



EXECUTIVE SUMMARY

Ecological and energetic assessment of re-refining used oils to base oils: Substitution of primarily produced base oils including semi-synthetic and synthetic compounds

commissioned by
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de l'Industrie de la Régénération**

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Executive Summary

Council Directive 75/469 EEC on the disposal of used oils, as amended by Council Directive 87/101/EEC establishes priority for re-refining of used oil for recovery of base oil as long as there are no technical, economic or organisational obstacles. The priority given to re-refining was based on the goal of resource preservation. The environmental benefits of used oil regeneration as compared to refining of virgin base oil are established by a number of Life Cycle Assessment studies (LCA) published in Europe to date. However, some of these earlier studies gave rise to an indifferent assessment of re-refining when comparing it with combustion options in certain large-scale facilities, such as cement kilns.

In recent years developments of a regulatory nature and within the lubricants industry and the re-refining industry have given rise to changes to several important environmental and economic aspects affecting the re-refining industry. In view of these changes the European Association of the re-refining industry (GEIR) considers that the results of LCA studies published in the past and which focus on re-refining industry practices and lubricant qualities of the 1990's are no longer valid. Key developments supporting this view include:

- New regeneration technologies with improved performance have been developed and implemented;
- Regulatory requirements concerning motor vehicle emissions have enhanced the quality of lubricants; and
- In today's markets, the amounts of synthetic and semi-synthetic compounds used have increased significantly and keep on increasing. These more sophisticated and stable oils require far more energy to manufacture and allow re-refiners to manufacture high quality base oils more easily because the inherent quality of collected used oils is substantially improving.

In order to take into account these important developments the, GEIR commissioned the Institut für Energie- und Umweltforschung (IFEU), in Heidelberg Germany to carry out a new LCA of the ecological and energetic benefits of re-refining used oils. The focus of the study is based on the core cycle: "base oil production → used oil → base oil re-refining".

This study has been **reviewed** by a panel of experts in accordance with ISO 14040 section 7.3. The review process was started after the finalisation of a draft report of the assessment. The majority of amendments have been taken into consideration during the final editing of the study. There remain minor controversial issues that have not been taken up in the report. These subjects are included in the report of the critical review panel.

The **goal of the study** is provide an updated and forward-looking vision of the ecological and energetic aspects of re-refining of used oil. The conclusions of the previous

LCA studies representing the situation of the 1990's, shall be modified to reflect the current situation and anticipated developments in the following decades.

- Five advanced techniques of re-refining are assessed considering their environmental impact and their environmental benefits due to the substitution of primary products.
- An average of the advanced re-refining techniques considered is compared with combustion.
- The most decisive parameters shall be worked out in a transparent way.

The study is intended for policymakers and stakeholders in the field of the waste management of used oil.

Within the **scope of this study**, the material and energy flows of advanced re-refining techniques – represented by four companies operating in Europe and one in the USA – are analysed and evaluated to include impacts of auxiliary processes, such as electricity or fuel pre-chains. Primary lube industry processes and process chains that are substituted by recycling of base oils are also considered. To acknowledge the issue of improving quality of used feedstock and re-refined products, a range of 0 to 30 % synthetic components is taken into account in the analyses. Figure 1 shows a strongly simplified scheme of the system boundary.

The **functional unit** for calculation of inventory and impacts refers to the treatment of 1 Mg of collected and re-refinable used oil. All inventory data offered by the participating re-refining companies are taken as baseline data to identify the average quality of used oil for this assessment. For normalisation purposes the results will be scaled up on the reference quantity of 600,000 Mg, which is assumed to be the entire annual quantity of re-refinable used oil within the European Union. Today this number has increased to 800.000 Mg per year according to GEIR statistics. It is not within the goal and scope of the study to analyse the used oil market with all its flows.

The **methodology** of this assessment follows the requirements of ISO standards 14040ff. An inventory is calculated for each of the re-refining techniques regarding transport, up-stream energy production and downstream treatments. Inventories are also calculated for the equivalency systems substituted by the benefits of recycling and recovery. For the substituted products out of mineral oil derive from multi-output processes allocations are inevitable. A strictly mass orientated allocation rule is chosen.

The environmental impact categories to be analyzed include:

- resource depletion (with respect to fossil energy resources);
- global warming;
- terrestrial nutrification;
- acidification; and
- toxicity (with respect to carcinogenic pollutants and fine particulates).

