	i	16		16		45		63	
Site acquisition	j	3.6							
Non core processes	m	18				10		14	
Depreciation cost *o=(h+i)*1000/yrs/(g*h)...*		*yrs*	**61**	*yrs*	**40**	*yrs*	**65**	*yrs*	**83**
Core processes & engineering		10	40	10	40	10	53	10	74
Site & non core processes *o=(j+m)*1000/yrs/(g*h)*		20	22	20		10	12	20	8
		%		%		%		%	
Risk adjusted rate of return on finance *p=i*%*1000/(g*h)*		10.0%	**83**	10.0%	**40**	15.0%	**97**	10.0%	**91**
Fixed operational cost *q=r+s+t*		*nb (1)*	**93**	*nb (1)*	**84**	*nb (1)*	**46**		**64**
Staff	r	50	46	40	37	24	12.80		18
Equipements maintenance	s		24		24	[6]	33		46
Sg&a (2)	t		23		23				
Variable operational cost *u=v+w+x*		*nb (1)*	**58**	*nb (1)*	**58**	*nb (1)*	**13**		**18**
Staff	v					*included*	*included*		*included*
Utilities & chemicals	w		50		50		12.66 [8]		18
Residues treatment *x=e1*f1+e2*f2+...*			8		8				
Other costs		[3]	**25**	[3]	**25**	[6]	**10**		**14**
Revenues *Y=Z+ae*			**224**		**224**		**218.73**	[7]	**224**
Sales of products *Z=aa+ab+ac+ad*			**221**		**221**		**215.73**		**221**
re-refined base oil *aa=c1*d1*			214		214		201.60		214
gasoil *ab=c2*d2*			7		7		14.13		7
________ *ac=c3*d3*									
________ *ad=c4*d4*									
Sales of residues *ae=e1*g1+e2*g2+...*			**3**		**3**		**3**		**3**
WO gate fees *af=C-Y*		Euros/t	**96**	Euros/t	**23**	$ 1994/t	**11.58**	Euros/t	**45**

(*) the letter (and number if any) indicates that the data come from a GEIR member having a plant in the country (I for Italy and G for Germany;
3 industrialists having plants (or projects) in Germany are distinguished)

(1) nb of persons equivalent full time (all shifts included)

(2) Sales, General & Administration

(3) Production losses and transport costs

(4) source: report [19] page 105, investment based on the licensor declaration (+30% not considered)

(5) a lower selling price compared to the TDA + hydro process because of a lower quality due to a medium pressure

(6) Hypotheses: inflation rate = 2 % / yr; 1 $ 2001 = 1.22 Euros 2001; calculation formula: X $ 1994 = [X * (1+0.02)^(2001-1994) * 1.22] Euros 2001

(7) Because the selling prices depends on the crude oil price, the actualisation formula is senseless. The GEIR 2001 hypotheses are considered instead.

(8) Financial burden

(9) the Concawe data differ from the GEIR data because they include only utilities and operating workers relating to the technological area (the GEIR data are related to the whole factory, including the services not strictly connected with the technology. Ofor re-refining, i.e. lighting, office heating and all other electrical and energetical consumptions connected with all the infrastructures)

(10) since May 2001

(11) another plant operates the PDA process in Belgrade but followed by another treatment than hydrotreatment

Appendix 7

Cost and WO Gate Fee for a Thermal-Cracking Plant

Cost and WO Gate Fee for a Thermal-Cracking Plant

The same economic model as the one developed for regeneration has been used (see appendix 6).