For interpretation of the analyses, the two processes described in ISO 14042 are applied:

- Normalization: Calculation of the magnitude of the impact category indicator results relative to reference values (specific contribution). In this case, the total inventory of resource consumption and emissions in Germany was used as a reference.
- Grouping: Ranking the impact categories in a given order of hierarchy, such as very high, high, medium and low priority.

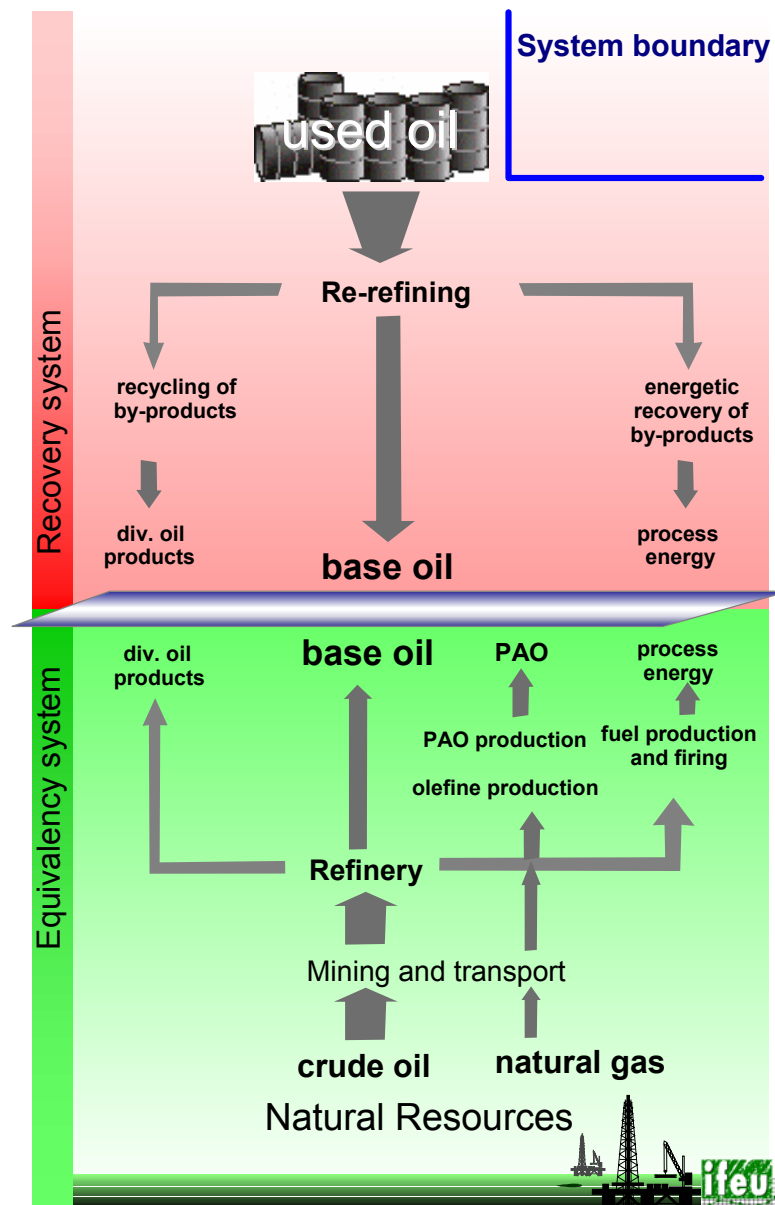


Figure 1 Simplified scheme of the re-refining system;
from above: the re-refining system itself
from below: the functionally equal primary production system, which is substituted by re-refining

The **data sources** for the calculation of inventories comprise:

- specifications given by the re-refining companies (specific consumptions, emissions and product yields of their techniques)
- specific data assessed by IFEU (concerning mineral oil refining, petrochemical processes and energy processes)
- generally available data banks (ECOINVENT, APME etc.)
- specific literature (e.g. concerning PAO production)

The **re-refining technology** considered represents advanced technical standards. The five options aim for high quality products. Four of them are based on hydrogenation and one on extraction technology. The yield of base oil is ranging from 55 to 77 percent. This is a high rate of closed loop recycling because the products can be recycled several times. By-products are applied for secondary fuel. Waste waters are treated by advanced purification plants. The techniques considered are free from waste for disposal.

Results

In assessing the overall impact or benefit of re-refining in relation to the substitution of primary products, the balance result between the re-refining system and the equivalency system can be directly compared. Both systems are equal in benefits but the first derives them from waste (used oil), the second from primary resources (crude oil etc.). Subtracting the balance result of the first from the second gives an overall balance in favour of re-refining. An overview of all environmental impact categories considered is shown in figure 2. This graph shows that re-refining base oil to base oil causes far less environmental impact than processing base oil from crude oil across the board. Re-refining therefore clearly leads to a decrease in environmental burdens.

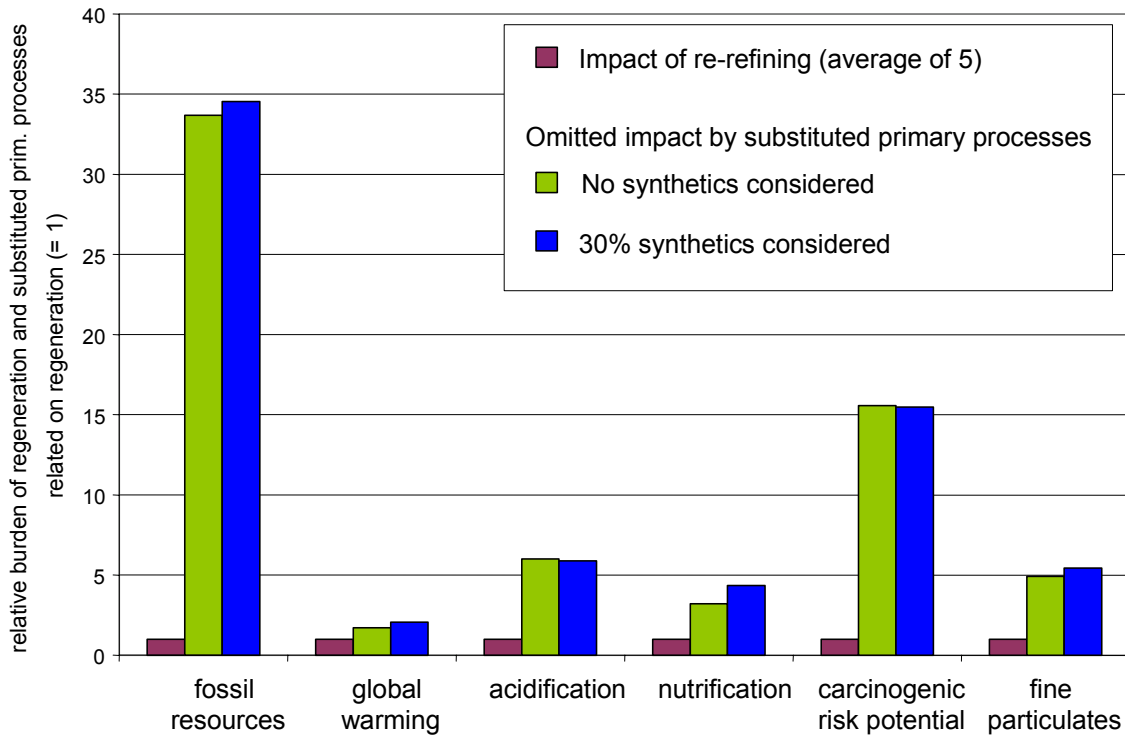


Figure 2 Overview of the impact assessment results, where all figures are related to the particular result of “re-refining”, e.g. a value of five means that the impact of the substituted processes is five times higher than the impact of re-refining.

The second goal of the study is to clarify the question as to whether combustion might not be even more beneficial to the environment than re-refining.. To assess this it has to be defined which type of fuel will be substituted by used oil combustion. This is difficult to define from a purely scientific point of view. Waste oil can be used to fuel a broad range of facilities. Most LCA studies of used oil recovery have considered use in cement kilns, although it is only one (approximately 16 %) of several options practised in the European Union. The European cement industry’s main fuel sources are coal and petroleum coke. In this respect, it could be assumed that coal and coke are the main fuels substituted. However, in order to give rise to an optimal firing operation a portion of liquid fuel is required. As such, there is no general evidence as to which fuel type is the one to be substituted. With respect to other combustion facilities besides cement works, the question of which fuel source is substituted is much clearer, with mainly fuel oil being replaced.