Cost analysis of processes *Euros / t of WO (water included)*

Description

Type of process & technology		**Thermal cracking (adjustment of the process to produce primarily gasoil) with a purification / stabilisation stage**

Localisation		Europe	B	other MS	Non Eur (USA)	Existing plants	Projects
total existing capacity	*kt*	60	40		160+		
nb of plants	*units*	2	1		7+	+	+
		min	max				
capacity of existing plants	*kt*	7	40				
Main output & quality		Gasoil (light heating oil or diesel oil)					

Parameters of operation

	de-watering	thermal cracking	distillation	purification stabilisation	total
Yields	95%	90%	83%	99.5%	71%

Main inputs		quantity *kg/t of WO*		purchasing price *Euros/t of input*
waste oil	*a1*	1000		
___________	*a2*		*b2*	
___________	*a3*		*b3*	
___________	*a4*		*b4*	

Main products (outputs sold)		quantity *kg/t of WO*		selling price *Euros/t of output*	
gasoil	*c1*	706	*d1*	200	
naphtha	*c2*	51	*d2*	10	
bitumen	*c3*	38	*d3*	70	asphalt extender
	c4		*d4*		

Main residues (outputs treated or sold)		quantity *kg/t of WO*		treatment cost *Euros/t of output*	or selling price *Euros/t of output*		
waste waters	*e1*	50	*f1*	25		*g1*	
solvent	*e2*	29	*f2*	50		*g2*	
heavy residues	*e3*	61	*f3*	90		*g3*	
naphtha	*e4*	36	*f4*			*g4*	burned internally for energetic purposes
off-gases	*e5*	29	*f5*			*g5*	burned internally for energetic purposes

Source		**GEIR - 2001 (B[0]) grass-root plant**			**GEIR - 2001 (B[0]) grass-root plant**			**GEIR - 2001 (B[0]) grass-root plant**	
Other parameters of operation									
Capacity	*g*	**40**	*kt/yr*		**50**	*kt/yr*		**80**	*kt/yr*
Utilisation rate *(input / capacity)*	*h*	85%			85%			85%	
Operational duration		7 500	*hours/yr*		7 500	*hours/yr*		7 500	*hours/yr*

			Euros / t of WO		***Euros / t of WO***		***Euros / t of WO***
Cost	*C=o+p+q+u*	*mEuros*	**135**	*mEuros*	**123**	*mEuros*	**112**
Capital cost	*i=j+k+l+m*	**11.4**		**13.0**		**19.9**	
Engineering	*k*	1.5		1.7		2.6	
Core processes	*l*	6.0		6.7		10.0	
Site acquisition	*j*	0.2		0.3		0.5	
Non core processes	*m*	3.7		4.3		6.8	
Depreciation cost	*n=(k+l)*1000/yrs/(g*h)*	*yrs*	**28**	*yrs*	**25**	*yrs*	**24**
Core processes & engineering		10	22	10	20	10	19
Site & non core processes	*o=(j+m)*1000/yrs/(g*h)*	20	6	20	5	20	5
		%		%		%	
Risk adjusted rate of return on finance	*p=i*%*1000/(g*h)*	15%	**50**	15.0%	**46**	15.0%	**44**
Fixed operational cost	*q=r+s+t*	*nb (1)*	**33**	*nb (1)*	**30**	*nb (1)*	**20**
Staff	*r*	12	14	12	12	12	6
Equipements maintenance	*s*		8		8		7
Sg&a (2)	*t*		11		10		7
Variable operational cost	*u=v+w+x*	*nb (1)*	**23**	*nb (1)*	**23**	*nb (1)*	**24**
Staff	*v*	2	3	2	3	3	4
Utilities & chemicals	*w*		12		12		12
Residues treatment	*x=e1*f1+e2*f2+...*		8		8		8
Other costs (3)						(6)	
Revenues	*Y=z+ae*		**144**		**144**		**144**
Sales of products	*z=aa+ab+ac*		**144**		**144**		**144**
gasoil	*aa=c1*d1*		141		141		141
naphtha	*ab=c2*d2*		1		1		1
bitumen	*ac=c3*d3*		3		3		3
	*ad=c4*d4*						
Sales of residues	*ae=e1*g1+e2*g2+...*						
WO gate fees	*af=C-Y*	Euros/t	**-10**	Euros/t	**-21**	Euros/t	**-32**

(0) the letter indicates that the data come from a GEIR member having a plant in the country (B for Belgium)

(1) nb of persons equivalent full time (all shifts included)

(2) sales, general & administration

Appendix 8

Some Elements from 'Collection and Disposal of Used Lubricant' [19], 1996, CONCAWE

Some Elements from 'Collection and Disposal of Used Lubricant' [19], 1996, CONCAWE

Scope

The report covers all aspects of used oil generation and disposal in Western Europe for the year 1993.

The report considers the various ways of disposing of WO and compares their environmental impacts. Both burning and regeneration options are considered and are compared from both the technical and economic aspects. But it is claimed that LCA data are missing.

Actually, environmental data cover only energy use and CO_2 emissions. General environmental considerations about accumulation of pollutants are discussed.

Limitation

An overall ranking of the options has not been made as this would require a full Life Cycle Analysis which is not the purpose of this report.

General environmental considerations

A list of typical contaminants in WO is given in the report. According to the authors, from the many studies completed during the last 10-15 years (from 1996), it can be said that today (1996), the majority of technologies can be environmentally acceptable, provided proper precautions are taken.

Burning options

Cement kiln disposal

High operating temperatures are required in a cement kiln to convert the raw materials into cement and the raw materials used are highly alkaline. According to the authors, dangerous contaminants such as polycyclic aromatic hydrocarbons (PAH), chlorinated hydrocarbons and heavy metals are either destroyed or rendered harmless by the cement manufacturing process.

Burning in space heaters

Used oil is burned in space heaters specially designed for burning WO and are typically used in some countries to heat automotive repair garages. Volatile metals and chlorine compounds are emitted with the stack gas from the burner. The metal of most concern is lead (from leaded gasoline). Although the lead problem must soon disappear, as leaded fuel is banned from 2000, combustion in such equipment cannot be tightly monitored. [Note: With respect to European Directive, this option is illegal].

Burning after "mild" reprocessing in road limestone coating plants

According to a report on the range of emissions observed at 26 sites in UK, the emissions of metals from stone coating plants was, in 1996, above those of cement kilns, but below the European emission limit values [Note: this assertion may be not true anymore since the new emission limit values are much more stringent in the new incineration directive]

In these plants, the pollutants, particularly metals, are captured by the stones, which are then encapsulated by bitumen for roads thus preventing leaching. The combustion temperature is not high enough to destroy PCBs and the report did not include information on emissions of chlorinated compounds (dioxin…).

Regeneration options (WO back to base oil)

Acid/clay process

The polycyclic aromatic hydrocarbon (PAH) content of the base oils produced can be comparatively high (4 to 17 times higher than virgin oils, according to the authors), and the health implications need to be assessed.

Other processes

Vacuum distillation + chemical treatment or clay treatment

The base oils produced by clay treating or by chemical treatment have a metal content of < 1 ppm. This process may not reduce the PAH content of the oil by as much as hydro-treatment.

Used clay and used chemicals must be safely disposed of; the best route is to burn them in cement kilns or in a chemical waste incinerator.

Vacuum distillation + hydro-treatment

This process reduces the PAH content of oil much more (no figure) than the clay treatment or chemical treatment. The disposal of spent hydro-treating catalyst should be handled by a specialised company familiar to this problem.

New regeneration options under development

UOP- DCH-process

By treating the whole used oil with hydrogen, the DCH process generates effluents with low environmental loads. By-products requiring disposal will include spent catalyst, sodium chloride and sodium sulphate. [Note: no data in the report about PAH content]

Refinery recycling

This disposal option has been studied on a small scale in France. All the metal contaminants will be encapsulated in asphalt and leaching of metals will be extremely low (no figure in the report) . However, problems of corrosion damage to the plant need to be solved before this can be considered viable option. [Note: this process has been studied in the ADEME study, 2000]

PCB content is not considered to be a significant problem for WO disposal in Europe (as under the WO directive, the maximum content of PCB allowed in WO to be treated for disposal is 50 ppm).