To give a clear overview both scenarios are addressed by this study: the substitution of coal type fuel and of fuel oil. Figure 4 shows the relative differences between the environmental impacts of re-refining (here presuming 30 % synthetics) and combustion considering both substitution scenarios. It is evident that for both scenarios the majority of advantages are in favour of re-refining. If synthetics are neglected the relative differences will get smaller and might be slightly in favour of combustion in relation to nutrification.

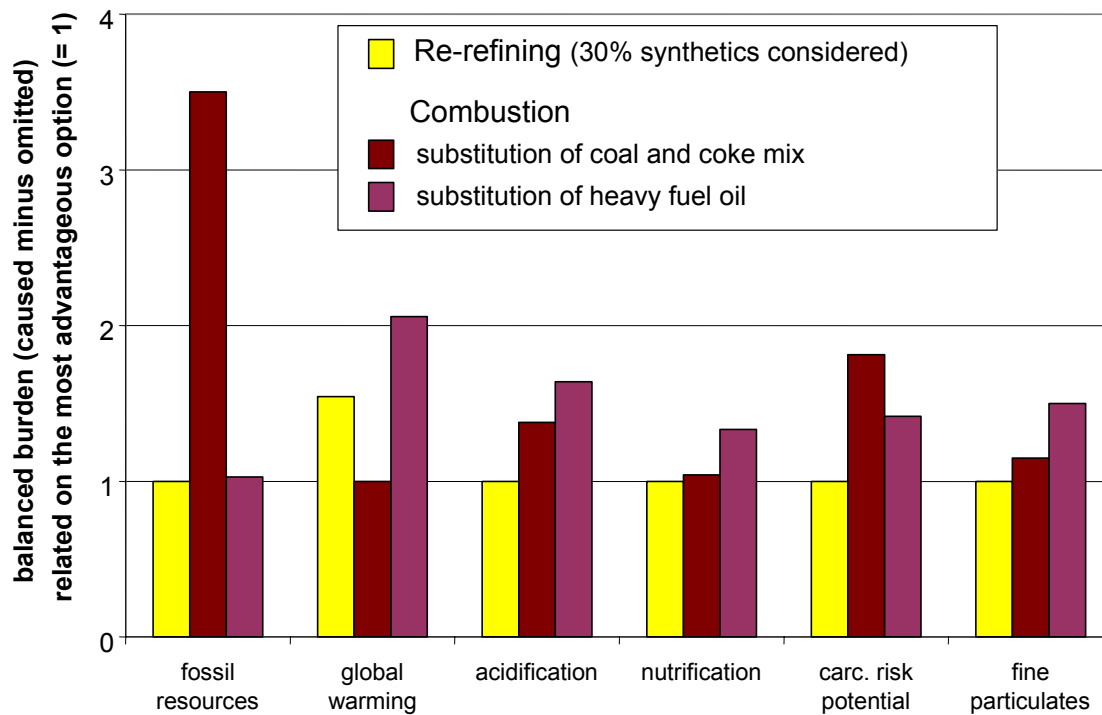


Figure 3 Overview of the impact assessment results, where all figures are related to the particular result of “re-refining”; e.g. a scenario with a value of 2 is half as beneficial as the scenario with the value 1.

Figure 3 does not provide any information either about the order of magnitude of the differences nor about the importance of the single impact categories. These two aspects are addressed by normalization and grouping. Figure 4 shows the differences between re-refining and combustion in a normalized way: the impact assessment results are scaled up to 600,000 Mg of used oil and the difference values between re-refining and combustion are divided by the per-capita-load on an average person (PEV, e.g. 2.38 Mg raw oil equivalents or 11.8 kg CO₂-equivalents per person and year). The graph shows most categories in a range of 10,000 to 30,000 person equivalents difference. In terms of resource conservation the advantage of re-refining extends up to 200,000 person equivalents. Presuming coal substitution by used oil combustion the particular advantage of this option is also about 20,000 to 30,000 PEV concerning global warming.