WO can have a significant, but variable, chlorine content, including organochlorines. This has implications for all the disposal options considered, whether regeneration or combustion. The fate of these chlorine compounds will vary, not only with the disposal route, but also with the form in which the chlorine is present. It is therefore difficult to make any general comment on the effects of chlorine other than that in the combustion routes there is a risk of dioxin formation and that in the reprocessing options there are risks of corrosion problems, acid gas emissions and contamination of products and by-products. These can only be assessed and compared with emissions from other sources on a case-by-case basis.

Health effects

Few studies have been reported on the toxicology and potential health effects of re-refined oils. Those studies which have been reported by some producers are only relevant for the oils arising from their specific regeneration process. Nevertheless, it seems that re-refined oils are not acutely toxic, nor are they skin or eyes irritant. Chronic impacts have not been studied.

Some re-refined oils have been shown to be non-mutagenic but the data are insufficient to draw a conclusion about re-refined oils in general.

To ensure that re-refined oils are not likely to be carcinogenic PAH levels need to be reduced to a sufficiently low level, e.g. hydro-treatment or solvent extraction under sufficiently severe conditions.

Environmental results

Extracted from the report: 'this assessment cannot be considered definitive and serves as a guide to the likely effects. It should be confirmed by a comprehensive Life Cycle Analysis and we understand that such a study is under consideration in France by the Environment agency (ADEME)'.

Quantitative values from this report cannot be further used thus are not discussed here.

Main conclusions of the authors

- There is a wide variety of processes currently offering ways to deal with WO.
- The assessment shows that the differences between the various acceptable options are small in terms of both economic and energy efficiency and that the ranking may vary with local circumstances.
- All the disposal options considered (both regeneration and burning) save significant quantities of crude oil (and also reduce CO_2 emissions) i.e. collecting 1600 kt of WO saves between 1400 and 2100 kt of crude. As the difference between the 'best' and 'worst' cases is only half of the worst case scenario, the most important point is, therefore, to ensure collection and beneficial disposal.

- The options which give the lowest crude oil consumption are burning as industrial gas oil and regeneration to base oil. Theses options, on the basis of 1600 kt/y of WO compared with the 'worst' option of burning as a HSFO (HSFO) replacement, save 200 to 500 kt/y of crude oil respectively, which means that the regeneration of WO saves 250% more crude oil than its use as industrial gas oil.
- Burning WO in cement kilns is unfavourable in CO_2 emissions terms if the oil displaces high sulphur fuel oil. However, if the oil displaces coal, then the effect on CO_2 emissions is favourable.
- No single WO disposal option can be clearly favoured over the others, because each option has a different ranking for the assessments of the various factors, and the differences between the various options are small.
- 'In any one area, site specific factors can be important in deciding which of the disposal options is available, and provides the greatest environmental benefit in the most cost-effective manner. Thus any further pan-European legislation to mandate any particular disposal option is unlikely to be appropriate for all local circumstances and will therefore not result in the best possible overall solution.'
- The environmental impacts of the various options (and indeed the quality of the re-refined products) depends upon the properties of the used oil under consideration (content of PCB, chlorine and organochlorine, metals). Such impacts therefore have to be considered on a case-by-case basis and these impacts described here are indicators of what are likely to occur but may not in all cases. The significance of the various impacts will also vary with the location and particular aspects of the technology applied.

Appendix 9

‘Environmental and Economic Impact of Re-Refined Products: a Life Cycle Analysis’ [20], FIAT (Italy)

'Environmental and Economic Impact of Re-Refined Products: a Life Cycle Analysis' [20], FIAT (Italy)

- Scope and goal

This report covers the environmental and economical analysis of two regeneration processes: thermal clay treatment and hydro-finishing treatment.

The acid/clay refining is by far the most common regeneration process in use today, with a share of world regeneration capacity as high as 92% (most plants are small with a capacity of 2 - 10 000 tons of WO per year). Base oils made by this process are usually darker in colour and have inferior quality to virgin mineral oils; they also tend to have a noticeable odour.

Here, the study compares both improved processes: the thermal clay treatment and the distillation/hydro-treatment (with the REVIVOIL process: it has been developed jointly by Viscolube Italiana company and IFP as a combination of the Viscolube exclusive TDA™ technology and IFP Hydro-finishing and Propane de-asphalting technologies).

- LCA methodology

The Boustead Model (software) has been adopted for LCI approach.

- Functional unit

1000 kg of WO

- Technological representativeness and sources of data

Data were supplied directly from the Viscolube company (Preflash treatment, TDA treatment, Clay treatment or, alternatively, Hydro-finishing treatment) and integrated with data derived from Boustead Model. No more details.

- System boundaries

The system boundaries are not described. Thus it is not possible to compare the results with other LCA studies.

Results

Environmental impacts of regeneration process with Hydro-finishing treatment are 2 to 4 times higher than those with Clay treatment (global and regional impacts):

	Regeneration with Thermal clay treatment	Regeneration with Hydro-finishing
Total energy consumption (MJ / kg of used oil)	4.26	9.93
Global Warming Potential (kg eq. CO_2 / kg of used oil)	0.3	0.7
Acidification Potential (g eq. SO_2/ kg of used oil)	4.6	11.9
Photo-Smog Potential (kg eq. ethylene/ kg of used oil)	0.1	0.4
Eutrophication Potential (g eq. NO_3^-/ kg of used oil)	3.2	6.4

Main conclusions of the authors

Prior to the study, the Viscolube process was based on the Thermal Clay treatment. But within few years the Hydro-finishing treatment will be the effective step closing the refining process and then it will substitute the thermal Clay Treatment.

In the future, Viscolube plant, because of the presence of the Hydro-finishing treatment instead of Clay treatment, will increase environmental impacts of the regeneration process. Some environmental benefits are nevertheless associated to the Hydro-finishing process:

- increasing the environmental quality of re-refined oil because of the reduction of Polycyclic Aromatic Hydrocarbons (PAH) (no data),
- disposal of clay consumption and consequent reduction of raw materials for the regeneration process,
- increasing of plant efficiency because of the disposal of oil loss into the clay selling off.

Appendix 10

Impact Categories in LCA

Impact Categories in LCA

- Impact assessment

An impact assessment is carried out in order to condense the information contained in the inventory. For this, the environmentally significant material flows compiled in the inventory must be described in terms of their potential impact on the environment.

This section gives a description of categories and modelling of inventory data within impact categories (characterisation). For the purpose of this review, we have selected the impact categories which have been calculated in a majority of studies as follows:

- Impact category indicators

Area of protection	Impact category	Scientific unit for the indicator	Reliability of the calculation methods	Confidence in the inventory data
Consumption of resources	Fossils fuels	kg eq. crude oil MJ	+++	+++
	Total energy	MJ	+++	+++
	Water	kg	+++	+++
Air pollution	Global warming potential	kg eq. CO2	+++	+++
	Acidification potential	kg eq. SO2	++	++
	Photochemical pollution	kg eq ethylene kg of COVs	++	+
Water pollution	Nutrification potential	kg eq. PO4	++	++
Waste	Solid waste	kg	++++	+++
Human and Ecosystem Health	Human toxicity	kg eq. As kg eq. 1-4 dichlorobenzen	+	+
	Aquatic ecotoxicity	kg eq. 1-4 dichlorobenzen	+	+
	Terrestrial ecotoxicity	kg eq. 1-4 dichlorobenzen	+	+

Source: BIO Intelligence Service, 2001

The impact category for ozone depletion has not been included in the LCA studies because it is not a significant impact for the investigated systems UNDER CONSIDERATION.

- Sources of uncertainty

Two basic kinds of uncertainty have to be distinguished: the first one is due to the calculation modelling (used to describe a physical phenomenon), the other one is introduced as far as the inventory dataset may be reliable and accurate.

The soundness of every impact indicator is scored ('++++' high reliability to '+' = very low reliability) in the table above. The scores for the reliability of the calculation methods, are representative of the today's state of the art for impact assessment within the LCA framework ; additional works are in progress to improve the indicators related to human and ecosystem health.