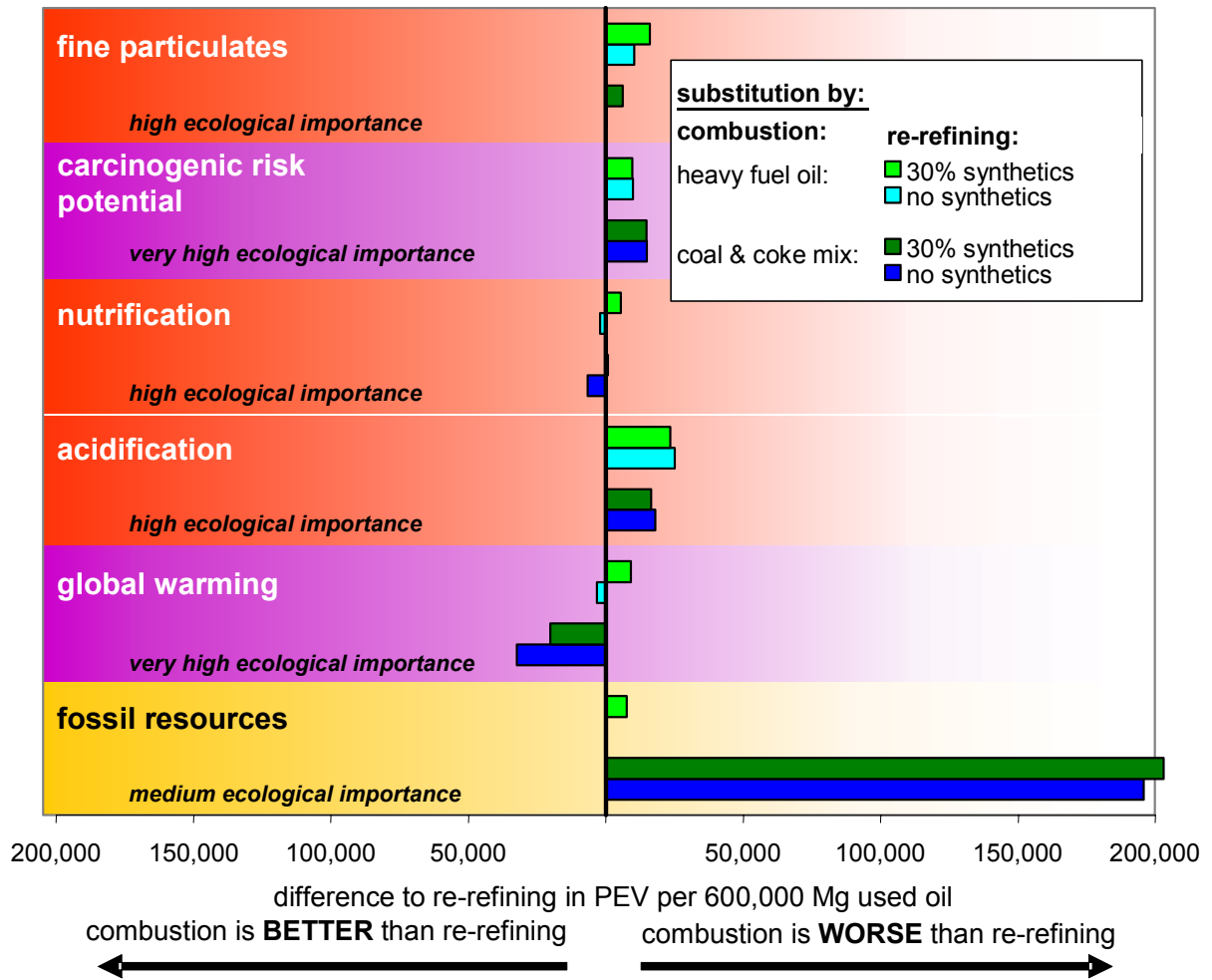


Figure 4 Overview of impact-related and normalized differences between average re-refining and combustion; 1 PEV equals the general per-capita-load on average.

Conclusions

The assessment leads to the following main conclusions:

1. For all five re-refining techniques considered, there are clear environmental benefits as compared to the production of base oils in standard oil refineries. This is true for all of the impact categories considered.
2. The trend towards using more synthetic or semi-synthetic compounds in lubricants is reflected in the significant increases in these environmental benefits as the proportion of the compounds in used oil grows toward the 30% limit used in this study.
3. The result of comparing re-refining is strongly influenced by the question of which primary fuels are substituted by waste oil combustion. For the majority of impact categories regeneration is shown to be more beneficial than direct burning. This can be categorically stated where the fuel to be replaced is fuel oil or gas. Where coal and petroleum coke are substituted, combustion is more beneficial in relation to global warming.
As the proportion of synthetic compounds in used oil increases, the benefit with respect to global warming when burning used oil directly is significantly reduced. On the other hand the apparent advantages of re-refining remain stable or increase.
4. The analysis of some sensitive parameters shows additional aspects developing in favour of regeneration, especially with regard to allocation method and when the increasing pool of secondary fuels which are starting to compete is taken into account.