The scores for the confidence in the inventory data, are representative of the reviewed studies and they reflect the today's state of the art for the inventory stage within the LCA framework (for instance, considering human toxicity, the low score comes partly from data gaps for heavy metals emissions all over the investigated systems).

- Consumption of resources

Environmental impact linked to the use of raw materials should be viewed primarily in terms of the depletion of scarce environmental resources.

A total impact potential of all raw materials assessed, in the sense of assessing potential impact in terms of a single equivalence value, does not appear feasible, since the environmental impacts connected with consumption of different raw materials cannot be compared with one another. Therefore, the various raw materials are grouped together into three sub-categories:

- fossil fuels,
- total energy,
- water from various sources.

- Fossil fuels: lignite, coal, natural gas, crude oil
  - 1) method used in the UBA (2000) study

    For the collation of the environmental impacts of fossil fuel use, an aggregation value with respect to crude oil, the crude oil resource equivalent factor (Oeq), is determined by its scarcity, as a measure of the environmental importance of its consumption, and by its (lower) calorific value H.

    As a measure of the scarcity of a non-renewable raw material, the "static range" Rstat (in years) is used. This describes how long the raw material in question will last, given constant consumption at today's levels. The smaller the static range of a raw material, the scarcer it is considered to be.

The crude oil resource equivalent factor for a fossil fuel is calculated as follows from the static ranges and lower calorific values of the raw material and of crude oil. Its value is inversely proportional to the static range, and directly proportional to the lower calorific value of the raw material under consideration:

$R_{eq,\ material} = (R_{stat,\ crude} / R_{stat,\ material}) \times (H_{material} / H_{crude})$.

R_{eq}: Crude oil resource equivalent factor (no dimension)
R_{stat}: Static range (in years)
H: Lower calorific value (in kJ / kg or kJ / Nm3)

The following table shows the equivalence factors of the fossil fuels considered in the inventory. From this table, it is clear that raw materials with a low static range and/ or a high calorific value also have a relatively large crude oil equivalence factor.

Crude Oil Resource Equivalence Factors for Various Fossil Fuels

Fuel:	Static range (years)	Calorific value (H in kJ/kg or Nm3)	Crude oil eq. factor
Lignite	200	8303	0.0409
Natural gas	60	31736	0.5212
Coal	160	29809	0.1836
Crude oil	42	42622	1.0000

The crude oil resource equivalent (kg) of a particular raw material is calculated by multiplying the mass of the raw material shown in the inventory by the crude oil resource equivalence factor.

A broader impact assessment, taking into account of distinctive characteristics of the use of various fuels (eg destruction of landscape and ecosystem in open cast lignite mining, which cannot be considered fully reversible even with careful recultivation, or the risk of accidents with tankers involved in the transport of crude oil, and their serious consequences for landscape, seascape and ecosystem) was not investigated in the studies under consideration.

- 2) method used in both the Norwegian EPA (1995) and the ADEME (2000) studies

For the collation of the environmental impacts of fossil fuel use, an aggregation value with respect to fossil fuel consumption, the energy equivalent factor (MJ), is determined by its (lower) calorific value H.

The fossil fuel resource equivalent (MJ) of a particular raw material is directly shown in the inventory table of the LCA study. The indicator is calculated by summing the values of the raw material shown in the inventory. Let us call hereafter this second method as "1:1:1".

The scarcity of fossil fuel is not included in this method.

Lessons from this review:

The conclusions of the LCA studies under consideration are highly dependent upon which indicator is used to describe the environmental impact of fossil fuel use.

Let's compare how the indicator influence the results, for instance, in the UBA study (2000).

	Regeneration			Burning	
values for 1000 kg WO	**MRD**	**BKM**	**SVZ**	**cement**	comments
Primary energy (GJ)	**-40**	**-40**	**-40**	**-40**	- saving for every option ; - no difference between options
Fossil fuel consumption (kg eq. Crude oil) - method 1	**-1000**	**-1000**	**-500**	**-100**	- saving for every option ; - advantage for the regeneration (MRD) and the fuel reprocessing (BKM)
Fossil fuel consumption (MJ) "1:1:1"- method 2	**-1000**	**-1000**	**-2000**	**-2000**	- saving for every option ; - advantage for the cement kiln and the gasification process (SVZ)

Despite the total consumption of energy is equal for every investigated waste management options, the fossil fuel consumption is a very distinctive criteria useful to compare regeneration with energy recovery systems. This criteria is useful to show a hierarchy but this hierarchy is opposite with the two indicators proposed. No standard indicator is provided from the today's code of practice of LCA practioners.

- Total energy

Energy carriers are divided in renewable and non-renewable resources. For determining the energy content of resources, the method considers the fundamental material input and the net calorific value. This is done irrespective of whether the resources are to serve for material purposes or for energy refining. For the latter, the following methodology is generally employed in LCA studies.

The energy demands of an analysed system (as far as fossil fuels are concerned) are traced back in the inventory to the removal of the primary energy carriers from a raw materials source. Conversion energies, too, needed for energy preparation were materially taken into account in every studies.

Based on the material input (given in mass unit in the inventory), the resource demand can be assessed by taking the net calorific value because for the majority of technical applications the net calorific value and not the gross calorific value represents the relevant information.

For the assessment hydropower, the potential energy of the water before energy production is assumed in order to ascertain the resource demand. The demand of nuclear power is expressed in uranium equivalents (given in kWh) for the energy production. It is thus possible to quantify resource demands in the inventory even for non-material energy resources.

- Water from various sources

When considering the extraction of ground or surface water, one cannot regard it as a scarce resource from the point of view of consumption, since the water is not, strictly speaking, lost (or "consumed") during the life-cycle of a product. The problems associated with water extraction are less concerned with quantity, and more with the quality of water, which can be adversely affected through use, and this aspect is already covered by other impact categories (environmental toxicity, acidification, input of nutrients).

The environmental impact to be considered at this stage is thus restricted to damage connected with the extraction of water, such as lowering of the water table and the landscape changes associated with dam construction.

- Global warming

When determining the climatic impact of a substance, the Global Warming Potential (GWP) is used. This is a measure of the effect on radiation of a particular quantity of the substance over time relative to that of the same quantity of CO_2. The GWP depends thus on the time spent in the atmosphere by the gas, and on the gas's capacity to affect radiation, which describes the immediate effects on overall radiation of a rise in concentration of the gas.

The GWP is calculated with combined climatic and chemical models and covers two effects: the direct effect a substance has through the absorption of infrared radiation and the indirect chemical effects on overall radiation.

In the life cycle assessment of WO, radiation effects due to CO_2, methane (CH_4) and nitrogen protoxide (N_2O) are considered in the impact assessment.

The GWP value for CO_2 is chosen as equivalence factor. Considered over a time span of 100 years, methane should have a GWP CO_2 value of 21, and N_2O a GWP of 210.

- Acidifying gas emission and Acidification of land and water

In order to describe the acidifying effect of substances, their acid formation potential (ability to form H+ ions) is calculated and set against a reference substance, SO_2.

SO_2 Equivalence Factors of Various Acid Producers

Acid producer (in air)	SO_2 equivalence factor
Hydrogen chloride (HCl)	0.88
Hydrogen fluoride (HF)	1.60
Nitrogen oxides (as NO_2)	0.70
Sulphur oxides (as SO_2)	1.00
Hydrogen sulphide (H_2S)	1.88

- Formation of photochemical oxidants
  - 1) method used in the UBA (2000) study

    As a measure for estimating airborne substances' potential for forming atmospheric oxidants, POCP (Photochemical Ozone Creation potential) values are used. The POCP value of a particular hydrocarbon is a relative measure of how much the ozone concentration measured at a single location varies if emission of the hydrocarbon in question is altered by the same amount as that of a reference hydrocarbon, usually ethylene.

    The POCP value is not a constant, but can very over distance and time, since formation of oxidants along the path of an air pocket is determined by the composition of the prior mixture and the meteorological conditions, which can also vary spatially and chronologically.