In summary, re-refining of used oil leads to significant resource preservation and relief from environmental burdens when compared to the production of base oils in large-scale crude oil refineries.

Most of the LCA studies performed in the past have concluded with an indifferent evaluation when re-refining was compared with the combustion option for used oil. This study shows that efficient regeneration technology, the future potential of the re-refining industry, and other sensitive environmental aspects lead to conclusions favouring re-refining of used oils to recover base oil. This LCA is evidence of improved environmental benefits from re-refining: supporting the priority given it by EU policies.

Critical review report - Summary

The IFEU Life Cycle Analysis (LCA) examined in this critical review was carried out within the constraint of making a comparison with the results of an earlier LCA (Arcadis/IFEU 2000). This constraint inevitably reduced the scope for the authors of the LCA to change the methodology and analysis to take account of best practice introduced since 2000. Equally, the critical review panel was established after the study had been completed and we were therefore unable significantly to influence its structural elements. We were however given unrestricted access to the data and authors during the review process.

Section 7.1 of ISO 14040 defines the objectives of the critical review as being to ensure that:

- The methods used to carry out the LCA are consistent with ISO 14040 series;
- The methods used to carry out the LCA are scientifically and technically valid;
- The data used are appropriate and reasonable in relation to the goal of the study;
- The interpretation reflects the limitations identified and the goal of the study;
- The study report is transparent and consistent.

We are satisfied that, within the constraints placed on the scope of this study and subject to a small number of reservations, the LCA has been conducted in a way that is consistent with ISO 14040 series. Our reservations are:

1. Updated data for re-refineries have been compared with data for conventional refineries that are assumed to be unchanged.
2. The same functional unit has been used to evaluate two distinctly different goals; the second goal (comparing re-refining with burning used oil in a cement kiln) may require a different functional unit from the one used.
3. No consideration has been given to the marginal impact on the management of existing conventional oil refineries when used oil is re-refined.

After detailed consideration and review we are satisfied that the methods used for allocation in the manufacture of polyalphaolefins (PAOs) comply with ISO requirements. We would welcome further comments on the allocation methodology from the oil refining industry.

We are satisfied that the LCA methods are scientifically and technically valid although we have expressed the following reservations:

1. The “best case” scenario in which PAO constitutes a 30% share of the lubricant market may be unrealistic. We acknowledge that in page 9 of the study the 30% market share includes synthetic and other high viscosity oils.
2. The exclusion of impact categories concerned with the aquatic environment, malodorous emissions and solid waste needs further justification. We acknowledge that malodorous emissions used to be an issue for old style re-refining technologies but are not considered significant for the five modern techniques used in this LCA.
3. The *marginal* fuel displaced in a cement kiln that accepts used oil should have been identified. The method used in the LCA based on an average-mix fuel is not correct. It is likely that the results would be more clearly in favour of re-refining if this had been done.

We are generally satisfied that the data used are appropriate and reasonable. We have suggested the following issues deserve closer attention:

1. The sampling of mass balance data for one of the re-refining techniques revealed some errors. The final version of the LCA has been corrected to take account of the minor errors discovered during the review.
2. There is no evidence that data provided by the re-refining operators and co-ordinated by the trade association has been subjected to an external validation process. We acknowledge that a method for data gathering was established and since all of the operators use quality management systems we do not consider this to be a major issue but one of detail and transparency.
3. The use of crude oil equivalents and the weighting attached to the various fossil fuels requires further justification for an international audience. The use of these weightings (based on estimates of reserves and current patterns of consumption) is especially sensitive in a study of used oil.

We are satisfied that the interpretation of the data is accurate within the limitations identified and the goals of the study.

We have made a number of minor recommendations to improve the transparency and consistency of the LCA:

The basis on which the five re-refinery operators provided comparative data needs further explanation. We understand that the data were from a yearly average and careful consideration was given to this issue before the study began.

1. We have identified a number of places in which operators of conventional oil refineries and cement kilns could be invited to comment on the data used. These are: the marginal impact on refineries when re-refining occurs, the allocation method for the manufacture of PAO, and the identification of the marginal fuel displaced in cement kilns by used oil.
2. The transparency of the LCA was identified as a general weakness by the panel. The publication of this critical review alongside the LCA will largely compensate for this weakness.