    In the LCA inventory, the greater part of the hydrocarbon emissions appears as group parameters (eg "NMVOC": non methanic volatile organic compounds, or "hydrocarbons, classified").

    Therefore, the resulting value for this indicator may be considered as approximate.
  - 2) method used in both the Norwegian EPA (1995) and the ADEME (2000) studies

    For the collation of the environmental impacts of the emission of photochemical precursors, an aggregation value with respect to VOC emission is simply determined by summing all the hydrocarbons emission into the air from the LCA inventory.

    The resulting value for this indicator may not be considered as well sound scientifically (as the indicator is not supported by any environmental mechanism).

- Nutrification of land and water (eutrophication potential)

Additional input of plant nutrients into water can bring about excessive growth of water weeds (phytobenthon), free-floating plant organisms (phytoplankton) and higher plant forms (macrophytes). This does not only represent a change in the stock of a species, but also in the balance between species. Due tot the increased generation of biomass and the consequently heavier sedimentation of dead organic material, the oxygen dissolved in deep water is consumed faster, through aerobic decomposition. This can lead to serious damage in the biological populations inhabiting the sediment. In addition to this, direct toxic effects on higher organisms, including humans must be taken into account when certain species of algae appear in mass.

While phosphorus determines the degree of eutrophic activity in the majority of cases in the limbic area, in marine and terrestrial ecosystems nitrogen is most often the decisive factor. Equivalence factors suggested by CML (University of Leiden, 1992) are generally used in LCA.

PO_4 equivalence factors of various substances

Nutrient	PO_4 equivalence factor
Nitrogen oxides (NOx, air)	0.13
Total nitrogen (water)	0.42
Total phosphorous (water)	3.06
Chemical O_2 demand (COD)	0.022

■ Detriment to human health (human toxicity) and Direct damage to organisms and ecosystems (ecotoxicity)

The calculation of a total impact potential within these categories is very difficult at present, for the following reasons:

- The application of methods for characterising the effect of harmful chemicals in the fields of both human and environmental toxicity requires consideration of the extent of exposure. But the figures compiled in the life-cycle inventory are independent of exposure levels. It follows that current indicators cannot consider exposure levels.
- A further problem is the fact that a large number of presumably toxicologically significant substances were collected together under group parameters (eg AOX, NMVOC, unspecified heavy metals) during the gathering of data for the inventory. The possibilities to assess the impacts related to such group parameters are unclear at the moment, and also appear very doubtful for the future.
- Thus a value for the total environmental impact of the various chemicals which are important in terms of human end environmental toxicity cannot be fairly calculated at present. They appear therefore individually within two categories of "detriment to human health" and 'direct damage to organisms and ecosystems".

Two methods have been used in the LCA studies analysed:

- 1) method used in the UBA (2000) study

  Only human toxicity has been assessed, using the following equivalence factors:

Chemical (in air)	**Arsenic equivalence factor**
kg arsenic	1
kg benzo[a[pyren	20.9
kg benzol	0.0019
kg cadmium	0.42
kg Cr VI	0
kg dioxin	10500
kg Ni	0.056

- 2) method used in the ADEME (2000) study

  Equivalence factors are based on the USES method, which is a reference method for environmental policy at the EU level. Based on exposure scenarios, this approach is still under development for a better integration in LCA. In order to describe the toxicity effect of (many) substances, their toxicity potential is calculated and set against a reference substance, 1-4 dichlorobenzene.

- Impact categories which cannot be derived from life cycle inventory data
  - Noise: it is not sensible to quantify noise emissions released within a global system (spatially and temporally located elsewhere) and to relate them as a sum parameter to an impact category.
  - Odour: (see "Noise").
  - Nature conservation (biodiversity, etc.): cannot be derived from life-cycle inventory data.
  - Land use: inventory data are quite differently documented for the different systems.
  - Risk of nuclear accidents: cannot be derived from inventory data. Nuclear waste have not been quantified in any study under consideration.