IFEU's comments to the Critical Review Report

The IFEU team expresses its thanks for a fair and effective review process by the review panel. The expertise of all three members of the review team is a guarantee for a solid synthesis of the LCA and the critical review report.

We appreciate the conclusion in the report that our LCA complies with the ISO 14040 series. Because an LCA is always a complex work product, it is always to be expected that open points are identified in a review that require clarification, discussion and potentially a revision on our side. This is particularly true for the issue of refining and re-refining that requires a large number of methodical assumptions. We accept the critique where it is justified and explain our differing point of view in some cases.

The areas requiring our comments to the critique are “disregarding marginal effects”, “fuel substitution” and “data of the re-refineries”.

1. The review concludes that marginal impact on the management of existing conventional oil refineries when used oil is re-refined were not considered by us. This is a valid critique. However, assessing the real marginal impact would be a very complex and time-consuming analysis if it could be carried out at all. The markets of mineral oil products are very fluctuant and the refineries are bound to adapt to developments all the time. While we agree that this is an important issue, we doubt that it is possible to properly measure the impact of re-refining on the base oil sector.
2. The review concludes that it is not correct to take an average fuel mix as the marginal type of fuel to be displaced in a cement kiln. While there may be alternative and possibly more precise and appropriate approaches to identify the “correct fuel”, alternative approaches will involve further complications and are subject to considerable uncertainties. In our opinion, simple parameters such as medium fuel prices are not the correct indicators. Each combustion plant derives its fuel mix based on a number of specific requirements, price not being the only criterion. Because the knowledge of which fuel exactly is replaced in each individual cement kiln, we feel confident that taking an average mix in account is the best approach under the circumstances. We would further like to point out that our report includes calculations for the option of the “correct fuel” from a marginal point of view. The results are reported in the LCA and reflected in our conclusions.
3. A further point of the review addressed the quality of the data regarding the re-refining techniques. The review claims that it is not equivalent to the data for standard refineries. We cannot provide a guarantee that each data point is exact because we have to trust the companies delivering such data. We have interviewed the persons that are responsible for the technical data and we have checked its plausibility. Likewise, the data concerning standard refineries was also derived from company information. Consequently, we cannot agree with the claim made by the review team.

Horst Fehrenbach

**GEIR**

Groupement Européen de l'Industrie de la Régénération - The Re-refining Industry Section of UEIL

Statement of GEIR

The Groupement Européen de l'Industrie de la Régénération (GEIR) is glad to present this study to experts and interested audience. This study clarifies existing uncertainties and takes the advantages of modern re-refining into account.

Our special thanks are addressed to the re-refining operators from Europe and overseas who provided the necessary operating and quality data for the LCA. We are particularly grateful to Horst Fehrenbach, author of the LCA for his professional commitment to create this study and to coordinate a significant number of meetings and telephone conferences. We appreciate him being a competent expert. We would also like to thank the members of the Critical Review team Mr. David Fitzsimons, Prof. Dr. rer. nat. Birgit Grahl, Prof. Dr.-Ing. Günter Fleischer and Joachim Küssner for their work. The Critical Review went in great detail and encouraged vital discussions. Finally, the result of everybody's endeavours is a study which shows a number of aspects which have not been considered in other studies so far. The data of five up-to-date re-refining techniques have been considered. The focus has also been put to the use of new synthetic and semi-synthetic components.

We especially agree with the opinion of the Critical Review team that the study has given reliable proof of the advantages of re-refining in comparison with the virgin refineries. With choosing the "right" substitute fuel the re-refining would have an ever greater advantage in comparison to burning.

With the help of re-refining it is possible to improve significant environmental impacts and especially to avoid CO2 emissions.

The result clarifies the slightly ambiguous conclusions of former LCAs and critical reviews.

After stating the ecological advantages of re-refining experts will now apply also to the economic considerations. In the light of exploding prices of crude oil the re-refining as a "domestic source" will become more valuable again. The flexibility of the branch has led to an enormous increase of productivity. As soon as the existing problems regarding excise duty derogations for the burning are overcome a sustainable resource industry can make a significant contribution to society.

The final scientific results, the achieved high level of re-refining technology and the provision of additional workplaces are sufficient to justify the priority of waste oil recycling in a more precise way.

Brussels, 25th February 2005

C. Hartmann
President

